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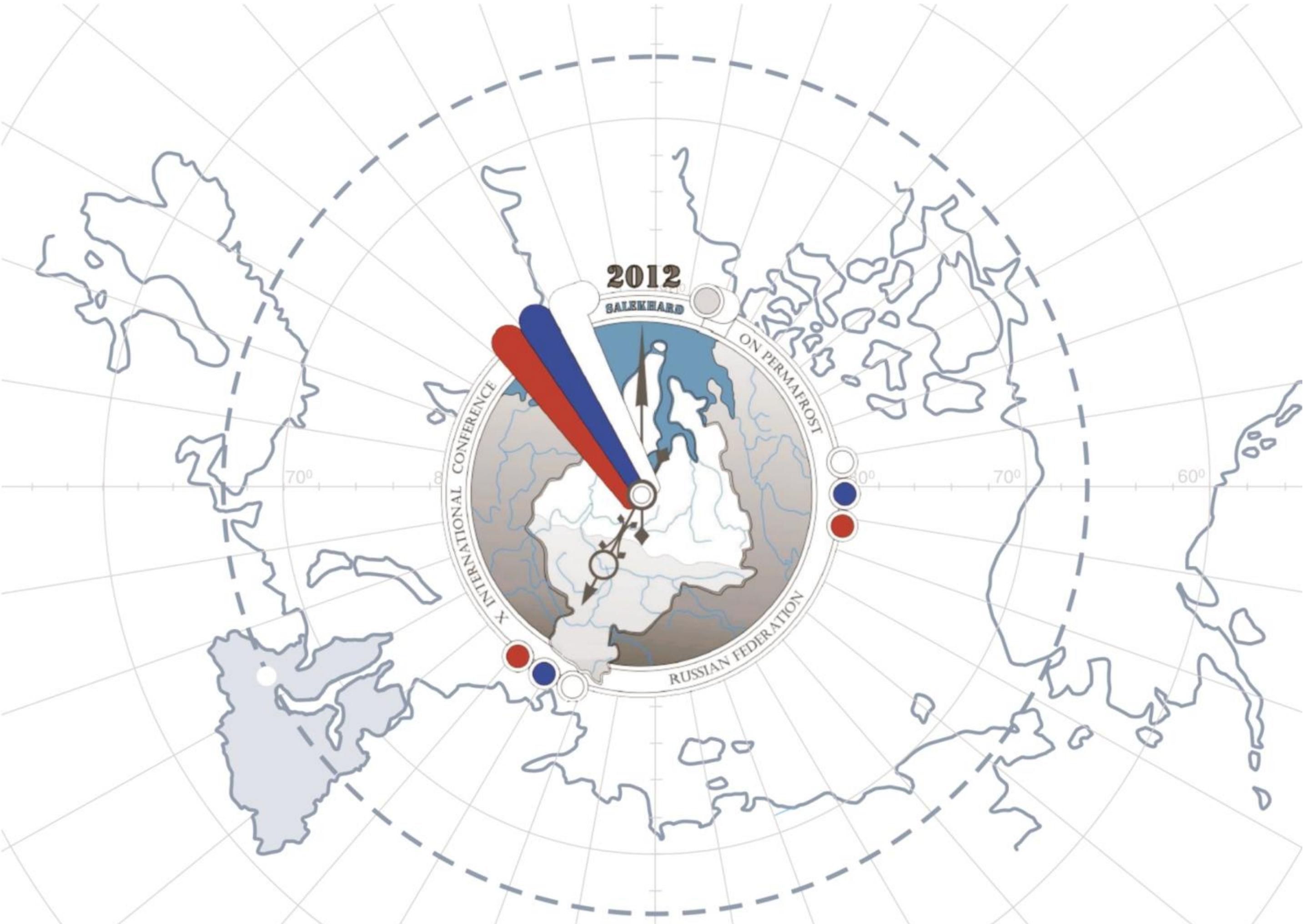

Extended abstracts of the Tenth International Conference on Permafrost

Salekhard, Yamal-Nenets Autonomous District, Russia
June 25–29, 2012

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VOLUME 4 EXTENDED ABSTRACTS

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2012

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Resources and Risks of Permafrost Areas in a Changing World

Труды Десятой Международной конференции по мерзлотоведению
Салехард, Ямало-Ненецкий автономный округ (ЯНАО), Россия
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Том 4

Расширенные тезисы

(на английском зыке)

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Resources and Risks of Permafrost Areas in a Changing World

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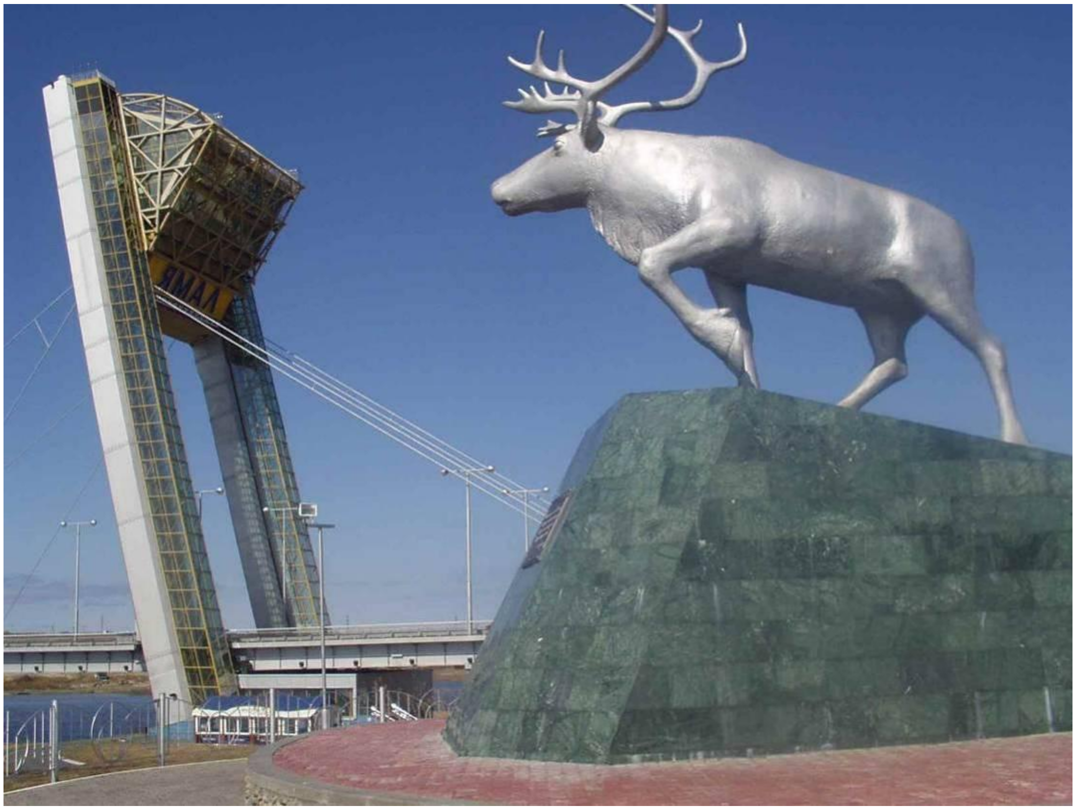
ЯМАЛ

Assessment and Prediction of the Change of Geotechnical Conditions for the Purpose of Ensuring Stability of Buildings and Structures in Nadym

I.V. Abaturova, I.A. Yemelyanova
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Geological environment of urban infrastructure in the cryogenic zone is extremely sensitive to anthropogenic impact and is not resistant to it. When developing, this environment is seriously disturbed, this resulting in elimination of shrub and tree vegetation, slope trimming, filling construction sites and carriageways with sandy ground, snowdrifting of the area etc. All these factors cause a significant change of temperature and moisture conditions, depths of seasonal freezing and thawing, an increase in depth of the permafrost table, appearing of new permafrost formations.

In this regard, the most prominent example is the town of Nadym. Construction works were launched there in 1972 due to the development of the Medvezhye major gas field. The buildings were erected in compliance with the construction method II using strip foundations. Basements and vent-holes were originally planned to be a part of constructions but they were later eliminated due to snow drifting and surface discharge water flooding of the basements. Development of the suburban areas started in context of the ongoing industrial development of the region. Construction works were performed in compliance with the construction method I, using pile footing and preserving frozen grounds there. Deformations such as cracks in plasters and walls started to appear just in 3-5 years after operation of the buildings had started. The degree and properties of the deformations keep on getting more hazardous with time, so that the constructions may even lose their operational reliability and stability.

Considering all that, there appeared a demand for an objective assessment and forecast of changes of the geotechnical conditions underlain by identification of the main natural components and regularities of their spatial variability, carrying out a special geotechnical zoning in order to ensure the optimal operation of the buildings.

Assessment and forecast of conditions of a lithotechnical system of urban areas in complicated geotechnical conditions cannot be carried out by means of the traditional methods of the engineering geology. To this end, one should apply fundamentally new methods based on analysis and design of different interactions between the components of the geotechnical conditions and the urban structures considered as an integrated lithotechnical system which are interdependent and related to each other by cause-and-effect relationships.

We suggest a methodology of prediction of changes of the geotechnical conditions based on integral evaluation of the natural components. The fundamentals of this methodology were developed by G.K. Bondarik and V.V. Pendin. The integral evaluation procedure is described in terms of the following algorithm: formation of a set of the components of the geotechnical conditions and their quantification, development of models of the fields of the geological parameters, choice of the target predicate, creation and analysis of the correlation matrix, calculation of the weighting coefficients, normalization of the characteristics, calculation and development of the model of the field of the integral index which, in its turn, is a basis for development of a special geotechnical zoning map of the city area considering stability degree and indicating zones favorable for construction and operation of buildings and structures.

In order to reveal regularities in the spatial variability of the components of the geotechnical conditions, it is necessary to quantify the qualitative information obtained. The following geological parameters of the estimate of the components of the geotechnical conditions were suggested to solve this problem: granulation factor (C_d), peat thickness (m_t), depth of peat base (h_t), thickness of short-term permafrost (mper.), depth of permafrost table (KMMP), density of frozen ground ($\rho merz.$), density of dry ground (ρ_d), total moisture (Ws), moisture due to unfrozen water (Wn), total ice content (Ls), depth of seasonal freezing (hSP), depth of seasonal thawing (hSO).

The models of the fields of the geological parameters have been developed by means of mathematic modeling using computer technologies and the ArcGis software, on the basis of the results of the geotechnical investigations. The models obtained enabled revealing of the general and local regularities in variation of the natural components which constitute a basis for the integral evaluation and forecast of the geotechnical conditions [*Abaturova et al. 2010*].

Wear of the buildings (according to the data of the Technical Inventory Bureau, the estimate of physical deterioration of all the structural elements of a building, %) is further chosen as the target predicate (the dependent variable) for the purpose of evaluation and prediction of variation of the geotechnical conditions in the city by means of the integral index.

The statistically important correlations between the wear of the buildings and the geological parameters of the components of the geotechnical conditions were revealed by means of the correlation and regression analysis. These procedures have yielded the following multiple regression equation:

$$\begin{gathered} \mathrm{If}{=}\ 37.73 + 8.74\cdot\ C_d + 1.03\cdot\ m_t + 2.12\cdot\ h_t + 0.96\cdot\ mper_{.} - \\ -\cdot 0.23\mathrm{KMMP} - 2.18\cdot\ \rho merz_{.} - 43.89\cdot\ \rho_d + 2.66\cdot\ Ws + \\ +0.01\cdot\ Wn - 1.47\cdot\ \mathrm{Ls} - 2.48\cdot\ hSP - 2.36\cdot\ hSO, \end{gathered}$$

where Cd is the granulation factor, unit fractions; mt is the peat thickness, m; ht is the depth of the peat base, m; mper. is the thickness of the short-term permafrost, m; KMMP is the depth of the permafrost table, m; ρmerz. is the density of the frozen ground, g/cm^3; ρd is the density of the dry ground, g/cm^3; Ws is the total moisture, unit fractions; Wn is the moisture due to unfrozen water, unit fractions; Ls is the total ice content, unit fractions; hSP is the depth of the seasonal freezing, m; hSO is the depth of the seasonal thawing, m.

The value of the multiple correlation coefficient (0.92) indicates close correlation between the wear of the buildings and the components of the geotechnical conditions and, therefore, confirms that the conceptual model has been developed in a correct way.

The value of integral index of complexity of the geotechnical conditions was calculated for each of the 1310 grid elements taking into account the mean values of the normalized estimates of the geological parameters. This integral index is a linear and additive function of the normalized values of the components of the geotechnical conditions weighted according to their contribution to the estimate:

$$J_{\Sigma} = \sum_{i=1}^{n} g_i \cdot R_i^n$$

where g_i is the weighting coefficient;

R_i^n is the normalized estimate of the i-th parameter of the geotechnical conditions;

n is the number of the value parameters of the geotechnical conditions.

The diagram of degree of the wear of the buildings as a function of the integral index was made in order to determine the limit values of the integral index (Fig. 1).

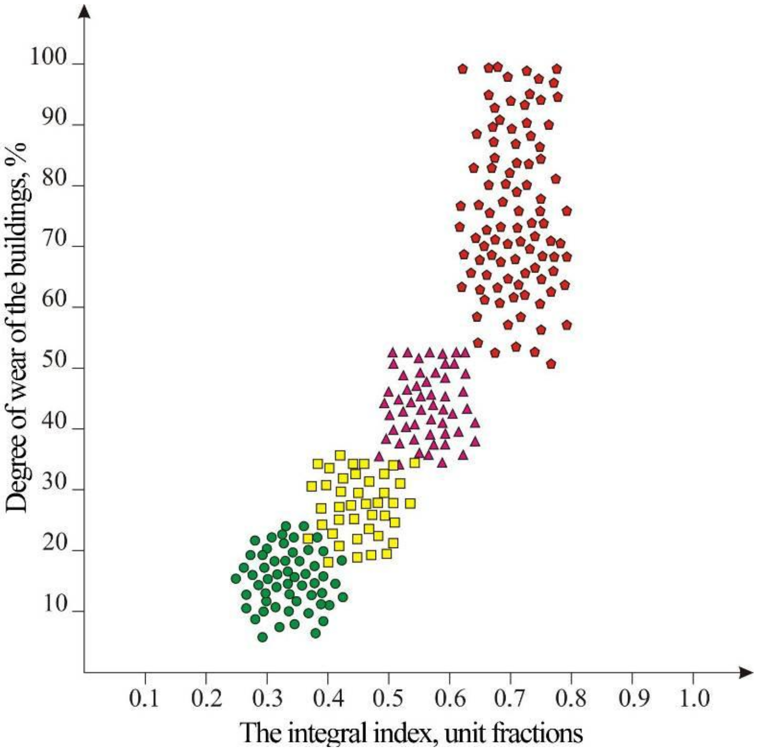

Figure 1. Degree of the wear of the buildings as a function of the integral index

A special (predictive) geotechnical zoning of Nadym was carried out by means of matching the model of the field of the integral index and the diagram of the degree of the wear of the buildings as a function of the integral index. The four stability classes corresponding to geotechnical conditions of different complexity were identified. Class I corresponds to relative stability and J equal to 0.32–0.4 unit fractions; Class II corresponds to medium stability and J equal to 0.4–0.5 unit fractions; Class III corresponds to low stability and J equal to 0.5–0.6 unit fractions; Class IV corresponds to instability and J equal to 0.6–0.76 unit fractions.

The obtained estimates of impact of the geological processes are in good general agreement with both expansion of deformations of the industrial and civil buildings within their limits and the data on the construction geotechnical conditions at individual sites.

The cartographic model proposed may be a basis for design of buildings and structures, development and organization of monitoring of the lithotechnical system in Nadym.

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Hydrologic and Gaseous Export of Carbon and Nitrogen from Upland Thermokarst Features on the North Slope of Alaska

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Introduction

Permafrost soil organic matter

Soils in the permafrost region contain more than half the world’s soil organic matter (SOM), storing between 1400-1850 Pg carbon (C) [*Tarnocai et al. 2009*], and 40-60 Pg nitrogen (N), assuming an average C:N ratio of 30:1 [*Jonasson et al. 1999, Weintraub & Schimel 2003*]. Persistent cold and saturated soil conditions limit decomposition, leading to the buildup of this large SOM pool. As the Arctic warms and permafrost degrades, the soil temperature and moisture conditions currently protecting SOM will also change. Because the permafrost SOM pool is so large, the release of even a small portion could entrain serious consequences for regional ecosystem processes and global C and N cycles.

Pathways of permafrost degradation

As temperature increases, permafrost SOM will become vulnerable to release through two major pathways: 1, gradual deepening of the active layer or 2, catastrophic subsidence and collapse of soil structure due to the melting of ground ice (thermokarst). Thermokarst rapidly exposes ancient SOM to decomposition and hydrologic transport.

Thermokarst affects C and N dynamics by deepening subsurface flowpaths, mobilizing sediment and SOM, modifying soil moisture conditions, disrupting soil structure, increasing soil temperature, and elevating nutrient availability. As a consequence, thermokarst formation catalyzes biogeochemical activity, and may have different effects on ecosystems compared with gradual thaw of permafrost. We hypothesize that thermokarst, compared to gradual thaw, increases the rate, bioavailability, and total amount of C and N released from SOM in the affected permafrost.

Frequency of thermokarst formation

While the pan-arctic rate of thermokarst formation has yet to be comprehensively characterized due to lack of monitoring and high resolution imagery, site-based estimates indicate a 3.5-8 % average increase of the areal extent of thermokarst in the last 50 years [*Jorgenson et al. 2009*]. On the coastal plain of the North Slope of Alaska, thermokarst features currently cover 3.8% of the landscape and could impact another 10-30% with only a minor increase in temperature [*Jorgenson et al. 2006*].

Methods

Experimental design and analyses

Because thermokarst formation causes both hydrologic and gaseous release of SOM, we employed a coupled terrestrial/aquatic experimental approach. We collected soil, water, and gas from upland thermo-erosional features in various stages of development. Over 60 features were sampled, split between three feature morphologies: thaw slumps, thermo-erosional gullies, and active layer detachments. We divided features into ecologically relevant surface patches based on type and severity of permafrost degradation (Fig. 1).

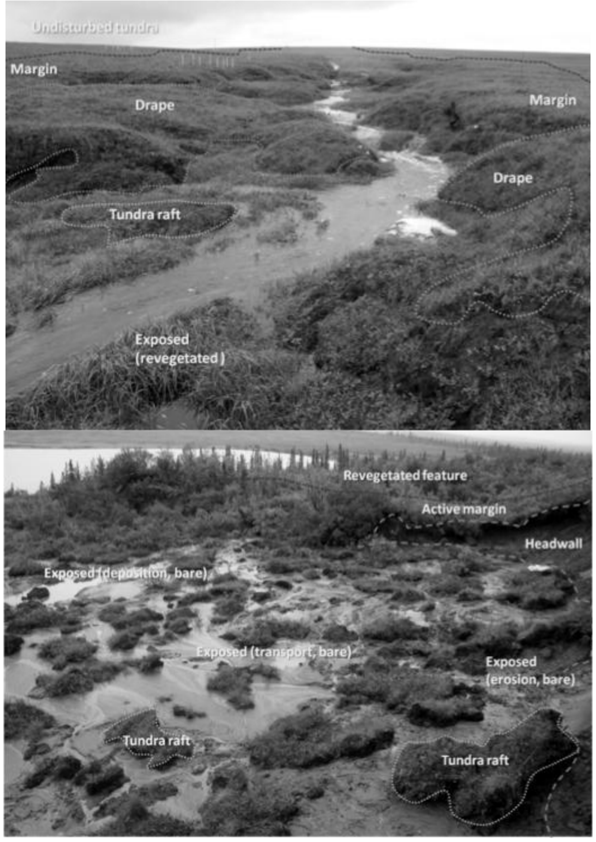

Figure 1. Patch type classification based on form and severity of permafrost degradation for thaw slump (above) and thermo-erosional gully (below). Divisions are defined as follows: undisturbed tundra is at least 5 m outside visible disturbance, margins are within 5 m of visible disturbance but have not experienced subsidence, drapes have subsided but vegetation is still attached to surrounding tundra, tundra rafts have subsided and detached from surrounding tundra, exposed patches are bare mineral soil, and revegetated patches are previously exposed sites recolonized by moss and other plants.

Soil, water, and gas samples were collected from features of various ages as well as undisturbed tundra, water tracks, and streams. Water collected from control and impacted soils and surface waters was analyzed for dissolved organic and inorganic C and N (DOC, DIC, DON, DIN) as well as anion and cation chemistry. We tested the lability of DOC from a subset of samples with 40-day incubations. Dissolved gas was extracted from water samples in the field, and soil pore gas was collected from a 15 cm depth with metal straws. Gases were analyzed by gas chromatography for CO_2, CH_4, and N_2O. Soil respiration, temperature, and volumetric soil moisture were measured in the field with an infrared gas analyzer and auxiliary probes.

Site description

We sampled three clusters of thermokarst features in the foothills of the Brooks Range on the North Slope of Alaska. Features around the Toolik Lake Field Station (68.63°N, 149.60°W) were sampled three times a summer from 2009-2011. We supplemented the temporally intensive Toolik sampling with spatially extensive expeditions to the Kelly River ranger station (67.94°N, 162.39°W) in 2010, and Feniak Lake (68.27°N, 158.34°W) in 2011, both in the Noatak National Preserve. All sites were located in the continuous permafrost zone with features occurring in areas of various vegetation and substrate (tussock, non-tussock, graminoid tundra, erect, dwarf shrub tundra, and non-acidic mountain complex).

Results

Gaseous carbon and nitrogen release

Soil respiration was significantly elevated for raft, drape, and margin patch types compared to control tundra. In undisturbed tundra, soil moisture had a strong negative relationship with respiration, but within features had the opposite effect (indicating water-logging in the undisturbed tundra and water limitation within features). Temperature was more important than soil moisture, however, in predicting respiration within features across patches. The partial pressure of CH_4 in soils was suppressed relative to control tundra for all patch types except revegetated where CH_4 partial pressure was four times higher. Partial pressure of N_2O was two times higher than atmospheric background in drape and raft soils indicating denitrification.

Hydrologic carbon and nitrogen release

Patterns of DOC and DON concentration varied by site, in some cases increasing dramatically within or below thermokarst features, but not varying in others. However, DIC and DIN concentrations were consistently greater in impacted waters than control sites. On average, the concentration of NH_4^+ was twice as high in impacted waters, and concentrations of NO_3^- and DIC were ten times higher. Dissolved CH_4 and N_2O were detected more frequently and at higher partial pressures in impacted waters than reference waters. DOC loss after 40 days varied from 12% and 20% for reference water tracks and rivers to 19%, 32%, 40%, and 65% for gullies, active layer detachments, thaw slumps, and Yedoma exposures respectively.

Discussion

Biogeochemical implications

While upland thermokarst features vary in morphology, substrate, age, and size, some general patterns of this disturbance type exist. Thermokarst consistently increased inorganic N availability, particularly NO_3^-. This may be due to thermokarst simultaneously interfering with plant uptake by disrupting roots and also increasing N mineralization by warming and aerating soils. This surplus of inorganic N explains the drape and raft patch denitrification, a process which has previously only been detected in tundra in bare mineral soils. Soil conditions change substantially as features move from the initial active formation phase with wet and cool surface soils to a warm and dry state as ground ice is exhausted and features stabilize. This has implications for the type and timing of SOM hydrologic and gaseous release from thermokarst.

The delivery of bioavailable C and N to downstream and downslope ecosystems has the potential to influence off-site processes. This release particularly could stimulate primary productivity in aquatic ecosystems and increase CH_4 production by delivering large amounts of organic matter to low-oxygen environments such as wetlands and lake-bottoms.

Global implications

As thermokarst formation becomes more common in the Arctic it will accelerate the pace of permafrost degradation and subsequent SOM processing. Because a large portion of the Arctic is susceptible to this pathway of permafrost degradation, thermokarst has the potential to enhance C and N release at a landscape scale. The labile nature of DOC released from thermokarst emphasizes that permafrost region SOM is not only abundant but also very bioactive. Because thermokarst is not incorporated into current C cycle models, it represents an important unknown in our understanding of the future behavior of the permafrost region. Identifying and constraining biogeochemical mechanisms driving patterns of elemental cycling in thermokarst would facilitate parameterization and understanding of this important pathway of permafrost degradation.

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10 Years of Permafrost Monitoring on Volcanoes of Klyuchevskaya group, Kamchatka Layer

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Introduction

Kamchatka is situated in the Far East of Russia. The Klyuchevskaya volcano group is located in the Central Kamchatka Depression (55–56°N, 160–161°E) and consists of the active volcanoes Klyuchevkaya (4800 m a.s.l.), Bezymianny (2900 m a.s.l.), Ushkovsky (3900 m a.s.l.) and Plosky Tolbachik (3100 m a.s.l.) as well as ten other inactive volcanoes and numerous smaller volcanogenic landforms such as cinder cones or extrusive domes. There were no special permafrost investigations here until 2002. The first data about the properties of frozen volcanic deposits, ground temperatures and active layer depth were obtained by our expedition by drilling the boreholes in this area. The boreholes were drilled using compact equipment for slow rotary drilling. We used instrumental steel drilling bits with an inner diameter between 5 and 10 cm. The upper 2m of each borehole were cased with a plastic pipe. Initial temperature measurements in the boreholes were made several weeks after drilling with the use of a thermistor string. Continuous measurements were then made using Onset Hobo Pro series and LPC data loggers. One of the sensors was usually installed on the surface and the others - at the various depths inside a borehole. Permafrost underlies about 2000 km2 here, and periglacial processes and landforms are widespread at the elevations above 900 m a.s.l.; the lower boundary of permafrost is around 750–900 m a.s.l. on north-facing slopes and around 650–800 m a.s.l. on south-facing ones slopes with no forest vegetation. Numerous solifluction lobes, mud-boils, polygonal structures and areas of sorted patterned ground occur between 1000 and 1700 m a.s.l.

Permafrost monitoring results

Data about the air temperatures are available for the Klyuchi station, which is located in the Kamchatka river valley (30 m a.s.l.). The average MAAT for 2002-2011 is 0.3°C, which is higher than the value of -0.2°C for 1980-2000. Ground and surface temperatures were measured six times per day at eight locations, starting from 2005. The longest continuous record of MAGT (from September of 2007) is available for 1-06 borehole which was drilled at 1630 m a.s.l. near Tolbachik volcano (Fig. 1). The mean annual ground temperatures (MAGT) in the area vary from 1.3°C at 950 m a.s.l. down to -8°C at 2515 m a.s.l. The active layer thicknesses have been measured at three sites (100 m x 100 m and 50 m x 50 m) at the elevation range from 1300 to 1600 m a.s.l. as part of the CALM project (Table 1). The mean summer temperatures were in the range from 12,6 to 15,4°C, and the mean active layer depth ranged from 80 to 44 cm. During 2003-2011 the active layer depth didn’t show any significant increasing (more then 10 cm). We assume that the properties of the volcanic cinders, which have high porosity and are good thermal isolators, can be a reason for this. The ground temperatures at 10-15 m depth increased for 0,1-0,2°C from 2003.

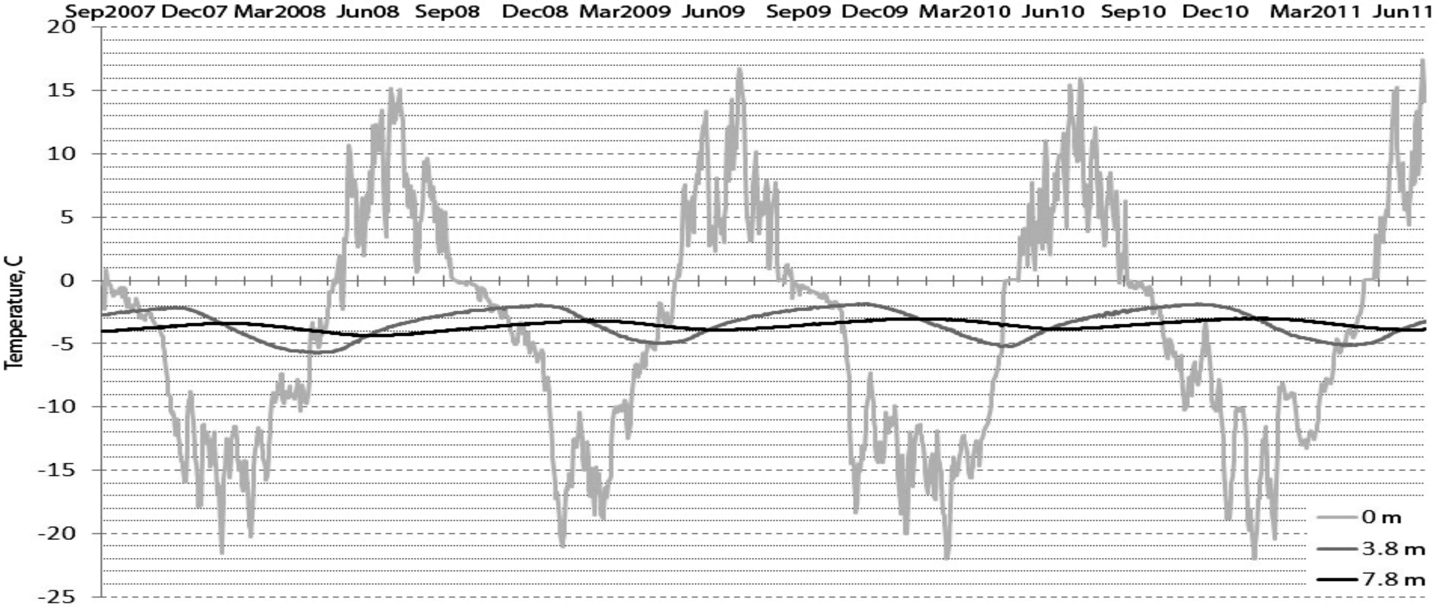

Figure 1. The temperature data from the 1-06 borehole.

Conclusions and perspectives

Despite of no significant changes in the ground temperatures and active layer depths in the area, some changes of the landscapes affected by permafrost are evident in the last 10 years. Some thermokarst features and melting of dead ice have been observed during the field excursions.

Temperature monitoring at 500 m a.s.l. in the forested area has proved the existence of the air temperature inversion in winter time. For more precise measurements of the inversion height we are planning to install some additional loggers. We're also going to drill new boreholes at the Erman plateau (2700 m a.s.l.) and install surface loggers at 4500 m a.s.l. (summit of the Kamen volcano) for more adequate calculation of the altitudinal temperature gradients. We are still waiting to find out some influence on the ground temperatures from volcanic activity near our boreholes.

This research was supported by the "Thermal State of Permafrost" and "Circumpolar Active Layer Monitoring" projects.

Table 1.The results of active layer depth measurements at CALM sites in Kamchatka.

Year	R30A (1330 m)		R30B (1630 m)		R30C (1630 m)	
	Data	ξ, cm	Data	ξ, cm	Data	ξ, cm
2003	06/09	78	-	-	-	-
2004	28/09	67	29/09	49	-	-
2005	05/09	71	06/09	56	-	-
2006	19/09	73	23/09	54	01/09	44
2007	18/09	72	19/09	53	16/09	45
2008	16/09	73	16/09	56	19/09	49
2009	24/09	80	24/09	63	20/09	49
2010	29/09	76	29/09	58	25/09	50
2011	05/09	72	05/09	59	02/09	50

Groundwater in the Permafrost Zone

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Abstract

Investigation into permafrost has been an important issue in the modern science as frozen ground occupies about 65% of the territory of Russia. Permafrost is uneven in lithology, structure, and extent. It is most often continuous (53% of the total permafrost area) and less often discontinuous (15%), sporadic (19%) or patchy (13%).

Keywords: Groundwater; perennially frozen rocks; permafrost zone; permafrost; taliks

Concept of permafrost

The territory which includes perennially frozen rocks is called a zone of permafrost (or cryolithozone, from *cryos* and *lithos*, Greek for *cold* and *stone*). It consists of frozen and frost-bound rocks, cryopegs, and an active layer.

Frozen rocks are ice-rich and have negative temperatures. Unlike these, frost-bound rocks bear neither water nor ice and are most often igneous and metamorphic rocks, or dry sand and pebble. Cryopegs (from *cryos* and *peg*, Greek for *cold* and *saline water*) likewise have temperatures below zero and are saturated by saline waters or brines.

Division of permafrost

The zone of permafrost encircles the Arctic Ocean and covers about 25 % of the Earth’s total land and 65 % of Russia. Perennially frozen ground occupies totally 3000,000 square kilometers existing also as isolated patches near mountain tops in the highlands of Alps, Caucasus, Tien-Shan, Pamirs, Himalayas, etc.

Permafrost in southern areas is patchy, with 10-25 m thick frozen lenses among unfrozen rocks. North of sporadic and patchy permafrost, there lies a zone of discontinuous permafrost, up to 100 m in thickness, with numerous taliks (layers and lenses of unfrozen ground). Permafrost further northward is continuous and as thick as 1000-1500 m.

Thus, the thickness of permafrost varies broadly from a few meters to 1000 or even 1500 m.

Origin of permafrost

Modern areas of perennially frozen ground appeared in the latest Pliocene-earliest Pleistocene, more than 2 Myr ago, but continuous permafrost which has never disappeared later on formed about 650 Kyr BP, in the Pleistocene, in the northern Siberian craton. The pattern of permafrost in continental plainland is latitude-controlled as the amount of net solar radiation decreases northward, mean annual ground temperatures decrease, while backscattered radiation increases due to long-lasting snow cover (albedo feedback): About 90% of incoming sunlight is reflected back from snow but only 7-8% from tilled land. In highlands, there is also altitude zoning, and permafrost may be as thick as 3000 m in the high Pamirs and Himalayas.

The permafrost thickness depends on many factors: latitude, landscape, terrain, geology, and heat flux.

Structure of permafrost

The permafrost table always lies at some depth below the ground surface corresponding to the thickness of the active layer. It consists of seasonally thawing rocks that thaw in warm seasons and freeze up completely in cold seasons; the seasonally freezing layer forms in winter in taliks above unfrozen rocks and thaws completely in summer.

The depth of freezing (thawing) is a critical parameter depending on the amount of solar heat coming to the area in winter and in summer.

Permafrost may have different patterns in geologically different areas. Some places are fully occupied by frozen ground while others, like those upon Precambrian cratons with a metamorphic basement and a thick sedimentary cover, consist of frozen rocks above (sediments) and frost-bound ones (bedrock) below.

Zones of cryopegs exist on the coasts of seas fringing the Arctic ocean, with brine-saturated lenses grading smoothly into the surrounding cold rocks. The upper part of frozen ground is younger than the lower one.

Groundwater in permafrost

Formation of permafrost which acts as confining beds for waters has changed dramatically the conditions of the air—ground water exchange. The greatest part of fresh groundwater in the permafrost zone is stored in taliks. Taliks are layers (lenses) of ground on the surface or beneath lakes and rivers that hold unfrozen for more than ten years. Taliks may be either open or closed: The former border frozen rocks on the sides while the latter lie over frozen rocks (supra-permafrost taliks). Or, taliks may exist between frozen layers or within them as tunnel- or tube-like lenses. Groundwaters may circulate above, below, between or within the confining frozen layers (cryogenic aquifuges), and are classified, respectively, as supra-, sub-, inter-, or intra-permafrost waters.

Suprapermafrost groundwaters include ephemeral waters in the active layer and perennial waters of closed taliks. Ephemeral waters exist only in summer and never lie above the permafrost table. Groundwater is a principal agent in solifluction, liquefaction, slumping, and heaving processes.

Perennial waters associated with closed taliks above the permafrost table are responsible for the origin of hydrolaccoliths, pingoes, and icing.

Interpermafrost groundwater commonly occurs between two frozen layers, e.g., between a Holocene layer above and a remnant Late Miocene layer below. Water of this kind is most often dynamically inert.

Intrapermafrost water is confined within closed bodies (talik lenses) in karst limestone.

Subpermafrost groundwater circulates near the bottom of frozen ground. It has temperatures above zero and high or low salinity; it may be pressurized or not, and may either contact frozen rocks directly or be separated from them by unfrozen rocks.

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Strength Properties of Warming Fine-Grained Permafrost

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Background

The bearing capacity of permafrost soils are usually high compared to non-frozen soils of the same composition. The strength of these frozen soils are challenged by the projected climatic ameliorations in the Arctic, which are expected to strongly influence the distribution and thickness of permafrost during the 21st century. In Western Greenland soil temperatures are projected to increase by 2-3°C inferring Permafrost Thaw Potentials of more than 2.5 m [*Daanen et al. 2011*].

Fine-grained permafrost soils are especially affected by the transition from frozen to unfrozen state, primarily due to the ability to hold large amounts of ice and the influence on the soil strength and deformation properties resulting from thaw. However, also properties such as the unfrozen water content and the soil salinity play an important role [*Arenson et al. 2007*]. With projected climate amelioration these property changes pose a challenge to the desired service life time and foundation design of new constructions.

For engineers striving to enhance and optimize the service life time of new industrial facilities and general infrastructure in permafrost areas, the projected warming poses a dilemma of whether to accommodate the subsequent change of soil properties in the foundation design or having to avoid constructing on permafrost at all. This study aims to delineate trends for the strength properties of fine-grained permafrost deposits that can be used to forecast end-of-service-lifetime-strength based on soil properties obtained from surveys performed at present day soil temperatures. The data basis is obtained from testing of natural permafrost soil core samples collected at two locations in inhabited areas of Western Greenland.

Methodology

Sample material

Permafrost soil cores have been sampled from the top of the permafrost zone in the townships of Sisimiut and Ilulissat situated at 66.9° to 69.2° northern latitude. Present soil temperatures vary from -3.5°C to 0°C. The preliminary testing classifies the soils as silty to very silty marine clays at both locations. The chloride concentration in the soil is seen to be virtually 0 mg/L indicating fully leached conditions resulting in no residual salinity. The samples from Sisimiut have a volumetric excess ice content of 18.5 % of the frozen sample volume on average while the samples from Ilulissat are virtually free of excess ice (0.1 % on average). Sample data are found in Table 1 below.

Test setup

For each location three samples have been subjected to isotropic consolidation at 100 kPa followed by undrained triaxial compression testing at a constant rate of strain (0.72%/h) maintaining a confining stress of 100 kPa to determine the shear strength at near-thawing temperatures of -3°C, -2°C and -1°C respectively. Tests were run until an axial strain of 4 %, defining the failure criterion, was obtained.

Results

Test results

The maximum shear strengths recorded of the individual triaxial tests range from 840 kPa at -1°C to more than 2 MPa at -3°C. All maximum strengths were obtained at the failure criterion after display of ductile behavior. The strength data is normalized relative to the maximum shear strength at -3°C for each location, like shown in Equation 1:

$$\tau_n = \tau_{max,T} / \tau_{max,-3} \tag{1}$$

Where $\tau_{max,T}$ is the obtained maximum shear strength and τmax,-3 is the maximum shear strength for test at -3°C. The resulting data points are then plotted against the temperature to obtain a trend for the development of the soil strength as a function of the soil temperature. See Figure 1. A global linear trend is expressed by the equation

$$\tau_n = -0.21 \cdot T + 0.37 \tag{2}$$

Where τ_n is the normalized shear strength relative to the shear strength at -3°C and T is the temperature in the range of tested temperatures from -3°C to -1°C.

From the shear strength failure values the soil's corresponding undrained shear strength for use for bearing capacity evaluation based on Terzaghi's bearing capacity theory can be determined as a function of the soil temperature.

Discussion

The two series of normalized shear strengths shown in Figure 1 display a common trend of approximately 20 % decrease of strength per degree temperature increase compared to the shear strength at -3°C. This is in spite of the fact that the samples from the Sisimiut area contain moderate amounts of excess ice, which generally lowers the maximum strength compared to the Ilulissat samples. The trend of decreasing strength with decreasing dry density is also demonstrated by Li et al. [*2004*], who present uniaxial compression strengths of remolded clay with variations of dry density, temperature and strain rate.

A slight trend of a decreasing gradient of the curve for the Ilulissat samples may be deduced while the opposite seems to be the case for the Sisimiut samples, but further experiments must be performed before any conclusions are made in this regard. However, it makes good sense that the strength of the more ice rich samples should decrease more rapidly as the temperature close in on the freezing point as the amount of unfrozen water increase and the viscosity of the ice decrease.

Table 1. Classification data for the tested fine-grained permafrost samples. Location abbreviations: 'ILU' denotes Ilulissat and 'SIS' denotes Sisimiut.

Sample ID	ρ_{bulk} [g/cm^3]	ρ_{dry} [g/cm^3]	$w_{i,vol}$ [%]	w_{nat}* [%]	Test temp. [°C]
ILU 1A	2.01	1.68	0.1	19.4	-2
ILU 2A	2.03	1.70	0.1	19.4	-3
ILU 3A	2.00	1.65	0.1	19.4	-1
SIS 4B	1.50	0.82	33.5	33.5	-3
SIS 6A	1.77	1.32	8.2	29.2	-1
SIS 7B	1.69	1.18	13.9	33.3	-2

* Gravimetric water content of sample after draining of excess ice upon thawing.

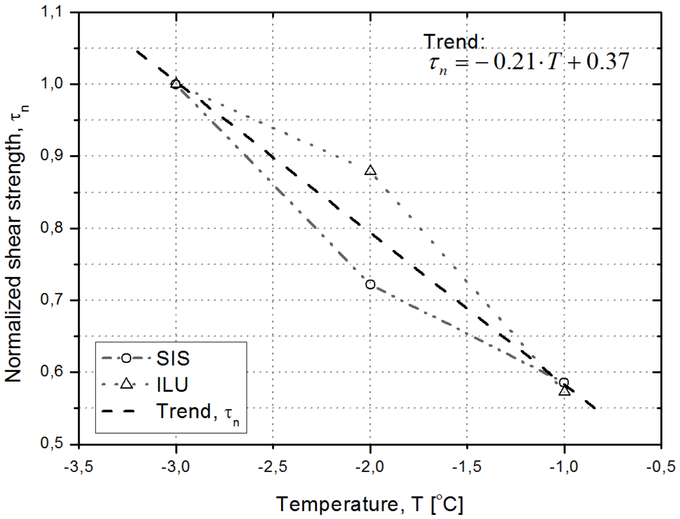

Figure 1. Normalized shear strength for natural fine-grained permafrost samples tested in triaxial compression at a confing pressure of 100 kPa.

If the shear strength of the design soil, having a present temperature within the tested temperature range, can be determined along with the expected soil temperature at end of construction service lifetime, then, given that the latter temperature also is within the temperature range of the tests in this study, the strength decrease due to soil temperature change can be estimated based on Equation 2. A series of these curves for different soil compositions could provide an efficient design tool for new construction designs in areas of fine-grained permafrost if used in combination with an improved regional climate model capable of delineating the development of soil temperature at a sufficient resolution. In this way the development of soil temperatures within the service life time of the construction can be predicted and the foundations designed based on the resulting corresponding bearing capacity available.

This approach is believed to contribute to a sustainable adaption of the new building mass to the projected climate changes and generally decrease maintenance costs of new constructions built on warming fine-grained permafrost and subsequently prolong the effective service life time.

Conclusion

Based on constant rate of strain triaxial compression testing of two series of natural fine-grained permafrost samples at near-thawing temperatures it is demonstrated, that a relation exists connecting the temperature and the normalized shear strength across variations in sample excess ice content. In the tested range of temperatures from -3°C to -1°C, the shear strength decrease approximately 20 % per degree temperature increase, relative to the shear strength at -3°C.

It is proposed, that the identified relationship can support the estimation of future soil strength properties for sustainable foundation design based on projected soil temperatures based on relevant climate models.

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The lower boundary of permafrost in Hurd Peninsula (Livingston Island, Antarctic)

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Introduction

Research on permafrost has a long tradition in the Northern Hemisphere where hundreds of boreholes for temperature monitoring have been installed [*Romanovsky et al. 2010*]. Antarctic permafrost is less studied and the borehole network is scarce, with short time-series [*Vieira et al. 2010*]. In order to coordinate data collection and monitoring, the International Permafrost Association together with the WMO/GTOS/FAO have implemented the Global Terrestrial Network for Permafrost (GTN-P) and the Circumpolar Active Layer Monitoring System (CALM). IPY projects TSP and ANTPAS boosted permafrost monitoring activities, resulting in infrastructure and in new assessments of permafrost thermal state. There are currently 39 active layer and permafrost boreholes and 8 CALM sites in the Antarctic Peninsula region (AP).

The AP has been one of Earth's regions showing a strongest warming trend, with ca. +2.5ºC in the mean annual air temperatures since the 1950's [*Turner et al. 2003*]. Effects on glaciers and ice-shelves have been widely reported [*Scambos et al. 2003*], but impacts on permafrost haven't yet been properly addressed to. Vieira et al [*2010*] present an overview of the thermal state of Antarctic permafrost and show that permafrost is cold in most of the Antarctic, except in the South Shetlands. There, permafrost temperatures are slightly below 0ºC and permafrost is at its climatic boundary. The northern AP is, therefore, an unique area in the Antarctic for evaluating the effects of permafrost degradation.

In this presentation we present a synthesis on the present status of knowledge on permafrost distribution and thermal state in Hurd Peninsula, Livingston Island and discuss the significance of these results for other areas of the South Shetlands. Hurd Peninsula is a rocky and rugged peninsula, with altitudes up to 392 m and mostly covered by Hurd Glacier, but with several ice-free sectors. Geology is dominated by the Miers Bluff Formation, a low-grade metasedimentary flysch formation. Bedrock outcrops are frequent, but most of the ice-free surface is covered by a decimeter to meter thick cover of angular cobbles and boulders. In some areas, close to the glacier boundary, till is present.

Methods

Continuous activities for monitoring the thermal state of the active layer and permafrost in Hurd Peninsula started in 2000 by the University of Alcalá de Henares in collaboration with the University of Lisbon. During the International Polar Year, in the framework of ANTPAS project, in a joint effort with other partners such as the University of Évora, the University of Zurich and the Bulgarian Antarctic Institute a new set of boreholes, as well as active layer monitoring sites was installed. The objective is to analyze the spatial and temporal controls on permafrost thermal state in Hurd Peninsula and to use the area as a case study allowing to better understand permafrost characteristics in other similar areas at the South Shetlands.

The following techniques are used:

- Active layer monitoring boreholes from 0.8 to 4m depth at key sites along altitudinal transects and in different types of terrain;
- Permafrost monitoring boreholes 15 and 25m depth at key sites planned for reflecting the regional climate forcing signal and characterizing permafrost thermal state;
- Electrical resistivity tomography profiles for determining the spatial distribution of permafrost;
- Snow cover monitoring using time-lapse cameras, temperature poles as well as remote sensing techniques;
- Detailed geomorphological mapping to identify geo-indicators of permafrost and periglacial dynamics;

Results and discussion

Bedrock sites

Permafrost in bedrock in Hurd Peninsula was found in the boreholes located above 260 m asl, with a temperature of about -1.8ºC at 20 m depth. In a borehole at 160 m, permafrost is possible but the deepest temperature sensor, placed at 4 m depth is in the seasonal frozen layer. At the same place freezing from below has been identified during autumn, indicating a possible presence of permafrost. The borehole at 35 m asl shows no permafrost. Plotting of average annual temperatures in bedrock sites with little snow cover along a vertical gradient shows a good regression fit (figure 1). Given the homogeneous topographical constraints of these boreholes, the limit of permafrost in bedrock seems to occur close to an altitude of ca. 150 m.

Electrical tomography resistivity supports the presence of a transition area with sporadic permafrost at around 100-150 m, with patches of frozen ground found in the profiles. Hauck et al [*2007*] have shown this for the vicinity of the Spanish station. Recent data from the area of the Bulgarian station shows similar results.

Sediment sites

Sediment sites are significantly more complex than bedrock sites due to their heterogeneous sedimentological characteristics and diverse water contents. Furthermore their geomorphic history is highly significant for their thermal state and ice-content. Permafrost, mainly as buried ice-masses has been found at different sites down to sea-level by means of Electrical Resistivity Tomography [*Hauck et al. 2007*]. Those sites are located at rock glaciers and moraines, which are glacier-derived. Incipient protalus lobes also occur. Currently some of these features are being monitored but no results for deformation are available yet.

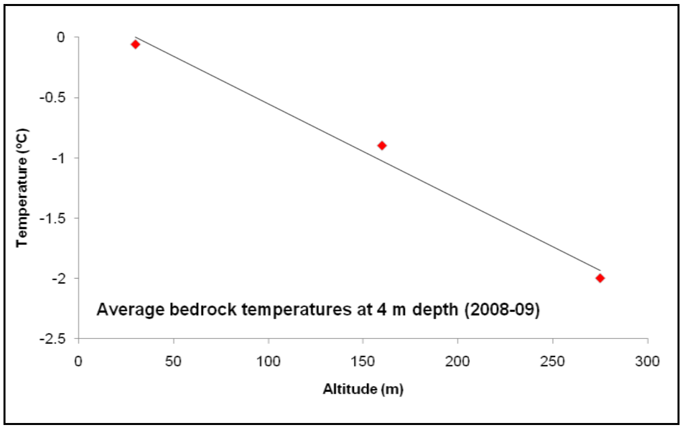

Figure 1. Mean annual bedrock temperatures at 4m depth in 2008-09 in boreholes in Hurd Peninsula.

Conclusions

Research in Hurd Peninsula shows that the area has warm permafrost in bedrock at least above 270 m asl in sites with little snow. At similar topographical conditions, sporadic or discontinuous permafrost starts to occur at 100-150 m asl. At lower altitudes, perennially frozen bedrock has not been found. However, permafrost can occur down to sea-level in sedimentary deposits, at least in those of glacier-derived origin. The high ice-content of such features may be the reason for the persistence of the frozen bodies reacting to climate change at lower rates.

The differences found in permafrost distribution between bedrock and sedimentary deposits suggest that there are different rates of reaction of permafrost to change in both settings. Bedrock sites should react faster to warming, while lower sites with higher ice-content should still preserve a relict thermal state. If this hypothesis is correct, this can be significant since there are areas at low altitudes with a high ice-content that could become unstable with warming, even at sites where permafrost is absent in bedrock terrains. Such a situation can also occur in other sites at the South Shetlands, a critical region at the boundary of permafrost.

Acknowledgements

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Thermophysical properties of surface organic layers

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Introduction

The reported study was run in the Upper Chara basin located between the Kodar and Udokan Ranges in northern Transbaikalia. The territory belongs to the zone of continuous permafrost, with mean annual air temperatures about -7.2°C, and an active layer thickness (thaw depth) from 0.5 to 0.8 m in floodplains of rivers.

Surface organic layers in boreal terrains include moss-peat and lichen components, forest floor, etc., which play a significant role in the air-ground heat exchange. This part of the soil cover has rapidly changing properties [*Gavriliev 2004*] and its thawing and freezing, as well as the related effects on ground temperature patterns, has to be taken into account in predictions of the temperature regime and the depth of seasonal thawing (freezing) of permafrost [*Feldman 1988*].

There is quite ample published evidence of thermal conductivity of surface organic layers [*Zabolotnik 1966, Chernyadiev & Pakulin 1989, Shendera 1986, Feldman et al. 1988, Fukui et al. 2008*], but it is difficult to synthesize for the lack of specific information on water contents and densities of the objects.

Methods and samples

The surface organic layers (vegetation cover) in the study area consist of sod, moss, lichen, and grass. Moisture in the samples collected in the field varies from 250 to 375% and their densities are from 100 to 1000 kg/m^3.

The thermophysical properties of the samples were measured in laboratory using the method of first-kind regular thermal regime [*Ershov 2004*] and with an TPM–λc–10 automated thermal conductivity meter.

Results and Discussion

Thermal conductivity (λ) and diffusivity (*a*) were measured in the vegetation samples at positive and negative temperatures. The water contents and densities being highly variable, all data were synthesized depending on volumetric moisture (W_n) for unfrozen and frozen ground, respectively:

$$W_n=W\cdot\rho_d, \quad (1)$$

$$W_n=W\cdot\rho_d\,/\,\rho_i \quad (2)$$

where W is the gravimetric moisture (%), ρ_d is the density of soil skeleton (kg/m^3), and ρ_i is the density of ice.

Figure 1 shows volumetric moisture dependences of thermal conductivity (A) and diffusivity (B) of the surface organic layers at temperatures above (1) and below (2) zero.

Both thermal parameters are the highest in unfrozen and frozen sod samples (points at moisture above 70% in Fig. 1).

The thermal conductivity of vegetation samples is lower than in peat (Fig. 2) because the former is less dense and bears more low-conductivity air.

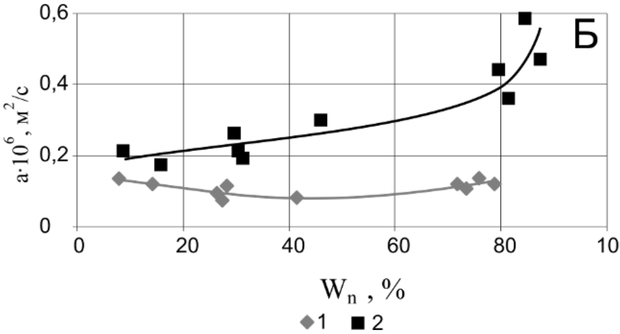

Fig. 1. Thermal conductivity (A) and diffusivity (B) as a function of volumetric moisture at temperatures above (1) and below (2) zero.

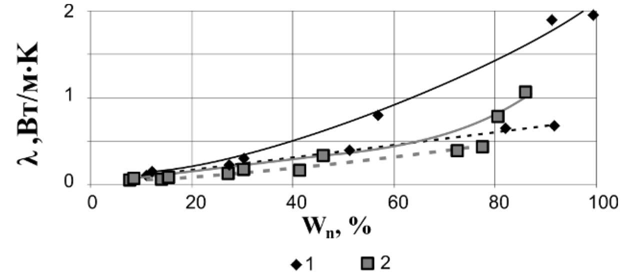

Fig. 2. Thermal conductivity of peat (1) and vegetation (2) samples as a function of volumetric moisture at temperatures above (dashed line) and below (solid line) zero.

The laboratory thermal conductivity data were compared with published results and synthesized as a function of W_n (Fig. 3).

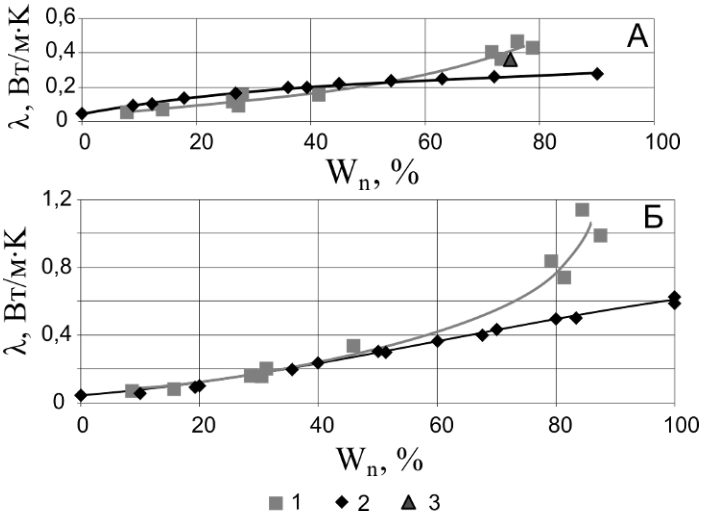

Fig. 3. Thermal conductivity of organic layers as a function of volumetric moisture at temperatures above (A) and below (B) zero. 1 – our data; 2, 3 – published data: Gavriliev (2004) (2) and Zabolotnik (1966) (3).

The laboratory thermal conductivity data we obtained showed good agreement with the published evidence and lent itself to generalization in a single W_n dependence.

The comparison for thermal diffusivity is shown in Fig. 4.

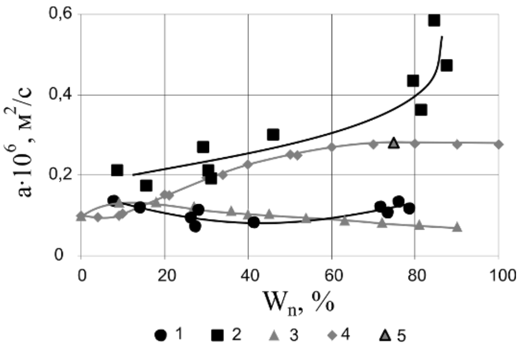

Fig. 4. Thermal diffusivity of surface organic layers as a function of volumetric moisture at temperatures above (1, 3, 5) and below (2, 4) zero. 1, 2 – our data; 3-5 – published data: Gavriliev (2004) (3, 4) and Zabolotnik (1966) (5).

The dissimilarity of thermal conductivity and diffusivity coefficients may be due to the natural diversity of the surface organic layers.

Conclusions

Thus, the experimental study allowed us to

- estimate the variation ranges of thermophysical properties in different surface organic layer varieties and to analyze them as a function of volumetric moisture;
- compare the thermal conductivity and diffucisivity coefficients of peat and vegetation;
- correlate our laboratory data with the published evidence.

Thus new results have been obtained on the thermophyscal properties of the soil cover, which is necessary for modeling the temperature regime and seasonal thaw depths.

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Late Pleistocene Cryogenesis and Contemporary Soil Formation

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Abstract

The study concerns the effect of Late Pleistocene glaciation on the contempoary pedogenesis. The effect shows up (i) as formation of different types and subtypes of soils upon various elements of paleo-permafrost polygonal pattern (soil cover level) and (ii) as difference in soil profiles and in physico-chemical parameters between genetic soil units (soil profile level).

Keywords: Paleocryogenesis; paleogeography; soil formation; soil profile; soil cover.

The historic and genetic aspects of soil formation are becoming increasingly more important for the today's knowledge of soils as part of the Earth's biosphere. However, the history of soil formation at the Pleistocene-Holocene boundary, when pedogenesis was subject to effects from Pleistocene cryogenic events, remains the least explored.

The Late Pleistocene was the time of frequent changes in geological and ecological processes of different scales, and their consequences influence directly the contemporary soil formation.

The modern soils and soil cover have a long and complex history since the Late Pleistocene and, for this reason, the soil science relies largely upon data from allied fields of research. The persistent cooling trend in the Pleistocene [*Markov 1986*] provided mainly anticyclonic conditions and a climate which was the most severe and strongly continental over the entire Pleistocene, and the Cenozoic in general. In the second half of the Valdai stage, Europe underwent intense periglacial processes [*Markov 1986, Velichko 1973, 2009*]. The main cooling peak (between 20 and 18 Kyr BP) led to a culmination of permafrost and produced a global-scale permafrost zone with its southern limits reaching 48° N in the East European Plain.

There are three main glacial intervals distinguished in paleogeography for the European Late Pleistocene section. The lowermost one (Smolensk) spans the time 100-110 (phase a) and 85-90 (phase b) Kyr. The second (Vladimir) interval disturbs soils of the Bryansk interstadial and has its main evolution phase at 25-23 Kyr BP. The Yaroslavl cold interval, the youngest one, that formed during the cooling peak 20-18 Kyr ago, records the coldest climate. It was exactly the period when the Late Pleistocene periglacial zone of the Northern Hemisphere reached its maximum extent [*Velichko 2009*] and when networks of ice, ice-soil, and soil veins, up to 3-4 m high with 15-20 m polygons developed in the center of the East European Plain [*Velichko 1973, Alifanov 1995, Alifanov et al. 2010*]. These conditions correspond to the phase *a* of the Yaroslavl glacial; during the phase *b* (Younger Dryas), the ground underwent active small-polygonal frost cracking. In the time of the Yaroslavl cooling, the permafrost propagated 700-800 km southward.

By the earliest Holocene, the polygonal micro-topography of the Yaroslavl glacial had become buried under newly deposited loam upon which modern soils were forming. However, even being at 1-2 m below the ground, the relict permafrost structure influences the contemporary soil formation as it controls the today's surface pattern. Namely, remnant depressions between blocks in the former polygonal ground became projected onto the ground surface having produced a regular network of depressions and, eventually, a pattern consisting of different elements (Fig. 1).

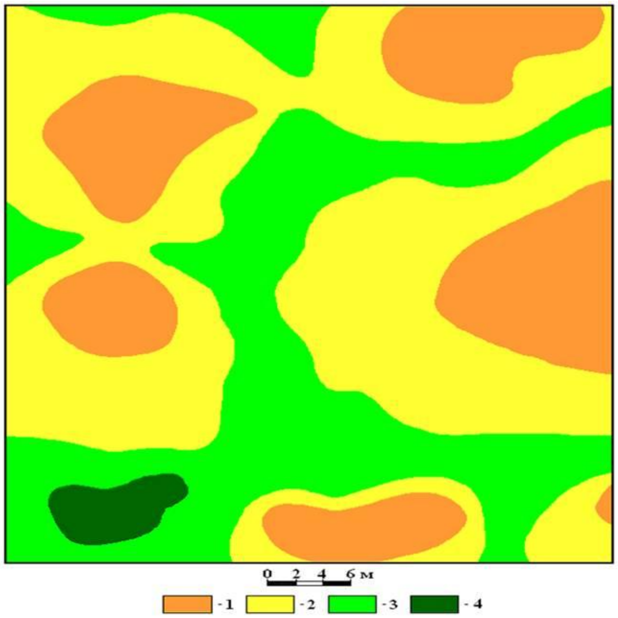

Fig.1. Map of paleo-periglacial polygonal ground pattern. Gray forest soils. Southern Moscow region. *1* – elevated blocks, *2* – block slopes, *3* – depressions between blocks, *4* – kettles.

The modern soil cover consists of soil complexes which include soils of elevated blocks and depressions between them. The inherited origin of the depressions from the paleo-polygonal ground is confirmed by the presence of large buried structures, up to 3 m high (Fig. 1) in sod-podzol and gray forest soils, as well as clusters of 1 m high tongue-like wedges in chernozem.

The buried fossil polygonal ground we discovered affects considerably the soil hydrology, the morphology and physicochemical parameters of chernozems, gray forest, and sod-podzol soils, and thus controls the heterogeneity of the soil cover.

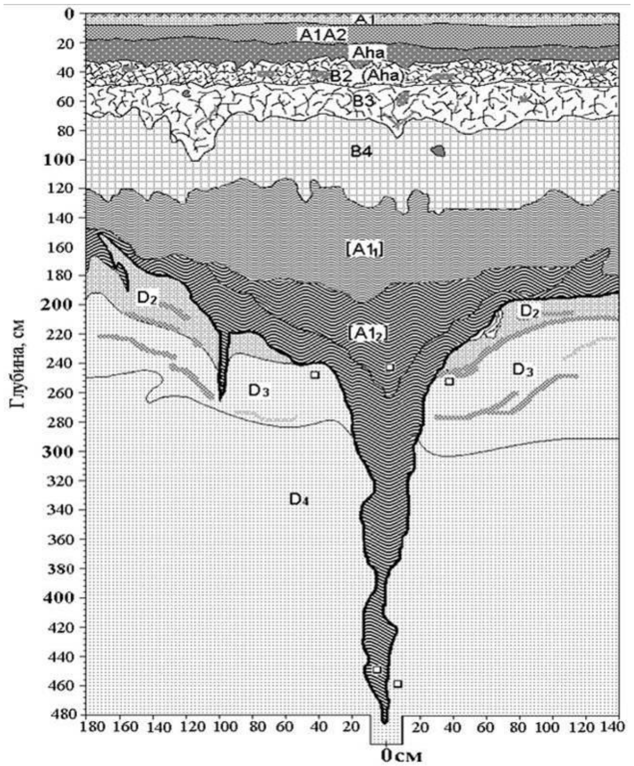

Fig. 2. Morphology of gray forest soil and a soil wedge. A depression between blocks. Southern Moscow region. A1, Aha, B4, [A1_1],D2, D3, etc. Are soil horizons.

The effects of paleo-periglacial processes on the soils we studied show up at different levels, namely, (i) at the level of soil cover: as formation of different soil types and sub-types upon different elements of the fossil polygonal ground; (ii) at the level of soil profile: as difference in the structure of soil profiles and in physical and chemical properties of genetic soil horizons, as well as polygonal patterns of different orders that record uneven intensity of paleo-periglacial deposition at different evolution stages of soil-forming material.

Thus, the current evolution of sod-podzol, gray forest, and chernozem soils superposed upon fossil permafrost polygonal ground produces structurally different soil profiles in elevated blocks and in depressions between them, which are the two zones of paleo-permafrost complexes. The jointly analyzed morphological and physicochemical parameters show that differences in the soil profile appear at the level of soil types and subtypes. Processes associated with the position of a soil in a remnant depression changes the soil classification status (Fig. 3). The soil cover structure of the East European Plain consists of rhythmic circular elementary units.

The reported results on the effect of Pleistocene glaciation on Holocene soil formation are based on ecological factors and, hence, may be useful for systematizing soils at the soil cover level.

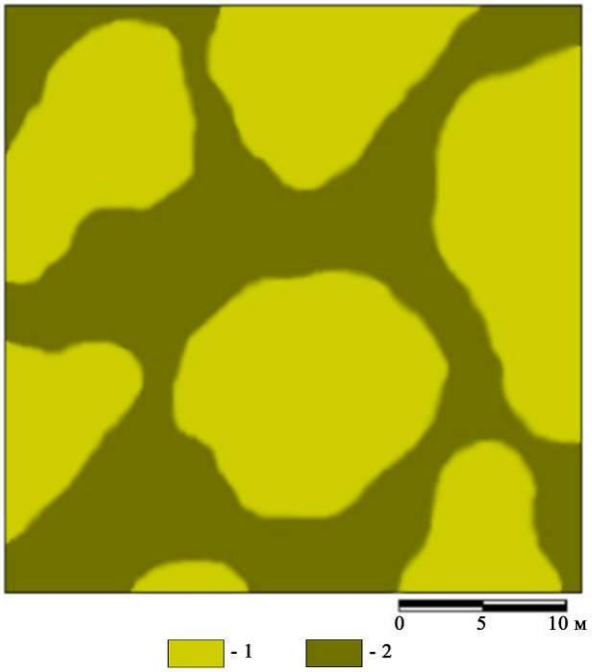

Fig. 3. Soil map. Black earth (chernozem). Kamennaya Step Reserve. Voronezh region. 1 – common chernozem, 2 – typical chernozem.

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Construction in Northern Areas

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Introduction

More than 60% of the Russian territory belongs to the kingdom of perennially frozen earth which is called briefly “the North”. In spite of harsh living conditions, the high-latitude regions remain attractive for people as a storage of petroleum, gold, and diamond. In the first half of the 20th century, with the onset of active development of the northern territories, many industrial, administrative, and residence buildings were put up, which formed rather large urban areas.

The value of the North, with its tremendous mineral wealth, for the Russian national economy cannot be overstated. For this reason, the problems of urban planning, development, and servicing have been largely discussed. Construction in permafrost requires special technologies, thorough knowledge of soils, and monitoring of the state of structures and buildings. Any technological error or improper adaptation of an architectural design to the severe climate can lead to deformation and subsidence of constructions. Furthermore, the situation is becoming ever more serious in view of global warming. Ice does make a solid foundation for houses, unless it begins thawing.

Solutions

Construction in high-latitude regions can be successful only with an integrate approach, from minute geological and soil studies to strict energy audit. The work in the conditions of perennial cold does not end with a high-quality design and construction with full respect of all regulations. Careful technical examination of buildings in order to reveal flaws (if any), estimate the suitability of all structures, and predict the future service performance are indispensable post-construction measures.

Thermal imaging is a good tool for detecting hidden flaws. The method consists in obtaining images at thermal bandwidths, imperceptible for a human eye, which furnish exhaustive information of temperature patterns on the surface of the object and highlight sites of air leakage, construction defects, sealant breakage, etc.

Another problem for northern territories lies with energy saving. The efficiency of heat consumption depends on many things, including design solutions (appropriate glazing, heat insulation, etc.) and trouble-proof heating systems. Energy diagnostics of constructions helps estimating the true heat transfer resistance of buildings as a whole and their separate parts (walls). Examination can reveal drawbacks whereby energy consumption can reduce for 30-40% and the quality of the whole heating system can improve markedly. The examination results are recorded in a special energy certificate assigned to the object, which gives the operation characteristics useful for further work toward the general energy balance.

Conclusions

The prospective measures such as implementation of new construction technologies and appropriate diagnostic efforts can help withstanding successfully the severe northern nature and resolving the vital problem of urban development in high-latitude Russia.

Geocryological components in the 1:2 500 000 Engineering Geological Map of Russia

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Abstract

The Engineering Geological Map of Russia complied in 2011 images the components of the engineering geological setting of the Russian territory at the scale 1:2 500 000. The geocryological components shown in the map include the extent and various properties of permafrost.

Keywords: Geocryological mapping components; engineering geological map of Russia; mapping objects.

The 1:2 500 000 Engineering Geological Map of Russia (IGM-2500) was completed in 2011 at All-Russian Research Institute of Hydrogeology and Engineering Geology (VSEGINGEO).

The new map provides a general-purpose synthetic image of principal natural controls of the engineering geological setting in the near-surface crust which influence the construction conditions.

The mapping objects of IGM-2500 include different components of the engineering geological setting and their characteristics (Fig. 1).

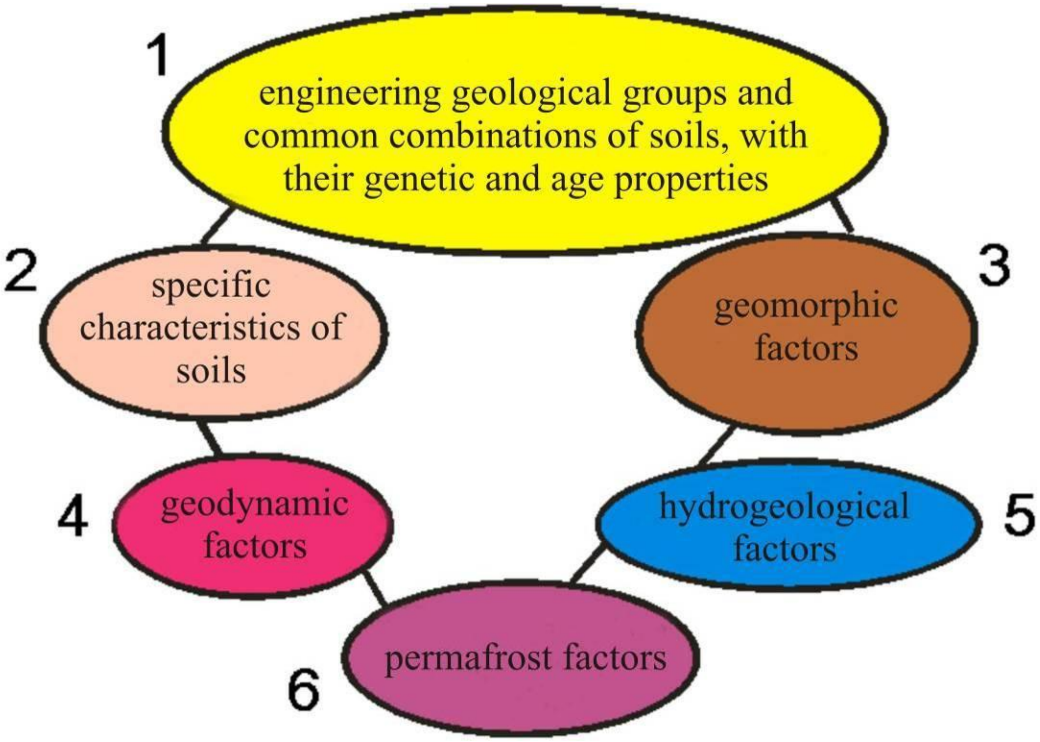

Fig. 1. Information structure of mapping objects (first-order system).

The IGM-2500 Map differs from the previous engineering geological map [*Churinov 1972*] in giving a more detailed image of the permafrost setting as a control of engineering geological conditions (Fig. 2).

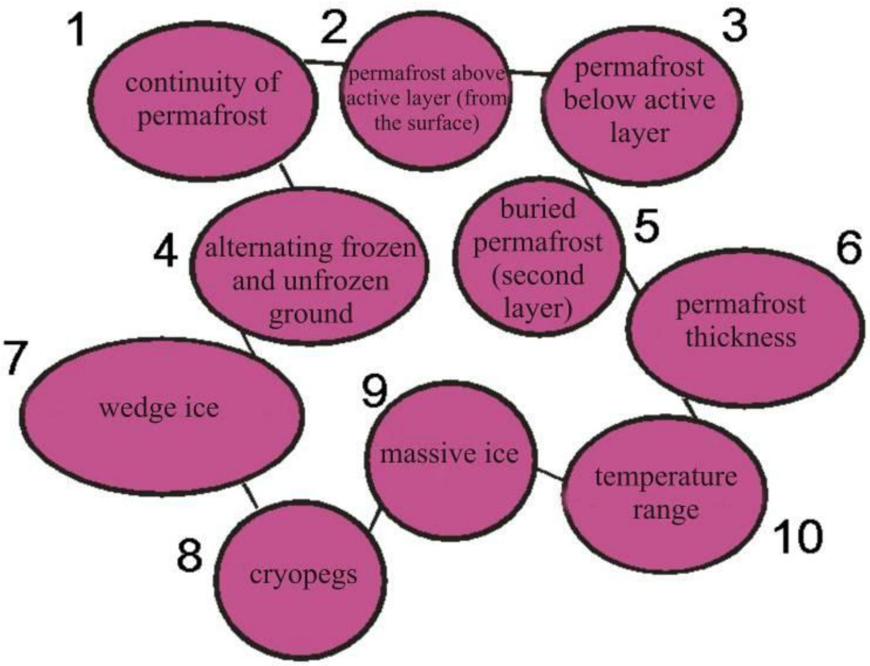

Fig. 2. Information structure of second-order mapping object. Permafrost factors (see Fig. 1).

The mapping objects of the geocryological (permafrost) factor are:

- ground perennially frozen from the surface divided into continuous permafrost, continuous permafrost with sites of unfrozen rocks; discontinuous (sporadic and patchy) permafrost; areas of intermittent frozen and unfrozen ground;
- permafrost below active layer;
- observed and inferred cryopegs;
- buried permafrost (second layer);
- intermittent frozen and unfrozen rocks;
- permafrost of different continuity;
- permafrost of different temperatures (temperature ranges), with grades of below -5°C; from -3 to -5°C; from -1° to -3°C; 0 to -1°C;
- ice content grades are: high; low; ice-rich ground upon low-ice ground;
- wedge ice;
- exposed massive ice;
- maximum permafrost thickness.

The continuity and temperatures of permafrost are shown by lilac oblique hatching of larger or smaller spacing; ice content grades are shown by different hatching line styles (heavy, solid, or dashed lines). The allied parameters of permafrost thickness and temperature have different hatching tilts for better presentation.

Other mapped permafrost characteristics are:

- permafrost below active layer;
- thinly intermittent areas of frozen and unfrozen ground with mean annual temperatures about 0°C are marked by with specks of different kinds;
- outcrops of massive ice;
- wedge ice;
- maximum permafrost thickness.
- maximum permafrost thickness are shown by various off-scale marks according to the legend.

Simulating the Operation of a Cooling System for an Oil Container at the Vankor Oil Field

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Abstract

Numerical simulation has been applied to study the operation of a cooling system for a 20,000 m^3 oil container at the Vankoroil field. The modeling shows that the performance of seasonal cooling systems depends on air temperatures averaged over certain time spans and wind speed, as well as on stochastic fluctuations of these parameters.

Keywords: cooling system; simulation; soil; thermal siphon.

The simulation procedure and the finite-difference scheme were as described in [*Spasennikova 2011*]. The work was performed on an NCS-30T SB RAS super-computer using the MPI technology of multiple programming [*Korneev 2002*].

The results are synthesized in Table 1, which shows that the cooling system not always operates during the winter season. Namely, it remained suspended for 258 days out of 729 days when the temperatures were below zero, over a three-year period.

This effect is due to different rates of air and ground temperature changes: for instance, the cooling system turns off at a time when the air temperature rises above the ground temperature, though remaining negative, and turns on when the temperature again falls to below the ground temperature. The suspension time makes 35% of the total duration of the cold season.

Thus, the numerical simulation has demonstrated that cooling systems remain suspended for a considerable part of the winter season (Table 1) as a result of air temperature fluctuations.

Table 1. Simulated operation of seasonal cooling systems (SCS)
Weather parameters are reported as monthly means

	Air tempe-rature (°C)	Evaporator temperature (average) (°C)	Condenser temperature (°C)	Temperature beneath polystyrene foam insulator (°C)	Time span (days, total)	Suspension time at negative air temperature (days)	Time of negative air temperature (days)	Power of cooling system (kW)
End of February 2010	-37.9	-28.81	-29.89	-20.49	181	0	151	62.65
End of August 2010	9.3	suspended	suspended	0.37	365	74	243	suspended
End of February 2011	-37.9	-30.6	-31.7	-23.1	546	74	394	48.4
End of August 2011	9.3	suspended	suspended	0.13	730	166	486	suspended
End of February 2012	-16.3	suspended	suspended	-23.94	912	167	638	suspended
End of August 2012	9.3	suspended	suspended	-0.25	1096	258	729	suspended

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Dynamics of Subsea Permafrost and Methane Emission in the East Siberian Arctic Shelf: Effects on Global Climate

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Introduction

Methane measured in the air and water of the East Siberian Arctic shelf exceeds the mean-latitude concentrations. Excess methane was hypothesized to release from gas hydrates and vent into the atmosphere through rapidly thawing and thus permeable subsea permafrost with open taliks [*Shakhova et al. 2010*]. This arouse much concern of methane hazard that may aggravate the greenhouse effect and cause dramatic global change. An alternative hypothesis, instead, attributes high methane emission rates rather to slow degradation of permafrost that became submerged in the East Siberian Arctic shelf about 6000-9000 years ago [*Dmitrenko et al., 2011*]. We investigate how the climate change over a few past decades can have increased methane emission in the area and predict the future scenario till the year 3000 using numerical modeling.

Modeling subsea permafrost

We used a physically complete hydrothermal model of subsea permafrost from [*Lavrov & Anisimov 2011*]. The calculations were performed with the input parameters of thermal conductivity, volumetric heat capacity, and porosity of shelf sediments, respectively, λ=2.2 W m^{-1} $°C^{-1}$, C = 1.2×10^6 J m^{-3} $°C^{-1}$, and η = 0.2. The sought parameters were the time-dependent vertical temperature profile T(z) and the subsea depths to the upper and lower boundaries of frozen sediments (Z_{PU}(t) and Z_{PL}(t), respectively) and gas hydrate stability zone (Z_{GU}(t), Z_{GL}(t)).

The time span was from 25,000 years BP (t_0 = -25000) to present, and on to the end of the second millennium. It was assumed that flooding of permafrost at t_f= -9000 ÷ -6000 caused an 11.5 °C warming of the mean annual temperature of shelf sediments: from -13 °C (about the air temperature) when the shelf was emerged to -1.5 °C (bottom water temperature) when it became submerged. The bottom water temperature was assumed to be constant till 1985 and then to rise at 0.09°C/yr till 2100, according to the trend observed over the period 1985 through 2009; after 2100 the temperature was fixed and the calculations continued till 3000.

The model included a warming effect from diffusion of salt into bottom sediments, with the bottom water salinity specified at 20.9 psu in summer and 26.6 psu in winter, which are the measured contemporary values [*Dmitrenko et al. 2011*].

The resulting time-dependent changes in the temperature of bottom sediments (T_0 on the bottom surface and T_{200} and T_{1000} at the 200 m and 1000 m subsea depths) and in the depths to the permafrost and gas-hydrate stability boundaries are shown in Fig. 1, for the above settings.

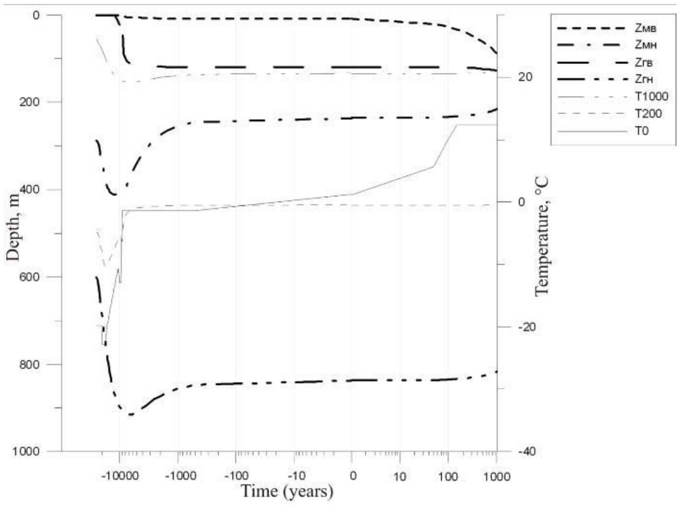

Fig. 1. Time series of bottom sediment temperatures and depths to permafrost (upper and lower boundaries) and zone of gas hydrate stability. Depth Temperature Time (years)

The thaw depth of bottom sediments from the onset of flooding at 9,000 – 6,000 yr BP to the mid-1980s was slightly less than 10 m, while the mean annual water temperature remained subzero. Those temperatures were maintained due to penetration of salt into the pore space which transformed ice into nonfreezing saline water and made it permeable for gas. The modeling results failed to constrain the exact position of the thawing front: it looks smeared over a few meters. There appeared also an intermediate layer of frozen saline sediments with different ice contents and salinities. Sediments having negative temperatures and salinities no less than 0.02 psu were assumed unfrozen.

For the past 25 years since the onset of warming, the bottom water temperature has risen for about 2.1 ºC, which may have caused thawing of another 6-8 m thick layer of sediments below 10 m, to a subbottom depth of 16-18 m. This result obviously disagrees with the hypothesis of methane venting through permeable bottom sediments because of open taliks [*Shakhova et al. 2010*].

The future trend for 2050, 2100, and 3000, predicted with the above parameters, is that the subsea depth to permafrost table Z_{PU} may move to 20 m, 28 m, and 90 m, respectively. The expected changes of the permafrost base depth from 1985 to 3000 are as small as 20 m, from 235 m to 215 m, and the temperature below 150 m remains almost invariable over the modeling period. Thus, it is very unlikely that the thaw depth of subsea permafrost reaches the present gas hydrate stability surface through the current millennium, even with the extreme scenario of rapid sediment thawing, which is hardly realistic.

Conclusions

The principal conclusion is that the permafrost table will stay above the methane hydrate stability zone at any expected temperature change, during the 21st century, and probably as long as the end of the current millennium. Even in the case of an unlikely climate scenario with overestimated temperature range of bottom water, the bottom sediments will have thawed to depths about 90 m by 3000, while the zone of methane hydrate stability in the shelf, at sea depths of 10 – 50 m, beings at the 140-100 m below the bottom. Thus, the zone of gas hydrates will remain isolated by permafrost with a nearly zero permeability.

When estimating the effects of uncertainty in model parameters, one has to be aware that the predicted dynamics of permafrost thawing is more sensitive to the future temperature trends and to the physical properties of sediments than to the accuracy of paleo-temperature reconstructions. The effect of seawater salinity on the permafrost state was to increase the depth of the permafrost table for about 9 m, from the flooding event to 1985, while the bottom water temperature remained negative. The thawing resulted from salt diffusion rather than from a thermal effect, as perennially frozen bottom sediments became impregnated with supercooled saline water.

Of special interest is the problem whether the present high-rate methane emission from the East Siberian Arctic shelf affects global warming. For this one has to estimate the contribution of the current annual flux of 7.9 Tg C [*Shakhova et al. 2010*] to the global atmospheric methane, taking into account the ~12 year average life time of a methane molecule in the atmosphere. Thus, at the equilibrium state, this methane flux will contribute more than 95-100 Tg, or 40 ppbv CH_4. Note that a methane flux of 1000 ppbv increases the global mean annual air temperature for 0.3 °C [*Semenov & Popov 2011*], i.e., methane emission from the East Siberian Arctic shelf is responsible for ~ 0.01 °C warming, which cannot cause any notable effect on the global climate. Even if the current emission rates become ten times greater, the related air warming will be within 0.1 °C, or notably below the uncertainty in climate reconstructions associated with insufficient knowledge of other climate controls.

The reported results lend no support to the hypothesis of a pending climate catastrophe because of methane venting into the atmosphere from thawing sediments in the East Siberian Arctic shelf. This hypothesis is neither consistent with paleoclimate data. Namely, there was already a climate optimum in the Holocene after the Late Pleistocene glaciation maximum, but there has been no evidence of any change that could be called disastrous, though the processes on the shelf during that warming event were similar to the contemporary trends.

Acknowledgments

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Distribution of Trace Metals in Permafrost-Affected Environments of Northern Siberia, Russia

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Introduction

Permafrost-affected soils are widespread in subarctic and arctic tundra where great amounts of organic matter are stored [*Tarnocai et. al. 2009*]. We assume that predicted increase of global air temperature will mobilize this large reservoir of carbon and enhance biogeochemical processes in the upper layers of the permafrost-affected soils. Studies of biogeochemical processes in the Arctic region are particularly important because its ecosystems react more sensitive to effects of climate change and human impacts. Organic matter and permafrost table act as geochemical barrier that regulate ecosystem metal flows. Therefore, studies of organic matter composition, biological activity, and changes in active layer depth of permafrost-affected soils provide the basis for understanding ecosystem stability. Our research aims to discover how the function of permafrost-affected soils as a buffering system for metal pollutants could change in response to predicted changes.

Investigation Sites and Methods

Samoylov Island (N 72°22’10’’; E 126°31’05’’) is one of about 1500 islands of the Lena River Delta, Northern Siberia. It is located in one of the main river channels (Olenyok Channel) and represents the south-central and eastern surfaces of the Lena River Delta [*Akhmadeeva et. al., 1999*].

Two dominating geomorphologic processes can be observed on the island. The western part of Samoylov Island represents the middle floodplain and encompasses sediments that consist of mostly fine to medium sand and silt fractions. Frequent changes of the river water level create different periods of sedimentation and result in the formation of stratified soils and sediment layers which are dominated either by mineral substrates with allochthonous organic matter or pure autochthonous peat. In contrast to the accumulative floodplain site, erosion processes dominate on the eastern part of the island and form an abrasion coast. This part is represented by a fluvial terrace and composed of middle to early Holocene deposits, which cover about 70% of the total area of the island [*Akhmadeeva et. al., 1999*]. Polygonal tundra is typical for the landscape and is characterized by two different formations: polygon centers that are water saturated and feature a large amount of organic matter due to the accumulation under anaerobic conditions, and polygon rims that show evidence of cryoturbation in more or less all horizons of the active layer. They show a distinctly deeper water level and lower accumulation of organic matter. The high flood-plain fragmentarily is situated between the east coast of the island and the western border of the fluvial terrace above flood-plain. It hypothetically consists of a thermokarst depression of the fluvial terrace above flood-plain, because it is composed by the same layered peatish-sand deposits of the ancient delta flood-plain. It is flooded with water only by high tide [*Akhmadeeva et. al., 1999*].

The field work was carried out on Samoylov Island in September during the “Lena Delta 2010” expedition when the seasonal thaw depth was greatest. In the course of field investigations to understand the influence of soil structure and soil properties on the distribution of trace metals, we chose three representative sites with five geomorphologic conditions and soil-forming processes: (1) ancient fluvial terrace represented by polygon rims (profile PJ1) and polygon centers (profile PJ2), (2) high floodplain with polygonal microrelief represented by poorly defined rims (profile PJ3) and centers (profile PJ 4), and (3) middle floodplain (profile PJ5). We focused our sampling on the thawed zones above the permafrost table where we suggested theoretically accumulation of trace elements. We determined the following soil characteristics: soil type, skeletal proportion, humus content, decomposition stage of organic matter, soil color, texture shape and size, inclusions, bulk density and root penetration. Macro- and microrelief forms, soil orders, anthropogenic changes, and vegetation cover were described as well. Soil types were determined according to both the Russian classification of Yelovskaya (1987) and the US Soil Taxonomy (2006) (Tab. 1).

Table1. Soil classification according to US Taxonomy (2006) and to Yelovskaya (1987).

Profile ID	US Taxonomy (2006)	Russian Soil Classification (Yelovskaya, 1987)
PJ1	Typic Aquiturbel	Permafrost Turfness-Gley Typical
PJ2	Typic Fibristel	Permafrost Peat
PJ3	Typic Histoturbel	Permafrost Peatish-Gley
PJ4	Typic Histothel	Permafrost Peat-Gley
PJ5	Typic Aquorthel	Permafrost Alluvial Turfness Typical

Laboratory analyses were carried out at the Institute of Soil Science (Hamburg, Germany) including determination of soil acidity (pH) and electrical conductivity (CG 820 Schott Geraete GmbH, Germany; Cond 330i, WTW, Germany), C/N analysis (Vario MAX CNS), water content, grain-size distribution (Sedimat 4-12, UGT, Germany) of the < 2 mm fraction, extraction of Fe, Mn, Zn, Cd, Ni, Cu, As, Pb, Co and Hg using HCl 30% and HNO3 60%, with a microwave method (Mars X Express, GmbH, Germany) and determination of trace metal contents (AAS Varian AA 280 Series).

Preliminary results

The first results of chemical analyses showed that the distribution of trace metals was related to geomorphological characteristics of the investigated landscape. Thus, the following factors strongly influenced on most of trace elements accumulation within profiles: (1) grain-size of sediment distribution, (2) redox conditions, (3) organic matter occurrence and (4) presence of permafrost table. The profile at the middle flood-plain differed from the profiles representing the more ancient parts of the island. Its soils were described as Typic Aquorthels containing more sandy material on the upper part and silty material on the bottom part of the profile. They had a more alkaline reaction compared to the soils of the fluvial terrace. This finding suggested that apart from the parent material, the second potential source of trace metals at the middle flood-plain was allochthonous substance input during annual flooding.

Table 2. Total metal concentration for investigated soil profiles of Samoylov Island (in mg×kg^{-1}, Fe in 10^3mg×kg^{-1}). Soil horizons are described according to US Taxonomy soil classification.

Horizon	Depth cm	Pb	Ni	Cu	As	Fe	Mn	Zn
Ancient fluvial terrace. PJ 1 Polygonal rim (location: 72° 22' 17.663" N, 126° 29' 11.659" E)								
Ajj1	0-3	5.0	15	4.2	3.1	18	313	43
Ajj2	-13	5.1	11	4.3	2.8	18	354	42
Bjjg1	-16	7.4	23	8.0	10	41	1206	58
Bjjg2	-24	7.0	22	4.8	2.8	20	375	60
Bjjg3	-44	6.7	20	2.7	2.1	18	224	61
Bjjg4	-61	7.4	23	6.0	3.2	22	314	60
Ancient fluvial terrace. PJ2 Center of polygon (location: 72° 22' 17.663" N, 126° 29' 11.659" E)								
Oi	0-10	8.0	19	11	3.4	21	481	49
Oie	-18	31	18	11	3.8	17	160	35
Oe1	-30	5.2	17	10	3.2	18	143	49
Oe2	-40	7.2	24	12	3.3	20	213	60
High flood-plain. PJ3 Rim of polygon (location: 72° 22' 19.459" N, 126° 28' 42.737" E)								
Oi	0-7	3.6	17	8.3	3.7	11	143	33
Ajj1	-13	4.7	15	2.5	2.2	16	215	40
Ajj2	-29	5.2	20	5.1	3.3	18	271	46
Bjjg1	-35	4.0	11	1.0	2.5	15	1385	24
Bjjg2	-40	5.4	19	4.5	3.2	17	568	48
High flood-plain. PJ4 Center of polygon (location: 72° 22' 19.546" N, 126° 28' 41.765" E)								
Oi	0-10	6.6	24	14	4.0	20	633	36
Oe	-22	5.7	20	12	3.0	16	354	55
Bjjg1	-31	4.0	12	2.6	2.1	12	139	30
Bjjg2	-50	5.0	16	4.1	2.6	15	165	40
Middle flood-plain. PJ5 (location: 72° 22' 51.611" N, 126° 28' 28.366" E)								
Ajj	0-8	7.2	21	4.0	5.1	27	315	55
B(jj)g1	-24	4.6	12	1.0	3.1	17	190	33
B(jj)g2	-29	6.0	20	2.3	4.6	22	293	50
B(jj)g3	-33	8.2	21	8.0	6.2	30	384	61
B(jj)g3	-37	5.6	19	3.0	4.8	25	387	55
Bjjg4	-91	10	31	9.1	6.2	35	433	79

Comparison of the polygonal rims and centers in ancient fluvial terrace and high flood-plain showed that average values of metals were higher in polygon centers characterized by accumulation of organic matter and more moist environments.

While the trace element concentrations for all sites did not exceed typical crustal abundances given by Vinogradov [*1957*] and average concentrations of metals in World soils given by Bowen [*1979*], the maximum concentrations of most of the metals were observed within the soil profile at the middle flood-plain. High gravimetric concentrations (related to dry mass of soil material) of Mn and Fe were found within all soil profiles and vary from 143 to 1385 mg kg-1 and from 11×103 to 41×103 mg kg-1, respectively. The highest concentration of iron we observed in profile PJ1 at the horizon at the 16 cm depth, characterized by sandy silt. The maximum value of manganese was found on the high flood-plain site at the 35 cm depth horizon. Higher concentrations of Pb, Ni, Cu and Zn were detected in most soil profiles in the deeper soil zones than in the top soil. That supported our suggestion that permafrost table, acting as a geochemical barrier, retarded further migration of elements into deeper horizons. We found highest values of As in silty layers of the middle flood-plain. In organic rich soil horizons of polygon centers (Tab. 2) high values of arsenic have been detected within in the first 10 cm. This observation reflects the general finding that higher concentrations of arsenic relate most often to alluvial soils and soils enriched in organic matter.

Correlation analysis between element concentrations, grain-size distribution and carbon content revealed a strong relationship of the element distribution with the mineralogical composition of soil materials for all soil profiles. Thus, trace metal concentrations were higher in silt horizons with high organic matter content and lower in horizons formed by fine sand and low organic matter content. Based on the results obtained, we suggested that the investigation site shows only negligible atmospheric depositions caused by human activity. Therefore, this site can serve as a reference point for determining human influences on permafrost-affected landscapes or comparing similar pristine areas in the Arctic region.

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Footing Stability of a Bridge across the Norilskaya River in Complicated Permafrost Conditions

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Introduction

A bridge across the Norilskaya River in the Norilsk industrial area offers good examples of problems the waterworks in permafrost may face. The object exists in complicated cryological conditions imposed by large amounts of ground ice in the area. A number of solutions have been suggested to ensure safe operation of structures of this kind.

Building transportation infrastructure in the permafrost-soil conditions of the Extreme North is a challenge, especially in the case of foundations with abundant ground ice or natural high-temperature permafrost. Heavy static and dynamic loads require footing with a high carrying capacity. Perturbations to heat exchange in the system "ambient air – active layer – permafrost" are especially dangerous for waterside bridge footing. Commonly the ground is unfrozen beneath large rivers and lakes but is frozen in their sides. Construction works interfere with the fragile natural thermodynamic balance whereby the boundary between the unfrozen (beneath a river) and frozen zones moves to the riverside soils, while unpredictable gradual thawing leads to instability of foundation soils [*Are 1985*]. The built transportation objects experience major deformation. The situation aggravates largely if the risky effects are not revealed timely [*Grebenets 2007*].

Study area

The study area in the vicinity of Norilsk city belongs to the subarctic climate zone. The mean annual air temperature over the period of observations has been 9.8°C; the mean annual precipitation is relatively low and makes about 300-400 mm [*SNiP 23.01.99 1999*]. The site is located on a watershed, in the Valyok lake terrace. The area lies in the forest-tundra zone but there are tundra patches within the site [*Sheveleva & Khomichevskaya 1967*].

Rapid development of the territory began with the construction of the Norlisk Nickel Combine since 1935, and a narrow-gauge railroad to Dudinka was built in 1938. Before that time, most of the local infrastructure consisted of Valyok port in summer and winter trails in winter. Valyok port became ever less used with increasing role of the Dudinka transportation junction. After construction of Talnakh city in 1960, it was decided to build a bridge across the Norilskaya River. The bridge was put up in 1962-64 upon anchored raker piles (45 cm in diameter) embedded to 20-25 m into the ground and relying upon the Valyok varved clay [*Grebenets 2007*].

Results and discussion

Threatening deformation and displacement of the left-side footing began almost immediately after the Norilskaya bridge construction had finished (Fig. 1).

The bridge, about 1 km long, has its left part lying upon frozen ground, with the following downward profile: 2-4 to 18-20 m of coarse-grained riprap embankment; 1 to 5 m of ice-rich (20-40 %) loam; 12-20 m of ice-rich (to 20 %) clay. In the depth interval 18-28 m, there is an ice lens which remained actually undetected during engineering geological surveys [*Grebenets et al. 1999*]. The ground ice began thawing as the natural permafrost balance was disturbed during piling. The bridge footing has undergone heavy deformation for 20 years and became displaced: subsided for 1800 mm and moved to 650 mm downstream. The unacceptable deformation damaged the rail- and motor-roads and caused traffic accidents. The bridge footing was lifted with powerful (5000 kN) jacks and adjusted four times. In 1978, a slurry pipeline was laid along the bridge which added 40 t more load. The left support was surrounded in 1983-84 with 123 vapor-liquid installations for freezing it into the riverside ground. The freezing units were mounted to depths of 20-40 m. The soil subsidence and footing displacement settled up for the first 4 or 5 years, and then stopped [*Grebenets 2007*].

Fig. 1. Deformed motor- and rail-road bridge across Norilskaya River, with deeply embedded vapor-liquid thermal units along the left pile contour (Photograph by A. Maslakov, July 2010).

The right footing part lying upon unfrozen soil was set stable with a drilled pier foundation after a soil subsidence event in 1980. The today's situation remains unclear.

Conclusions

Engineering geocryological exploration work has to include prediction of possible natural changes, especially, climate-sensitive permafrost conditions, with due regard to the duration and magnitude of anthropogenic loads. It is urgent to perform field studies of the thermal regime of waterside structures operated with the use of artificial freezing of soil foundations in the Norilsk district, to undertake geocryological prediction of the state of footing, and to develop recommendations for increasing their stability. These measures will provide the security of cutoff curtain grouting, save labor costs, and reduce the costs of artificial freezing works.

Acknowledgments

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Forecast Evaluation of the Geoecological Situation in the Area of Operations of Gazprom Dobycha Yamburg LLC

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Hydrocarbon extraction in the Far North, as well as other types of economic activity, is accompanied by changes of natural environment. The scale and the nature of these changes depend on intensity and peculiarities of the impact made. This determines the properties of the anthropogenic geoecological situation at local and regional levels. What is more, a successful operation of the manufacturing equipment and conditions of the infrastructure depend on natural geoecological conditions in areas of exploration of deposits (e.g. on resistance of the grounds to thawing, which, among other factors, depends on vegetation cover type). At the same time, criteria of evaluation of the existing geoecological conditions must include characteristics describing probability of occurrence of its eventual adverse changes and their significance.

These criteria include risk factors calculated considering the international methodology of critical loads and the data on emission amount of pollutants, mainly nitrogen oxides, because these compounds determine probability of occurrence of both eutrophication and acidation effects in ecosystems. Ranking of the total data on the risks followed by its analysis makes it possible to perform, based on this criterion, a retrospective, ongoing and/or predictive evaluation of the geoecological situation within the area of the economic responsibility of the enterprise.

When performing evaluation of the risk parameters, one takes into account the status of natural territorial complexes. For example, as regards specially protected natural areas, the forecast estimate of the geoecological situation in the area of activity of Gazprom Dobycha Yamburg LLC can be satisfactory provided that the risk level is low, i.e. probability of excess of the critical loads is confined within an interval of 5% - 25%. As to areas of traditional natural resources management (e.g. deer pastures, hunting lands, wetlands), the forecast estimate can be satisfactory if the risk level is moderate. That is, the probability of excess of the critical loads shall not exceed 25% either. Higher risk levels, namely 75% – 95%, are tolerated in case of areas located within the boundaries of sanitary protection zones.

Permafrost Engineering Guidelines: An Overview

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Introduction

Guidelines and regulations are typical tools for engineers. In most engineering professions, such documents exist to help engineers in their design but probably even more importantly to protect the public from poorly designed infrastructure. Guidelines, whether those are binding and of legal character or not, also help clients, who may not be experts, to obtain an engineering product that conforms to a certain standard. Hence, guidelines also help to ensure safe and economic design solutions. The permafrost engineering profession is no exception and various guidelines and documents exist around the world. The Permafrost Engineering Working Group (PEWG) of the International Permafrost Association (IPA) took the initiative to prepare an overview of such, internationally available documents. The main objective of this abstract, together with discussions during the Tenth International Conference on Permafrost 2012, is to identify potential gaps and needs for international guidelines to be prepared under the patronage of the IPA Engineering Working Group. We have prepared a summary of binding codes and enforced guidelines, non-binding guidelines as well as additional documents used by permafrost engineers for various design purposes. The focus lies on recent documentations. Page limitations do not allow for the full references to be listed herein, but enough information is provided so that the documents are trackable.

Binding Regulations

Only very limited number of documents exist that are legally binding. Code 50-305-2004, *Building Foundations on Frozen Ground* [*2005*], is such a document prepared by the Permafrost Institute Yakutsk together with several Russian organizations. This regional code applies to building foundations in permafrost and frost-susceptible seasonally frozen soils in the Chita Province, Russia.

In Switzerland, binding technical guidelines exist for the planning of snow supporting structures [*Defense structures in avalanche starting zones, 2007*]. Chapter 7 addresses structures build in permafrost environments.

General Guidelines

A different class of documents are guidelines that are not necessarily binding, but form the basis for engineering projects for governments, for example a department of transportation. Further, engineering associations present guidelines that formulate current state of the art and best practice. Such documents may become legally binding when defining best practice during potential legal actions. The American Society of Civil Engineers (ASCE) has presented various documents on permafrost engineering:

1983	*Cold Regions Construction: A State of the Practice Report*
1985	*Thermal Design Considerations in Frozen Ground Engineering: A State of the Practice Report*
1996	*Cold Regions Utilities Monograph, Third Edition*
2001	*Design and Construction of Frost-Protected Shallow Foundations*
2004	*Thermal Analysis, Construction, and Monitoring Methods for Frozen Ground*
2004	*Bridge Foundation Design Methodology in Alaska*
2007	*Permafrost Foundations: State of the Practice*

Similar to the ASCE Standards, the Permafrost Institute in Yakutsk has published several documents that help permafrost engineers in their design:

2000	*Guidelines for Hydrogeochemical Studies as Part of Geotechnical Investigations in Permafrost Areas*
2000	*Design, Construction, Operation and Maintenance of Small Dams in Permafrost Areas (on the Example of Yakutia)*
2001	*Permafrost Hydrogeology, Practical Course*
2002	*Engineering Structures, Methodological Guide*
2002	*Temperature Regime and Stability of Small Dams and Canals on Permafrost*
2003	*Basics of Integrated (Hydrogeological, Engineering-Geological, Geocryological and Geoecological) Surveying in Northern Areas*
2004	*Frozen Ground Engineering, Glaciology and Ice Engineering: Fundamental Information Sources in Russian*
2009	*Manual on Monitoring Site Establishment for Permafrost Temperature Observations*

In 1999,the Institute of Geography, Irkutsk, Russiapublished the“*Geocryological Monitoring Guidelines for Railroads*” that addresses various components of monitoring, including observations to control icings, snow, embankment thermal regime, frost heave and thaw settlement, frost disintegration, thermal erosion, drainages and culverts, power and communication lines, and land rehabilitation. Further, an extensive list of applicable standards, codes and references is given.

Foundation guidelines are available in North America, Europe as well as Russia. They generally provide assistance in thermal and settlement analysis for shallow and deep foundations in various permafrost environments or areas affected by seasonally frost. Some of those are:

1969 *Foundations of Structures in Cold Regions (CRREL), USA*
1980 *Design and Construction of Foundations in Areas of Deep Seasonal Frost and Permafrost (CRREL), USA*
1983 *Arctic and Subarctic Construction Foundations for Structures. Department of the Army and the Air Force, USA*
2000 *Design Manual for New Foundations on Permafrost, Alaska, USA*
2001 *Design Manual for Designing Foundations on Permafrost, Alaska, USA*
2002 *Analysis of Shallow Foundations, Russia*
2009 *Structures in Permafrost (WSL), Switzerland*

Additional guidelines are available for road construction and maintenance, preliminary via department of transportation or similar agencies.

2007 *Alaska Geotechnical Procedures Manual, Alaska Department of Transportation and Public Facilities*
2010 *Guidelines for Development and Management of Transportation Infrastructure in Permafrost Regions, Transport Association of Canada*

In 1998, a network from northern Finland, Norway, Scotland and Sweden started a collaboration known as ROADEX (www.roadex.org), which was later joined by Greenland and Iceland. In an initial phase road condition management and winter maintenance was the focus of the initiative. Additional stages followed with ROADEX II, ROADEX III and most recently the Northern Periphery Programme. Even though there is no particular focus on permafrost, various aspects of cold regions roads are addressed and discussed in some of the documents. Practical manuals for engineers, videos and brochures, and an e-learning tool were developed. The various programmes focuses are:

New monitoring techniques, new survey methods and new analyses to identify trends in road condition;

New road design and maintenance methodologies specifically suited to the climates, ground conditions and traffic flows of northern Europe;

New policies and protocols for politicians and decision-makers to give greater weight and funding to rural roads.

Site investigation is another key element in permafrost engineering, since ground information forms the basis for any design:

1963 *Engineering Site Investigations in Permafrost Areas*
1966 *Description and Classification of Frozen Soils*
2009 *Guidelines for Permafrost Investigation by Dynamic GPR Method, Russia*
2010 *Geotechnical Site Investigation Guidelines for Building Foundations in Permafrost, NWT, Canada*

In a recent publication by Hugh French and Yuri Shur [*2010*] called "*The principles of cryostratigraphy*", the need for mapping cryostructures in addition to a commonly used descriptive ground ice system, e.g. Johnston [*1981*], was reconsidered. The importance of understanding and characterizing the cryostratigraphy for an engineering design is an important aspect for permafrost engineers to consider.

Finally, designing infrastructure in permafrost environments taking into account scenarios for climate change has become a major challenge for engineers. Many guidelines address this aspect, but the focus of the following documents is on climate change impacts:

1998 *Climate change impacts on permafrost engineering design, Program of Energy Research and Development, Canada*
2005 *Infrastructure: buildings, support systems and industrial facilities, Arctic Climate Impact Assessment*
2010 *Infrastructure in permafrost: A guideline for climate change adaptation, Canadian Standard Association*

Textbooks

This abstract would not be complete without listing textbook-like documents that address and cover various aspects of frozen ground engineering, hence act as basis for many designs:

1978 *Geotechnical Engineering for Cold Regions*
1981 *Permafrost Engineering Design and Construction*
1983 *Introduction to Cold Regions Structural Design and Construction*
1985 *Frozen Ground Engineering (Phukan)*
2004 *Frozen Ground Engineering (Andersland&Ladanyi)*
2008 *Cold Regions Pavement Engineering*
2010 *Engineering Geocryology*

Conclusions

Documents that help permafrost engineers for designing infrastructure have been available for more than 60 years. Interestingly, there seems to be generational waves. A first set of documents was published in the 1960's then in the 1980's and now during the last 10 years. This trend is a clear indicator for the cyclic activities in the North, mainly driven by the resource industry around the world. The available documents are prepared with the aim of carrying out better and standardized designs in permafrost environments. As demonstrated herein, a good number of documents exist today. However, there are discrepancies between some recommendations, which may make it challenging for multinational clients (e.g., mining and energy sectors) and engineering firms to prepare designs in a globalized world. It is therefore believed that it would be beneficial if the IPA would initiate general guidelines on permafrost engineering.

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The authors would like to thank everyone that replied to our call for providing information on such guidelines. Thanks to the feedback a comprehensive list could be prepared, which we hope might be useful for the permafrost engineering community and results in good engineering practice.

Geomorphology of Antarctica, an Atlas: an excellent accomplishment of the Russian Geographic Science

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Publishing the atlas “Geomorphology of Antarctica” is an excellent accomplishment of geomorphologists and geographers from the Saint-Petersburg State University. No edition of this kind has ever come out, neither in Russia nor in the world. The Atlas is a new type of special cartographic works which synthesize fifty years of investigations by Antarctic polar expeditions. This is an event of utmost national value. The ways of presenting cartographic data employed in the Atlas may be a useful experience to share with scientists from different countries engaged anyhow in studies of high-latitude regions and shelf areas of the Arctic and Antarctic seas. In this respect, the Atlas is a rare example of mapping diverse geographic data.

Geology, geomorphology, and geophysics are the principle lines of today’s polar research. Among these, geomorphology is especially important for Antarctica as it provides knowledge of the surface topography and thus lays basis for many other geological and geographical disciplines. Russian scientists have gathered an ample collection of data for the past 50 years, which has been scrutinized and synthesized with great care.

Unlike all previous atlases of the southern continent, the one we present is a unique collection of subject maps. The maps image the sub-ice and sub-sea topography which can be analyzed and used for reference when describing different geological and geomorphic processes and structures. The novelty of information and processing technologies command the layout of the Atlas and the data sequence, which corresponds to the multipurpose character of the integrated geomorphic research.

The compiling work addressed three basic groups of issues:

(1) region-oriented issues of mapping the sub-ice and sub-sea topography of different areas of Antarctica and the related geological, lithological, and glacio-dynamic processes and structures. The mapping stems from most comprehensive and reliable evidence and is performed at different scales;

(2) theoretical and methodological issues required for developing new approaches to mapping and research of terrain-forming processes;

(3) practical objectives of testing the methods and ways of solving various applied problems, which are published for the first time.

The data shown in the Atlas include results of general mapping, structural-morphometric analysis, and specialized geomorphic mapping. General mapping has been performed at three levels: elements, geomorphic systems, and geomorphic provinces. The structural-morphometric analysis of topography is made in the vertical dimension and in map view, simultaneously at two angles and in side view. Specialized mapping includes morphotectonic mapping and zoning, estimating quantitatively various parameters of geodynamic processes (by the balance method), mapping the topography of the ground, sub-ice, sub-sea, and intermediate surfaces, with implications for glaciological and morphological dynamics; additionally, there are maps of separate elements and forms of the sub-ice and sub-sea surfaces that record dynamic processes in pre-glacial periods of the continent evolution, prior to the formation of the ice sheet. Research in terms of morpho-dynamics concerns issues of practical importance which cannot be studied by other methods or sciences. They are neotectonics, glacial processes in basal layers, and many others. The practical outcome is that the Atlas provides information for reliable predictions, especially in mineral exploration, for precise geothermal measurements, as well as studying for changes in ice thickness, sealevel, and global climate.

The Atlas is a product of joint efforts of many people, not only the compilers but also those who run field and laboratory work in the extreme conditions of Antarctica. They are, specifically, members of the Russian Antarctic expeditions and people from different institutions engaged in polar research, such as the Arctic and Antarctic Research Institute (Saint-Petersburg), Polar Marine Geological Survey Expedition (Saint-Petersburg); Institute of Geography of the Russian Academy of Sciences (Moscow); All-Russian Research Institute for Geology and Mineral Resources of the World Ocean (Saint-Petersburg), etc.

The ideology of the Atlas has been elaborated at the Department of Geomorphology of the Saint-Petersburg State University, by A.N. Lastochkin, Honorary Professor, Doctor of Geology & Mineralogy. The maps have been compiled and prepared for publication at the *Karta* Corporation, the first Russian private publisher of cartographic materials.

Special methods of comprehensive artistic design have been employed in preparing the Atlas for publication, for the first time in the Russian scientific publishing practice. Due to this design, the Atlas has become more austere and consistent, in both form and content, with perfectly systematized maps, legends, tables, and plots, which makes the book easy to handle and just very nice-looking: one of best books of Russia.

The Atlas consists of 256 pages, 25x35 cm, divided into eight sections. It contains 105 maps, of which many have never been published before. This is really a pioneering work, in Russia and abroad.

As it often happens, comprehending the content of the whole collection of data and its exceptional value will take some time. The ideas that stand behind the Atlas will probably become a reference against which to check the results of future research for at least fifty years ahead. What is obvious today is that the Atlas “Geomorphology of Antarctica” opens new avenues in Antarctic studies and will be useful for all scientists interested in the Earth’s polar regions.

Purification of Grounds and Restoration of the Disturbed Soil and Vegetation Cover under the Condition of the Cryolithozone by Use of Biotechnological Methods

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The expansion of the oil and gas production into regions characterized with complex natural and climatic conditions determines the new requirements for all associated technologies. Despite the use of modern technologies in the hydrocarbon production, transportation and processing sphere, the level of environmental objects' pollution with this raw material or its products remains very high. The accidents (in the example of spillage of million tonnes of oil in the Gulf of Mexico) showed that such phenomena can be not only of local but also of intercontinental nature.

The ecosystem of the Far North is characterized with a high susceptibility to anthropogenic impacts. The development of deposits inevitably leads to the increase in the technogenic load on the northern regions' ecosystem. This has an adverse effect on the ecological safety and raises a question about development of new approaches to the solution for environmental protection problems.

The prevention of the soil and vegetation cover degradation is one of the main conditions for preservation of the natural environment in the Far North because the indicated cover represents the main structure-forming and the most vulnerable element of natural landscapes. The stability and the integrity of the soil and vegetation cover ensure the safety not only of the natural environment but also of technical structures. The development of hazardous erosional and geocryological processes resulting from the soil cover disturbance can cause damage or destruction of fields' facilities.

The pollution of the soil and vegetation cover with such liquid hydrocarbons as gas condensate, oil and their processing products leads to its intense degradation and often to its complete destruction. Self-purification and restoration of the polluted areas occur very slowly and last for more than one decade in the Far North conditions.

A number of authors point out that the disappearance of the vegetation cover including the case when it disappears as a result of oil pollution leads to the development of the long-term thawing of frozen grounds.

Since 2009 the specialists of Gazprom VNIIGAZ LLC carried out extensive work connected with the study on application of modern methods for purification and restoration of disturbed and polluted land on the territory of the Yamal Peninsula.

The work describes the results obtained from the use of biotechnological purification methods (bioremediation) of oil-polluted soils as well as from the use of technologies of the soil and vegetation cover restoration.

The research on soil purification from hydrocarbon pollution was carried out with the use of the Bioros biopreparation on the basis of hydrocarbon-oxidizing microorganism cultures. A series of experiments was performed with the use of ex-situ methods (with soil purification in the solid-phase fermenter (with soil extraction)) and in-situ methods (at the area of pollution localization). The results of the experiments showed that purification is more efficient in the solid-phase fermenter than on open ground. The 87% degree of polluted soil purification was achieved for 14 research days.

The investigations on restoration of the soil and vegetation cover were carried out at technogenic sites having no vegetation. The Pseudomonas putida biopreparation was used. It represents a cultural liquid of soil microorganisms where the culture and the products of its activity contribute to optimization of the soil medium and improve the plants' resistance to the outer unfavorable factors. This accelerates plant growth and development and reduces the recovery periods of the grass stand.

The results of the research showed the high efficiency of biotechnological methods and determined their potential for application to purification and restoration of technogenically disturbed lands in the Far North regions.

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The Effect of Neotectonic Activity on Cryogenic Processes in the Russian Arctic

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The effect of neotectonic movements on the structure of permafrost and periglacial processes has been relatively little explored. However, the tectonic framework and neotectonic activity largely influence both the permafrost extent and the surface processes in frozen ground (e.g., formation of thermokarst, according to Velikotsky [*1972*]).

In this study, the relationship of cryogenic processes with tectonic framework and neotectonic uplift is investigated with the example of two key sites in the Russian Arctic (Buor-Khai Bay near Tiksi and Preobrazhenie Island in the Khatanga Gulf), using morphostructural analysis.

The island of Preobrazhenie (Russian for *Transfiguration*) is a tilted block within the Khatanga graben. The block is highly uplifted and is strongly asymmetrical, with a gentler western slope descending smoothly offshore and a steeper eastern slope delineated by a scarp, possibly of a tectonic origin. The scarp is locally counter-sloping and is composed of Cretaceous and Jurassic sandstone, siltstone, and mudstone [*Romanenko 1996*]. Note that the island rises quite high (altitudes above 80 m asl the highest), even above the elevated land of Taimyr Peninsula and Bolshoi Begichev Island located in the same area. On the other hand, it is surrounded by a relatively gently sloping seafloor rise where water depths are increasing slowly.

The steep eastern edge of the island most likely follows a young active fault, judging by its map-view configuration and up to 80 m high bedrock cliff walls. The fault zone has a pinnate structure with smaller cross faults and fractured zones. The western border likewise may correspond to a fault but of less prominent geomorphic expression. It is noteworthy that the N—S trending fault borders of the island show neither northward nor southward extensions, possibly, because they are buried under sediments (Fig. 1).

The island may be a crust block with, at its base, one of salt diapirs which are widespread in the Khatanga Bay, and the diapir may be responsible for the uplift. Another possible cause may be associated with neotectonic activity driven by mantle or asthenospheric processes. The two agents may have acted jointly and strengthened one another. The asymmetry of the block may have been due to the eccentric position of the diapir whereby the western and eastern parts of the island, though both being involved in general motion, uplifted at different rates.

The island has been subject to thermal erosion and slope processes at extremely high rates as a result of fast uplift along with high anthropogenic loads (from a polar station). Gullies reach a density of 1.6 km/km^2 and are growing rapidly, e.g., one gully became 20-30 cm deeper after a two-hour heavy rainfall [*Romanenko 1996*]. The surface area of the island decreases along its eastern cliff at the account of intense gravity processes (slumping and landsliding) and thermal erosion with formation of cirques.

Thus, rapid tectonic uplift accelerates strongly the cryogenic processes in the island.

The setting of Muostakh Island located within the Buor-Khaya Bay in the Laptev Sea is different. The coast of the island is likewise being eroded. However, rapid thermal erosion eating up ice-rich rocks of its ice complex is rather associated with general subsidence of the island. The surface area decreases progressively every year as a result of coast retreat at a rate from 13 to 6 m annually. The subsidence tendency is further confirmed by the fact that the ice complex constitutes the entire visible section of soft sediments and continues below the sealevel [*Grigoriev 1993*].

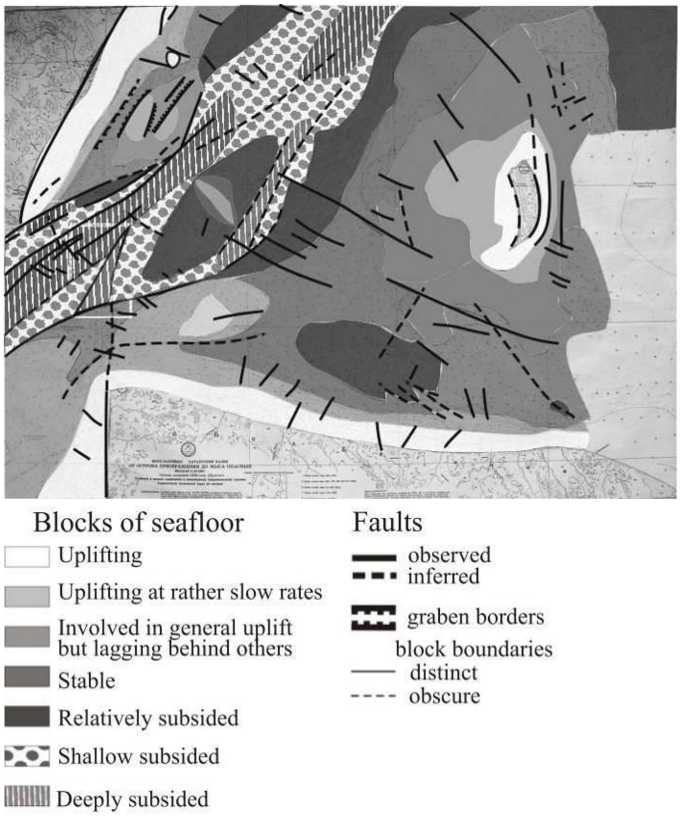

Fig. 1. Morphostructure of the Khatanga Bay around reobrazheanie Island

The western side of the Buor-Khaya Bay at Tiksi, though being proximal to Muostakh Island, is undergoing considerable uplift. However, unlike the previously described sites, it mainly consists of bedrock while unconsolidated sediments (mostly peat) are restricted to plainland and closed subsided areas. Formation of permafrost polygonal ground and ice wedges in these rocks is controlled by tectonic fractures: frost cracking follows weak zones corresponding to fractures in the underlying bedrock. The orientation of polygons evidently correlates with dominant lineament directions in rose diagrams of fractures. Linear chains of lakes likewise align with weak zones, because fractured rocks maintain active groundwater circulation thus providing warming of frozen ground.

Thus, cryogenic processes and the surface topography are in most cases closely linked with neotectonic movements and the existing tectonic framework.

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Monitoring of Active Rock Glaciers with X-Band Differential SAR Interferometry: Case-studies in Western Swiss Alps

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Introduction

Rock glaciers are large masses of ice/rock debris mixture acting as sediments conveyors moving typically in the order of 0.1 to 1.0 m/year in the mountain periglacial environment. At their snout some rock glaciers may regularly deliver volumes of loose material in steep slopes or torrential gullies, hence contributing significantly to the so-called sediment cascade on mountain slopes. According to recent studies, ground warming in the 20th century seems to have generated an acceleration of slope movements related to the creep of permafrost, particularly since the end of the 1980s. Consequently, an increase of potential natural hazard for people and infrastructures cannot be excluded and requires the knowledge of the regional overview of slope instabilities as well as the process understanding of slope movement in permafrost areas. Several rock glaciers displaying surface velocities (much) larger than 5 m/year have even been described during the last decade especially.

The use of differential SAR interferometry (DInSAR), especially ERS-1/2 DInSAR, to estimate magnitude and spatial pattern of slope motion has been evaluated and shows the efficiency of this remote sensing for inventorying creeping landforms in mountain periglacial environment, but also estimating and categorizing their displacement rates [*Delaloye et al. 2007, Lambiel et al. 2008*]. Several studies have also demonstrated the efficiency of DInSAR for monitoring large width rock glacier displacements with velocity up to half a meter per year in alpine environment [*e.g. Strozzi et al. 2004*]. According to a recent study [*Barboux et al. 2011*], it is possible to monitor some very active rock glaciers (1 to 3.5 m/year) when geometrical distortions do not hide them with the shortest Terrasar-X (TSX) repeat pass of 11 days and especially using mode facing slope (i.e. ascending, resp. descending, mode for west, resp. east, oriented slope). Lower velocity rates could be well monitored using longer time lags. At higher rate velocities TSX appears, like other radar sensors, to be unsuitable for a precise analysis of these kinds of landforms.

Method and Datasets

The present contribution intends to briefly describe a method for monitoring very active rock glaciers using X-Band DInSAR [*Barboux et al. 2012*]; and to illustrate, through different case-studies, to which level DInSAR can be used independently of field surveying as a monitoring tool of mass wasting dynamics in rough alpine terrain topography. The test sites consist of several rock glaciers located in Valais Alps (46°4’0’’N/7°36’0’’E) and being for the most part annually or seasonally surveyed by DGPS field measurements. TSX data used for this project are acquired with facing mode during the late summers 2009 to 2011. Only high quality interferometric pairs are selected according to well-known requirements (small perpendicular component, no perennial snow patches, and no weather/atmospheric influences).

Due to the relative small size and the complex movements of the studied rock glaciers, the spatial distribution of their surface deformation derived from the DInSAR data using conventional unwrapping processes failed in most cases. Thus, we have developed a method consisting on defining a profile through the rock glacier on which the quantification of movements will be estimated. The profile is firstly used to roughly evaluate the change in the activity rate along the landform by analyzing the coherence trend combined with interferometric phase interpretations. Then, when the quality is efficient (high coherency values), the interferometric phase is used to estimate precisely the deformation rate along the profile in the radar Line Of Sight (LOS) direction.

Results on case-studies

Results were finally compared with existing GPS measurements, and show a good correspondence of DInSAR to monitor velocity with respect to different parameters: the size of the landform (minimum narrow width of the landform), the velocity (deformation rate lower than $\lambda/2$ in the LOS, that is 1.55 cm/11 days with 11-day TSX interferograms), the quality of interferometric products in term of period of acquisition (no noise related to weather, snow, rain, atmosphere) and in term of phase stability (no high drops in interferometric phase), as well as the acquisition date (snapshot of InSAR comparing to seasonal GPS measurements).

For successful results, a large dataset of SAR scenes is recommended increasing considerably the relevance of DInSAR measurement for seasonal behavior analysis free from in situ measurements. When the interferometric phase cannot be accurately explored, the analysis of only the coherence parameter offers all the same the possibility to estimate annual variations. Finally, the combination with GPS measurements could even more reveals some intra-seasonal variations.

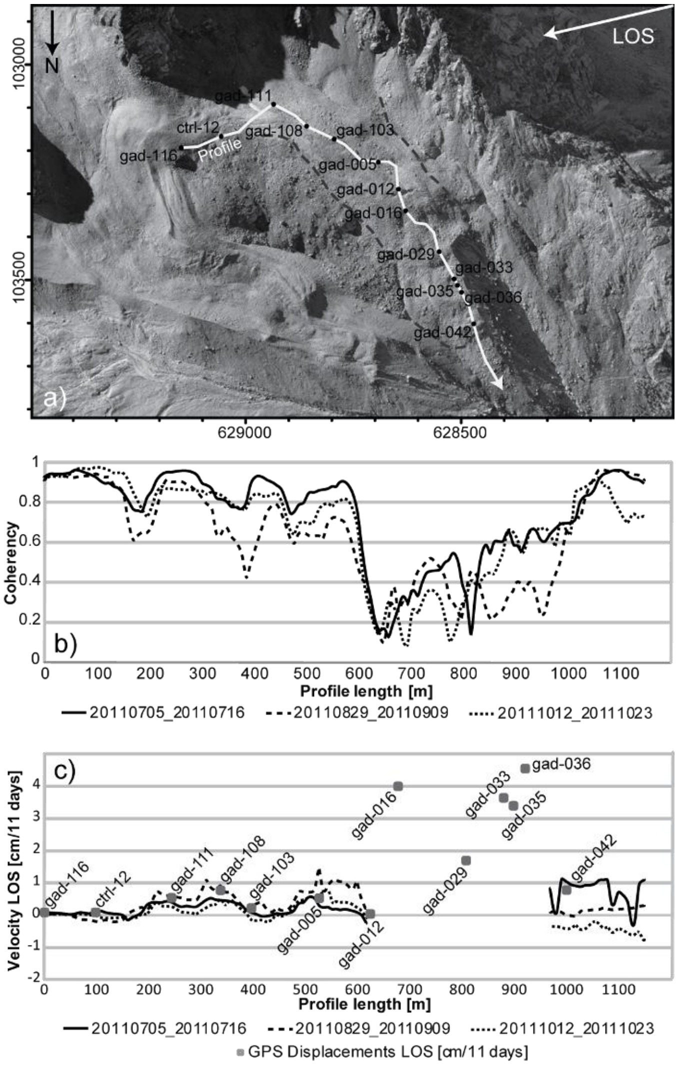

Figure 1. a) Orthoimage of Gänder rock glacier and localization of profile and GPS points - Swissimage © 2005; b) Coherency along the profile for 3 snapshots in 2011 and c) Displacements in the LOS along the profile for 3 snapshots in 2011 compared to seasonal GPS measurements projected in the LOS acquired during summer 2011.

Acknowledgements

TERRASAR-X Data are courtesy of LAN0411 © DLR; DHM25 is copyright 2003 Swisstopo, Swissimages & Pixel Maps 25 were reproduced by the permission of Swisstopo.

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The Global Seed Vault, Rock Caverns in Permafrost

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Introduction

The Norwegian government has established an International Seed Vault for the world’s future generations. The Seed Vault is located in rock caverns on the Norwegian arctic island of Svalbard. In this location the ground contains permafrost as far down as 200 m below surface in the mountainous areas. About 5 m below the surface the temperature of the permafrost remains around 5 ºC below zero all year round. In order to meet with the special storage demands, the Seed Vault must be cooled further down to 18 ºC below zero.

Design

Barlindhaug Consult and Multiconsult have been responsible for the planning and detail design. The total time available for the planning and the construction was limited to less than one year and the facility was completed in November 2007. The limited time available for the planning did not give room for a detail investigation and the design was therefore only based on the information given by the shape of the surface and geological maps. The geological map indicates that the Seed Vault would be located in bedrock containing layers of sandstone and very loose mudstone. The mudstone is so weak that rock normally will start weathering immediately after exposed to air with temperatures above zero. The bedrock at the selected location was covered by a thick layer of moraine.

Construction

Open cut excavation

Excavation of the portal was carried out during winter with air temperature below zero. Due to the permanent frozen ground, all excavation could be carried out with vertical slopes in both the moraine layer and in the weak rock underneath. These vertical slopes in the moraine and the loose rock would, however, not be stable when the air temperature rose above zero. For safety reason the open cut excavation and the beginning of the tunnel work had to be completed while the ground was completely frozen.

To maintain a safe access through the open cut, a steel pipe was erected and backfilled. The steel pipe was designed to allow access for all drill and excavation equipment and remained as the permanent access to the rock tunnel and caverns once the excavation was complete.

Underground excavation

Rock caverns in frozen ground will have only minor stability problems even if the rock is very weak. The principal challenge when excavating rock caverns in frozen ground is therefore during the construction period when warm ventilation air and heat from the equipment causes thawing.

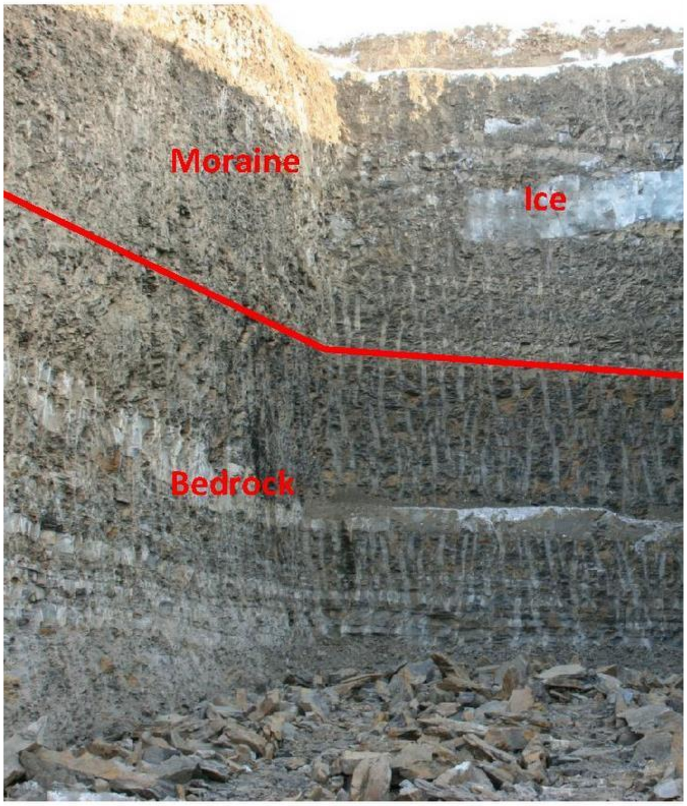

Figure 1. Open cut excavation. Photo: Sverre Barlindhaug.

Layout

There were no special design criteria for the cavern except for the required storage capacity. The shape of the caverns was therefore adjusted during construction according to the rock condition and to obtain the optimal construction cost. The final solution was three caverns, each 9.5 m wide and 27 m long. However, only one of the caverns will be needed for the storage requirement the first 10 years.

Additional freezing

The rock cavern is made without any additional insulation of the rock surface. The necessary energy required for the initial freezing of the cavern to 18 ºC below zero will be higher without inside insulation compared to insulated rock cavern. The energy cost would however be lower than the cost to make lager caverns and erect an insulation room inside the cavern. After the initial freezing period, the rock mass surrounding the cavern will also be cooled down. Due to the frozen rock surrounding the cavern only a small amount of energy will be required to maintain the low temperature in the cavern.

A Historic Sketch of Permafrost Studies in Northern West Siberia

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The history of permafrost research in West Siberia, generally same as in other large high-latitude provinces of Russia, is instructive in view of ever changing social, political, and economic conditions in the country.

Permafrost studies evolved in three major stages.

Stage 1 (before 1940-1950s): expeditions for exploring the natural conditions of the area, which were insufficiently covered in the Yamal Encyclopedia. The results furnished important evidence of the local engineering-geological and cryological settings.

Stage 2 (1950s-1990s): purposive studies of permafrost conditions as a background for organizing geological surveys and construction in northern West Siberia. Several research teams from different institutions of Moscow and Leningrad (NIIGA, VSEGEI, VNIGRI, Geologcial Surveys, Institute of Permafrost, Moscow University, etc.) provided the first description of regional cryological conditions of the West Siberian Plain. The collected data indicated the existence of another permafrost layer south of 66-67° N, which arose during past cold events and stored records of the long history of glaciation.

Permafrost studies were of special value for the construction project of the Lower Ob Hydro near Salekhard. Unfortunately, there is very little data on that project in the Yamal Encyclopedia. The project included four-years long continuous monitoring (1953 through 1958) of permafrost dynamics in the construction area undertaken for the first time by the Gidroproekt Surveys (Moscow) in cooperation with the Subdepartment of Permafrost of the Moscow University. The work has had no match afterwards. Exploration was run along four prospected dam sites where about 500 boreholes were drilled over an area of ~400 square kilometers; some holes were designated specially for permafrost surveys. The research, exceptional in its great scale, yielded a detailed engineering-geological cross section of the Ob valley near Salekhard. Permafrost mapping was with the use of all available soil study techniques (soil mechanics, geobotany, geophysics, etc.). Continuous monitoring of ground temperatures allowed estimating the true temperatures of permafrost, and furnished independent proof for the existence of two permafrost layers.

Stage 3 (since 1990s): mostly random permafrost studies, without a single national strategic plan. New data remained deposited in reports of different departments and were almost never synthesized. At the same time, geological surveys for exploration of new mineral and hydrocarbon fields have almost ceased.

More difficulty arose with closing down the center responsible for working out national-scale methodlogical standards for construction development. Since then, each economic department and administrative unit have produced their own regulations which not necessarily follow a general strategy of studies specific to engineering-geological conditions in high latitudes.

Thermokarst in the Vicinity of the Bridge across the Yuribei River at Obskaya-Bovanenkovo Railway Station

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Abstract

Landscapes, vegetation, soils, as well as deposits of watershed plains, sides and bottoms of dry thaw kettles in the middle reaches of the Yuribei River were studied in the course of landscape and geocryological surveys in 2011. The studies revealed a complex of structures produced by permafrost thermal erosion, karst, and frost cracking processes that control the contemporary patterns of surface topography and landscapes.

Keywords: khasyrei; landscape; permafrost conditions; thermokarst.

Introduction

The study area (Fig. 1 A) is located in the central Yamal Peninsula, in the middle reaches of the Yuribei River [*Ogorodny 1971*]. The area belongs to a zone of severe climate with t_{max} = 25-28ºC; t_{min} = –50-52ºC, mean annual precipitation ≈ 300 mm (lowest moisture in February and march), snow seasons as long as 8-9 months, and snow thickness 16-17 cm [*Kazachkova 1982*].

The local geomorphology consists of a Late Pleistocene plain, river terrace I, a floodplain, and dry lake basins [*Badu et al. 1984*]. The Late Pleistocene plain, with elevations 20-25 m, has loam and loamy sand in the uppermost section, locally overlain by sand. The river terrace I and floodplain deposits are loamy sand with biota and peat [*Trofimov 1975*]. According to the landscape division, this is a zone of southern tundras [*Ogorodny 1971*].

Permafrost is continuous, with closed taliks under shallow lakes and rivers. The thickness of permafrost in the coastal plain reaches 275-300 m, and its mean annual temperature is from -1ºC to -8ºC. The upper 5 or 10 m of permafrost consist of Late Pleistocene sediments frozen while deposition, and the sediments below froze up after being deposited (syngenetic and epigenetic units, respectively) [*Ershov 1989*].

Studies carried out in 2011 in remnants (outliers) of the coastal plain with khasyrei (dry lake) basins at two sites in the Yuribei valley (Fig. 1 B) allowed characterizing the local landscape patterns. A landscape is meant [*Kozin & Petrovsky 2005*] as a piece of ground surface, of any size, within which the environment components are in a complicated and continuous interaction making up an integral system.

Site 2 (Fig. 1, B) is located in the Yuribei valley, at the Khutyakha inlet. There is a floodplain fragment (5 m asl) in the right bank of the river, and a coastal plain fragment (26 m asl) and a repeatedly flooded khasyrei in the left bank. The plain is divided into local landscape zones according to micro-terrain, moisture, vegetation, and soil patterns (Fig. 2), which are grouped into three geomorphic and cryologic genetic units (Fig. 3).

Limnic landscapes (①,② in Fig. 2; 5-10 m asl), the youngest landscape group, are associated with syngenetically frozen fluviolacustrine peated sand and loamy sand. There are neither polygonal ground nor frost heaves, the soil cover is thin and the vegetation is azonal. The active layer has the highest water content; the thaw depth is 1.3-2.3 m.

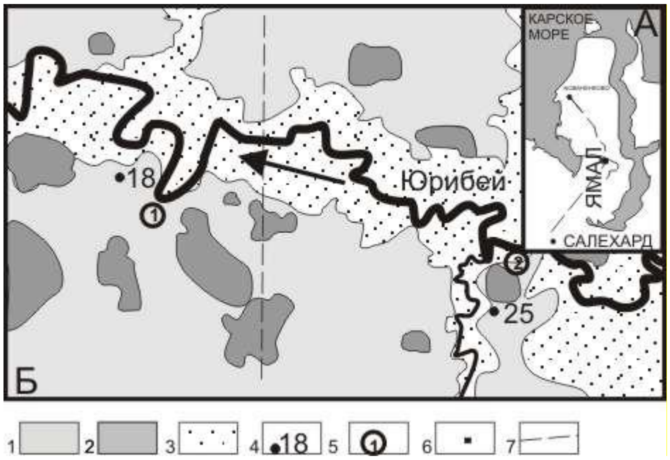

Fig. 1. Location map of study area.
1 – coastal plain; 2 – khasyrei complex; 3 – floodplain with remnants of terrace I; 4 – altitudes above sea level; 5 – sites of detailed studies; 6 – study area in map of Yamal (A); 7 – railway.

Slope landscapes (③, ④ in Fig. 2; 10-25 m asl) are composed of Holocene and Present syngenetically frozen fluviolacustrine peat and sand to loamy sand deposits. This is the most dynamic element of the area, with wedge-polygon patterns, isolated frost heaves, and azonal vegetation. The active layer is 0.5 to 1.2 m thick and has a uniform water content distribution.

Plain landscapes (⑤-⑧ in Fig. 2; 20-26 m asl) lie upon Late Pleistocene loam and sandy loam with interbeds of autochthonous and allochthonous peat and with signatures of ice-rich soils at elevations between 6 and 14 m. The landscapes typically have a rugged wedge-polygon surface pattern, thin soils, and zonal-azonal vegetation. The thaw depth is 0.7-1.5 m

Floodplain landscapes in the Yuribei right bank, with a uniform sandy lithology, differ in elevation, vegetation composition, and thaw depth controlled by elevation and greater snow thickness in depressions.

The landscape structure of a plain outlier and a khasyrei side were studied at site 1 located 5 km downstream of a bridge across the Yuribei at Obskaya-Bovenenkovo railway station (Fig. 1). Landscapes at the site belong to three genetic groups: limnic, slope, and plain landscapes similar to those described above for site 2.

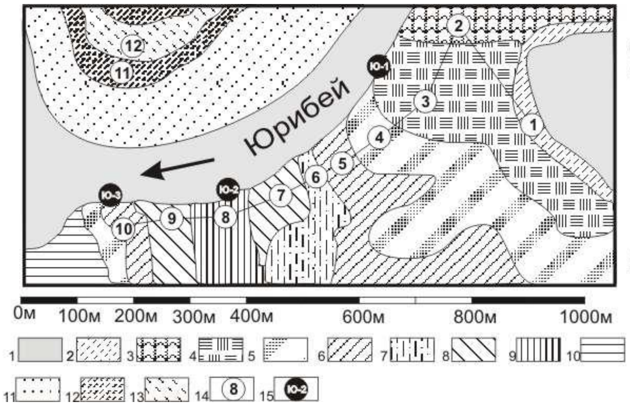

Fig. 2. Zoning of site 1, Yuribei valley.
1-8 – landscapes (environment and environment-territorial complexes) distinguished according to landscape and permafrost conditions: lakeside flat depression (1), high floodplain (2), gently dipping hummocky slope (3), drained slope with low hills (4), high drained plain with a wavy terrain (5), tussocky depression in the plain surface (6), high poorly drained polygonal plain (7), dry polygonal depression in the plain surface (8); 9 – water surface; 10 – gully; 11 – floodplain; 12 – flat low floodplain, with tussock patches; 13 – flat floodplain with small low hills; 14 – observation points on profile; 15 – sampling sites for ice and biota.

The landscape and permafrost characteristics revealed in the course of the studies indicate reduction in lake areas and drying of thaw kettles (limnic group of landscapes, with a concentric pattern).

The kettles are filled with deposits shed from slopes. In the lower part of slope peatland, there are wedge-polygon systems with traces of thawing (slope landscapes).

Thermal erosion and denudation act upon higher elevated plain outliers while polygon structures form in depressions, possibly of Holocene ages.

The landscape characteristics will be used in mapping the landscape and permafrost conditions in the middle course of the Yuribei.

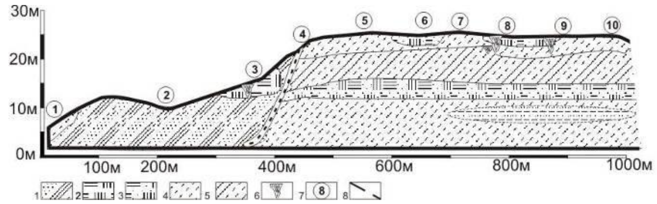

Fig. 3. Permafrost profile, points 1-10.
1 – sand and loamy sand; 2 – peat; 3 – loamy sand with peat; 4 – loamy sand; 5 – loamy sand and loam; 6 – ice; 7 – observation points; 8 – inferred layer boundaries.

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Immune and Physiological Responses to Bacteria Strains Isolated from Permafrost in Outbred White Mice

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Bacteria isolated from permafrost and ice as old as tens of thousand or possibly even millions of years arouse great scientific interest. Microorganisms that keep active in extreme conditions of retarded metabolism may become a unique source of molecules able of exerting pronounced biological effects on multicellular organisms [*Gilichinsky 2000; Katayama et al. 2006*]. However, the influence of these bacteria on physiology of extant organisms remains almost unexplored. In this study we investigate immune and physiological responses to some permafrost-borne bacterial strains in outbred laboratory white mice.

The bacteria used in the experiments were isolated from drill core permafrost samples at Tarko Sale, Yamal (strains 8/75-1, 4/25, 2/03) and Mamontova Gora (Mammoth Hill), Yakutia (strain F2) sites. The strains were identified by the ribosomal DNA sequence analysis as *Acinetobacter spp* (4/25), *Enterobacter spp* (2/03), *Bacillus megaterium* (8/75-1), and *Alcaligenaceae bacterium* (F2). The isolated strains were cultured at +26° C on fish protein hydrolysate (FPH). After two days of incubation, bacteria were washed off the solid nutrient medium with sterile saline. Thus obtained bacterial suspensions of a cell density up to $1x10^6$ cells/ml were injected intra-abdominally in mice, in a dose of 50,000 bacterial bodies. There were sixty mice divided into five groups of 12 mice in each. In two weeks after injection, the mice were tested for humoral immune, visceral, and blood responses. The immune responses were analyzed as counts of antibody-forming cells (AFC) and delayed-type hypersensitivity (DTH), in six animals from a group in each of two tests.

Visceral responses to bacterial injection showed up as confident spleen weight increase (to strains F2 and 4/25). All strains stimulated growth of thymus, which is a place of maturation and differentiation of T cells. No change to liver weight in response to infection was identified. The thymus increase records a Th1-dependent immune response.

The immune system is a basic regulator involved with biological adaptation to stress. In order to estimate its state, we investigated humoral immunity (Fig. 1), specifically the behavior of antibody-forming cells (AFC). Numbers of lymphocytes in spleen did not show confident change. Injection of 8/75-1, 4/25, and 2/03 caused growth of AFC/mln LP ratios and AFC in spleen as evidence of activity of antibody-forming cells and the organ as a whole. Thus, the mice developed a marked humoral response to small doses of strains 8/75-1, 4/25.

The optimum immune response includes both humoral and cell-mediated components, the latter being expressed in delayed-type hypersensitivity (DTH).

Strain 4/25 inhibited the cell-mediated immune response (Fig. 1), this indicating Th1 activity and generally lower anti-inflammatory activity of the organism as a whole.

DTH and, as a consequence, inflammatory activity increased slightly in response to F2, 8/75-1, and 2/03 injections.

Peripheral blood values represent the percentages of cells that mediate the immune response and adaptation to invasion of an alien agent.

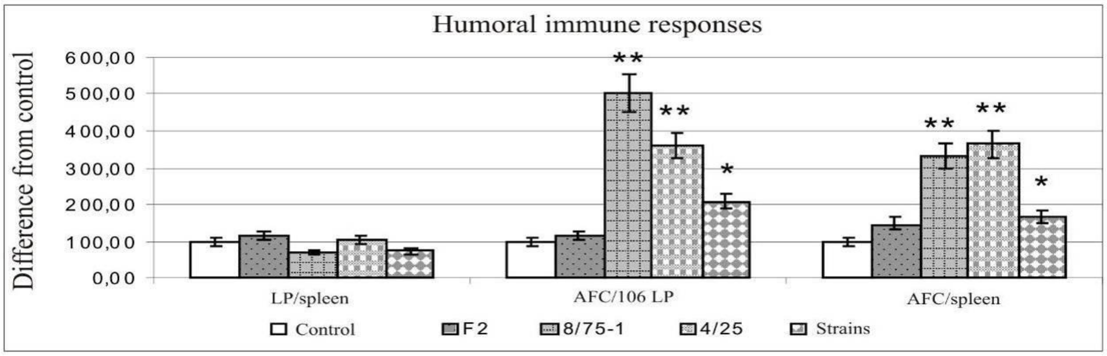

Fig. 1. Humoral immune responses in mice, 14 days after bacterial injection.
Note: * denotes statistically confident difference ($P < 0.05$) from the control group

In response to strains 4/25, 2/03, mice showed lower monocyte and granulocyte but higher lymphocyte counts, i.e., the inflammatory activity increased correspondingly.

Thus, the bacterial strains isolated from permafrost caused immune and physiological responses in the tested animals. The effect of strain F2 was minor; the others stimulated markedly the humoral immunity but influenced less strongly the cell-mediated immunity. In general, small doses of the studied strains activated T helpers of both types (Th1 and Th2, especially Th2-dependent responses), anti-inflammatory activity, and humoral immunity.

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Spatial variability and cryogenic impacts on nutrient availability in a polygonal tundra landscape in north-east Siberia

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Introduction

Polygonal tundra is characteristic of poorlydrained permafrostlandscapes. Frost cracks are filled in spring by re-freezingmelt water. Annual repetition of this process leads to the formation of ice-wedge polygons [*French, 2007*]. Elevated polygon rims and depressed polygon centers form a very heterogeneous landscape which has been investigated to be today a carbon sink [*Wille et al., 2008*] But further development of arctic ecosystems depends on complex interactions between hydrology regime, plant-species composition and nutrient supply [*Weintraub&Schimel, 2005; Schuur et al., 2008*]. Hence, understanding of the nutrient dynamics in arctic soils is an important factor to predict further responses of arctic ecosystems to climate change.

Fig. 1: Polygonal tundra in the Lena delta (Photo: S. Zubrzycki)

Questions

How are soil nitrogen and phosphorus contents distributed within the polygonal tundra landscapes?

What effects do cryogenic processes have on the bioavailability of the organic material and on nutrient transformation?

What effects may (global) warming have on the bioavailability of the organic material and on nutrient transformation?

Methods

Fieldwork has been conducted during the expedition POLYGON 2011 – Kytalyk. The POLYGON project (Polygons in tundra wetlands: State and dynamics under climate variability) is a DFG funded (KU1418/3-1) German-Russian joint project.

Fig. 2: Study areas of the POLYGON-project.

At the study area in the Indigirka-lowlands, one polygon has been investigated at a high resolution grid (2*2m). Also a soil core of 120cm has been investigated. On all samples, Ammonium, Nitrate and Phosphorus as well as water content, pH and electrical conductivity have been measured during the expedition.

More detailed analyses on nutrient-pools and nutrient availability are planned to be done in the laboratory.

Preliminary results

In Figure 3, data from the investigated peat core are shown. There has been a coinciding maximum of water content and amount of extractable Ammonium at a depth of 75cm. In the first twenty centimeters, the amount of extractable nitrate was following the water content.

The amounts of nutrients seem to correlate with the water contents of the soils. But whether the ammonium peak is indicating a state of wet soils in the past or can be explained by recent microbial activity has to be answered in the further progress of the project.

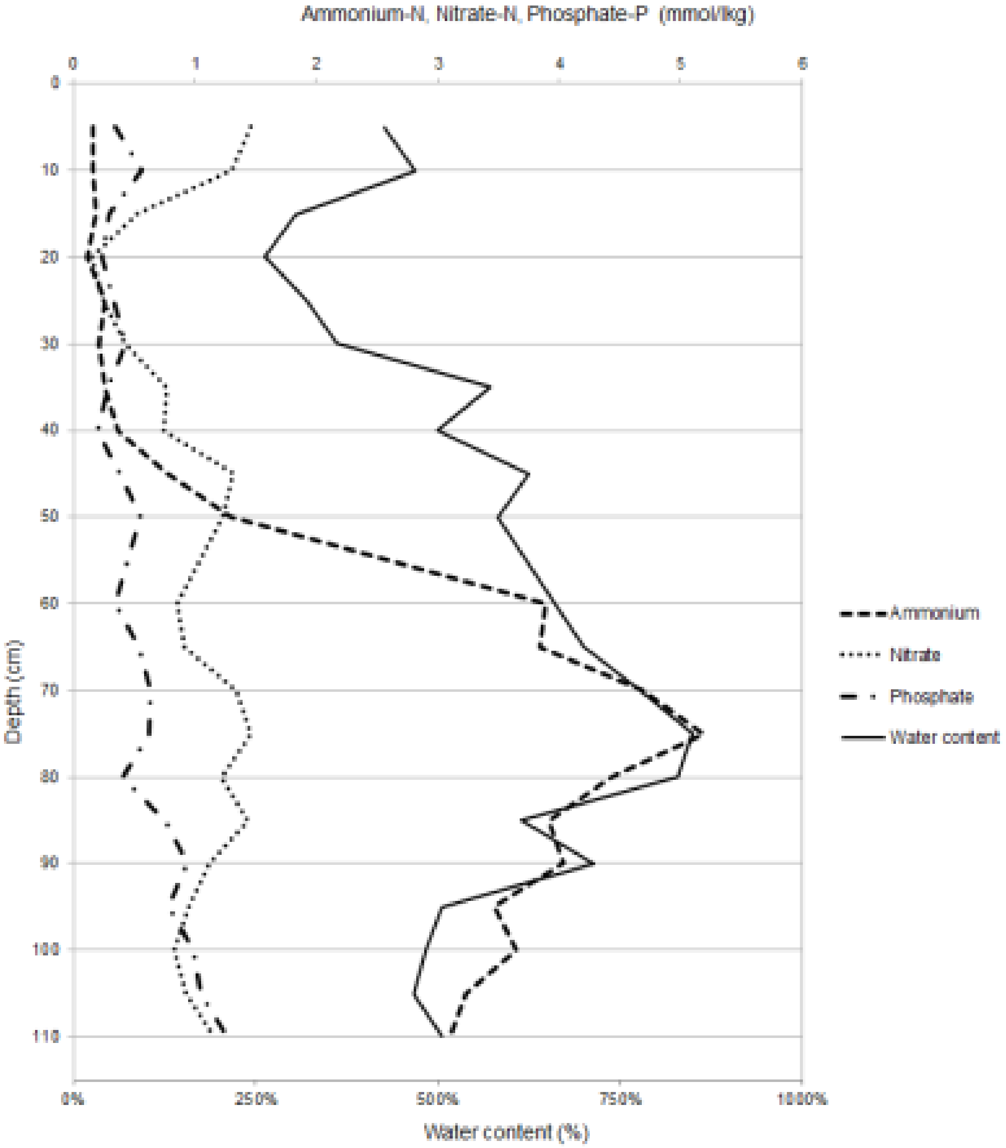

Fig. 3: Chemical data from one investigated peat core (Depth: 120cm)

Outlook

On a second expedition in 2012, foremost patterns of seasonal variability of nutrient availability shall be investigated. For this approach, a new method to monitor amounts of nutrients in soils shall be established.

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The Data of the Observations at the Kolyma Water Balance Station: the Potential of their Application in Academic and Applied Problems and the Need for the Resumption of Special Surveys

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Introduction

A grid of water-balance stations operated in the former USSR. Detailed observations of the water balance elements were conducted at them within the framework of a single program. The stations were located in all main natural regions of the country. The data of water-balance stations served as the basis for complex studies of the runoff formation regularities in different physiographic regions and also as the basis for the development of runoff calculation methodologies.

Natural conditions

The Kolyma Water Balance Station (KWBS) is located in the upper reaches of the Kolyma River, in the mountain area, in the zone of continuous permafrost. The climatic conditions are severe at the station - the multi-year mean air temperature is about -12 °C, and the amount of precipitation is from 250 to 440 mm per year. Most of the area is covered by rock slides, cedar elfin wood brush and larch light forest. The permafrost thickness reaches 400 m. The summer thawing depth is from 20 cm in bogged lowlands to 3 m and more on southern rocky slopes.

There are no other experimental catchment basins in the world that are characterized by such natural conditions. As the work [*Nasybulin 1976*] shows, runoff formation conditions and runoff characteristics at the station are representative of a wide area of the Upper Kolyma and the adjoining areas of the northeast of Russia.

Station history

The KWBS was organized in severe post-war years. Extended research of a number of areas was conducted in the upper reaches of the Kolyma River during 1947. The catchment basin of the Kontaktovy Creek characterized by a wide variety of the vegetative cover and soils is acknowledged to be the most suitable for observations. The station was built on the 15th of October 1947. First observations of the water runoff were started in May 1948 already, at the Kontaktovy and the Vstrecha Creeks. A grid of rainfall recording stations operated at the Vstrecha Creek catchment basin during 8 years (between 1949 and 1957). Multiple special observations were initiated at the same time on runoff, water-balance and water-non-permeable sites, including observations of the evaporation from the soil, water and snow surface as well as observations of **ground freezing and thawing in different conditions**. The observations program expanded from year to year, and the most remote and hard-to-access station zones were covered (Fig. 1). In 1968 runoff measurements were started at the unique object, in the basin of the Morozov Creek having no vegetative cover and completely composed of rock slides. Before 1978 the water runoff was observed in nine catchment basins with the area from 0.27 km^2 to 21.6 km^2. **The summer thawing depth was registered with 20 permafrost measurement devices located in different conditions.** Purely experimental studies were also executed. For example, they included the study of the impact of intra-ground condensation on the water runoff with the use of original devices and installations [*Boyarintsev et al. 1991*]. The station team included about 30 people with professional higher or secondary-level education.

Water balance observations were suspended at the KWBS since 1997. Only observations at the weather station as well as runoff observations at several creeks are presently carried out there without the participation of specialists-hydrologists. According to some data, the house where the station employees lived and where the long-term data record was kept, burnt out together with unpublished observation materials.

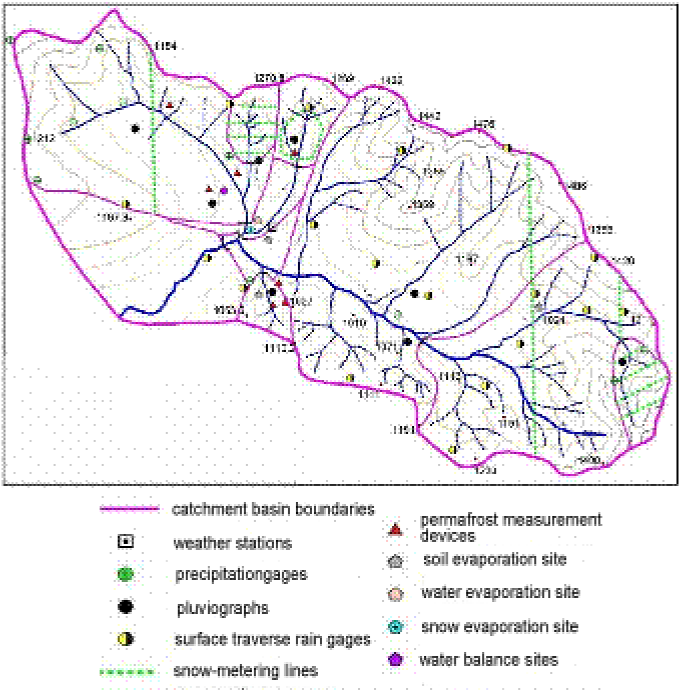
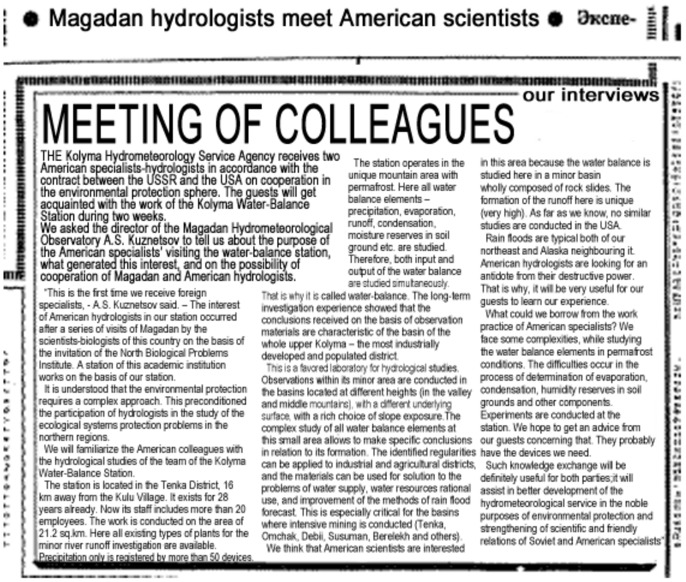


Figure 1. The map of the Kolyma Water Balance Station.

Huge material of hydrometeorological observations was accumulated during 40 years of work at the KWBS. By 1989 they were published in 30 issues the first one of which covers the period between 1948 and 1957. Later issues were published every year (KWBS observation materials, 1948-1987).

The observation results were reflected in multiple publications (there are more than 100 of them) dedicated to different aspects of the runoff formation in the continuous permafrost zone, the active layer dynamics, the structure of the underlying surface and its impact on hydrological processes.

In 1976 the station was visited by a team of American scientists (Fig. 2). They appreciated the professional and the personal qualities of station employees and their dedication to business. These qualities served as the basis for large-scale field and theoretical works despite the simplicity of the equipment available and severe climate. The American colleagues' report also noted the solicitous attitude to nature from the part of the Soviet scientists. According to Slaughter and Bilello [*1977*], the materials received at the KWBS do not have analogues in the world practice. A joint suggestion to regularly exchange the observations data, devices, research results in the form of articles and methodological instructions and other materials between American and Soviet scientists was made on the basis of the visit results. This initiative was not implemented unfortunately.



● Magadan hydrologists meet American scientists ● Экспе-

our interviews

MEETING OF COLLEAGUES

THE Kolyma Hydrometeorology Service Agency receives two American specialists-hydrologists in accordance with the contract between the USSR and the USA on cooperation in the environmental protection sphere. The guests will get acquainted with the work of the Kolyma Water-Balance Station during two weeks.

We asked the director of the Magadan Hydrometeorological Observatory A.S. Kuznetsov to tell us about the purpose of the American specialists' visiting the water-balance station, what generated this interest, and on the possibility of cooperation of Magadan and American hydrologists.

"This is the first time we receive foreign specialists, - A.S. Kuznetsov said. – The interest of American hydrologists in our station occurred after a series of visits of Magadan by the scientists-biologists of this country on the basis of the invitation of the North Biological Problems Institute. A station of this academic institution works on the basis of our station.

It is understood that the environmental protection requires a complex approach. This preconditioned the participation of hydrologists in the study of the ecological systems protection problems in the northern regions.

We will familiarize the American colleagues with the hydrological studies of the team of the Kolyma Water-Balance Station.

The station is located in the Tenka District, 16 km away from the Kulu Village. It exists for 28 years already. Now its staff includes more than 20 employees. The work is conducted on the area of 21.2 sq.km. Here all existing types of plants for the minor river runoff investigation are available. Precipitation only is registered by more than 50 devices.

The station operates in the unique mountain area with permafrost. Here all water balance elements – precipitation, evaporation, runoff, condensation, moisture reserves in soil ground etc. are studied. Therefore, both input and output of the water balance are studied simultaneously. That is why it is called water-balance. The long-term investigation experience showed that the conclusions received on the basis of observation materials are characteristic of the basin of the whole upper Kolyma – the most industrially developed and populated district.

This is a favored laboratory for hydrological studies. Observations within its minor area are conducted in the basins located at different heights (in the valley and middle mountains), with a different underlying surface, with a rich choice of slope exposure.The complex study of all water balance elements at this small area allows to make specific conclusions in relation to its formation. The identified regularities can be applied to industrial and agricultural districts, and the materials can be used for solution to the problems of water supply, water resources rational use, and improvement of the methods of rain flood forecast. This is especially critical for the basins where intensive mining is conducted (Tenka, Omchak, Debii, Susuman, Berelekh and others).

We think that American scientists are interested in this area because the water balance is studied here in a minor basin wholly composed of rock slides. The formation of the runoff here is unique (very high). As far as we know, no similar studies are conducted in the USA.

Rain floods are typical both of our northeast and Alaska neighbouring it. American hydrologists are looking for an antidote from their destructive power. That is why, it will be very useful for our guests to learn our experience.

What could we borrow from the work practice of American specialists? We face some complexities, while studying the water balance elements in permafrost conditions. The difficulties occur in the process of determination of evaporation, condensation, humidity reserves in soil grounds and other components. Experiments are conducted at the station. We hope to get an advice from our guests concerning that. They probably have the devices we need.

Such knowledge exchange will be definitely useful for both parties;it will assist in better development of the hydrometeorological service in the noble purposes of environmental protection and strengthening of scientific and friendly relations of Soviet and American specialists"

Figure 2. The article in the Magadanskaya Pravda newspaper dated 08 August 1976, Issue 4

Prospects of use of the KWBS data in academic and applied problems

The materials of special observations of rare duration (40-50 years) were gathered at the station. They characterize the natural conditions that, on the one hand, are not actually illustrated by the data and, on the other hand, are representative of a wide area of the Russia's northeast. Precipitation and flow rate observations together with such rarely measured values as evaporation, water loss from snow, surface runoff, ground thawing and the like make it possible to study the interactions of the particular processes of hydrological cycle with each other and with the landscape components in detail. The regularities of the runoff formation processes in the unstudied basins of the Russia's permafrost zone can be identified on the basis of the KWBS work results analysis.

The collected materials are invaluable for building and testing of different models: runoff formation, climatic, environmental and vegetation dynamics [*Kuchment et al. 2000; Lebedeva & Semenova 2012*].

The KWBS data could become a valuable indicator of climate changes and the basis for the study of their impact on the permafrost state and the hydrological regime of rivers, making it possible to penetrate the mechanisms of the ongoing processes. The absence of data for the period after 1990 is especially problematic within the framework of this scientific question because the most significant changes are thought to have begun at that time. Recommencement of the observations right now is very important due to this reason.

There is an urgent need to restart experimental studies at the Kolyma station due to the increased interest to the natural processes of the Arctic and the possibility of development of the Eastern Siberia rich natural resources.

29 water-balance stations were operating within the USSR. Now only four of them work. The observations program is significantly reduced at all currently active stations, up to standard runoff and meteorological measurements. Therefore, now they have the status of water-balance stations only conventionally.

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Massive Ground Ice on the South-Western Coast of the Kara Sea

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Introduction

Massive ground ice (MI) is widespread on the continental coast of the Kara Sea. The discussion about the MI genesis has been going on since when it first became the object of study. Some researchers believe that MI is of intrasedimental origin, while the others assume that it is of buried origin. Even now, after 50 years of studying the issue, there is no agreement of opinion. Researchers are still debating even over such well-known and well-studied areas of MI occurrence as the territories of the Marresale Polar Station, Bovanenkovo gas condensate field located in the valley of the Seyakha River on the Yamal Peninsula, or Shpindler stow located on the coast of the Yugorskiy Peninsula. In 2005-2008 MI collected in two key areas – the western coast of Baydaratskaya Bay in the area of the Oyuyakha River mouth [*Belova et al. 2008*] and in the area of Kharasavey village located on the Yamal Peninsula – were studied [*Belova et al. 2010*]. It was found out that the MI of the southwestern coast of the Kara Sea occurs in sediments of various age and genesis and that it varies in the formation time and mechanisms.

Massive ground ice on the western coast of Baydaratskaya Bay

A 25-45 m high steeply-sloping plain is adjacent to the shore in the area of the Oyuyakha River mouth. Along the shoreline it is lowered down to 15-20 m by numerous thermokarst basins (hasyreys). A number of sections are underlain by a clayey stratum with fragmentary material. The stratum is compared by F.A. Romanenko and his co-authors [*2007*] with Kara diamicton described by V.N. Gataullin [*Forman et al. 2002*]. Its uneven table which often retreats under the sea waterline is unconformably overlain by a sandy stratum having a complex structure, the thickness of up to 28 m and enclosing MI. Most of the stratum is composed of fine sand and silty sand that are enriched with plant detritus or are peaty. The sands bedding is cross, oblique and convolute, often interlaid with sandy silts, clayey silts and rolled pebble size coal. The stratum contains fragments and scallop shells of marine mollusks, bones and tusks of mammoths. The sandy stratum is characterized by a continental type of salinity and is dated using the radiocarbon method from 22.5 (1 date) to 44.9-49.6 (3 dates) thousand 14C years ago, i.e. at the limit of the method operation [*Romanenko et al. 2007*]. This lets us assume that the stratum began to form earlier, as early as 60-50 thousand years ago (MIS 4-3) during the phase of the retreat of the Kara Sea shelf ice sheet.

MI occurs in the sandy stratum in two layers. The ice of the upper (habs.= 9-15 m) and lower layers (habs. = 0-9 m) differ in thickness, structure and composition. The upper layer MI with the thickness of 3-6 m has an erosional upper contact, the isotopic composition of $\delta^{18}O$ = –21.8… –15.0‰ (Table 1), and its structure is similar to that of basal glacier ice. The $\delta^{18}O$ (δD) and deuterium excess (d) values do not have a visible connection, which is the evidence against the assumption that MI was formed as a result of liquid water freezing. The lower layer MI with the thickness of up to 3 m occurs conformably to the enclosing sediments and has a lighter isotopic composition, as compared to the upper layer MI (lighter by 3.2‰ based on the $\delta^{18}O$ value). The chemical composition of the MI in both layers is ultra-nonsaline.

Table 1. Isotopic composition of MI of two key areas according to the samples collected in 2006-2008 (in ‰ with reference to SMOW)

	$\delta^{18}O$			
Sampling location	aver.	min.	max.	N*
The Oyuyakha River mouth				
Upper layer MI	–18.4	–21.8	–15.0	44
Lower layer MI	–21.6	–25.2	–16.2	15
Kharasavey village: MI	–21.9	–26.3	–18.6	23
ice lenses above the MI	–18.4	–20.9	–17.0	6
	δD			
Sampling location	aver.	min.	max.	N*
The Oyuyakha River mouth				
Upper layer MI	–140	–164	–121	43
Lower layer MI	–163	–192	–121	14
Kharasavey village: MI	–166	–197	–143	23
ice lenses above the MI	–141	–159	–131	6

* N – number of samples

The composition of pollen and spores in the upper layer MI was determined by A.K. Vasilchuk at the end of 2011. Exotic far transported pollen of thermophilic grounds that is characteristic of the polar glaciers ice is not present. The ice contains spores of green mosses which are not present in atmospheric glacial ice. According to A.K. Vasilchuk, such composition of palynospectra indicates the intrasedimental mechanism of ice formation (Vasil'chuk & Vasil'chuk 2010). However, we believe that the upper layer MI is basal glacial ice which is very different from atmospheric glacier ice in the mechanisms of formation and in composition. Such palynospectra components as spores of green mosses could be included into the basal glacier ice together with bed sediments. In this case ice would be highly contaminated and dislocated [*Vasil'chuk & Vasil'chuk 2010*], which corresponds to the characteristic of the upper layer MI.

The primary indicator of the fact that MI is of buried origin is the erosional upper contact of MI that shears the stratification in ice with angular unconformity (there is no sign of secondary thawing in the overlaying sediments). The upper layer MI can be classified as glacier ice due to: 1) complex MI structure with lying folds and shear deformations; 2) similarities between MI facies and basal glacier ice facies in modern glaciers; 3) absence of the connection between $\delta^{18}O$ (δD) and d, absence of significant fluctuations in the isotopic composition (5-6‰ based on the $\delta^{18}O$ value).

We can assume that the MI was formed 60-50 thousand years ago during the Yermak (Early Weichselian) period (Q_{III}^2, MIS 4-3) at the stage of degradation of the Kara Sea shelf ice sheet. The lower layer MI was formed in the sandy stratum of fluvioglacial, coastal-marine and lacustrine-alluvial sediments. Apart from the buried perennial snow patches and lacustrine ice, there were also formed small ice and ice-ground strata as well as lenses and veins in the sediments. The upper layer MI was formed later, after a brief process of the ice sheet regeneration as a result of burying basal ice and its selvages.

Massive ground ice in the area of Kharasavey village

MI in the sediments of the northwestern coast of the Yamal Peninsula in the area of Kharasavey village is confined to the elevations of the table of sandy coastal-marine sediments conformably with the marine sediments overlaid by the clayey silty stratum. The marine sediments compose a 10 m high terrace. All the transitions between the benches of the sediments enclosing MI are gradual.

The MI occurs conformably with the stratification of the enclosing sediments and follows the sharp bends of the enclosing sands table. A series of lenses (with the thickness of 2-20 cm) that follow the contours of the deposit table was recorded in overlaid sediments at the distance of up to 2 m above the upper MI boundary. The thickness of the ice body under study is 1 m. The MI is represented by separate ice interlayers with the thickness of 5-35 cm that are separated by ground horizons (1-10 cm). The sands under the MI have a high ice content. They also contain tilted ice schlieren that form a reticulate-lenticular cryogenic structure.

MI has an ultra-nonsaline mineralization and mostly sodium chloride salinity type. The isotopic composition (Table 1) gradually becomes lighter in the direction from the ice lenses above the MI towards the upper part of the deposit, and the d values increase proportionally to the decrease in the content of isotopes ^{18}O and D, which indicates that the freezing goes from the top downwards. There is no uniform trend of changes in the content of ^{18}O and D in MI. However, the inverse relationship between the δ^{18}O (δD) and d values is preserved. It is probable that some interlayers of MI were formed in several stages of freezing.

The first data on the composition of pollen and spores in the deposit described were obtained in January 2012 by A.K. Vasilchuk. Ice contains a large amount of palynomorphs. The palynospectra are similar to the spectra in the sediments of the Kharasavey village area that were studied by A.K. Vasilchuk [*Vasil'chuk 2006*]. No signs of atmospheric origin of MI [*Vasil'chuk & Vasil'chuk 2010*] were found in the deposit.

The reasons in support of the assumption that the formation mechanism of the MI in the Kharasavey village area is intrasedimental mechanism are:

1) occurrence in conformity with the enclosing sediments; lensoid structure of the MI whose table follows the bends of the enclosing sediments stratification;

2) the chemical composition of the MI that coincides with that of schlieren ice and is similar to the chemical composition of water extracted from the enclosing sediments;

3) the inverse relationship between the changes in the ^{18}O (δD) and d values; the values of the isotopic composition that becomes lighter gradually in the direction from ice lenses above the MI towards the upper part of the deposit; and 4) the composition of palynospectra in ice is similar to the spectra in the enclosing sediments.

Conclusions

1. MI of the western coast of Baydaratskaya Bay forms two layers which differ in the thickness of strata as well as in ice structure and composition. The upper layer was formed in the process of burying the glacier ice by the sediments of the lacustrine-alluvial periglacial plain. The lower layer MI partly represents various primary surface buried ice bodies, partly – intrasedimental.

2. MI of the northwestern coast of the Yamal Peninsula in the Kharasavey village area is confined to the elevations of the table of sandy coastal-marine sediments in conformity with the marine sediments overlaid by a clayey silt stratum. MI occurs in conformity with the enclosing sediments. The composition is similar to that of structure-forming ices. It was formed during the epigenetic freezing of the enclosing sediments.

Acknowledgments

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Heaves in the West Siberian Northern Taiga

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Abstract

New drilling evidence and field reports are used to investigate the origin of heaves in the northern taiga of West Siberia. The heights of heaves are correlated with the total thickness of ice and depths of fine-grained sediments.

Keywords: Frost mound; genetic criteria of mounds; thermoremnant.

The study area is located in the northern taiga of West Siberia within lake-river terrace III, with elevations of 20-40 m. The mean annual air temperature is -5.6°C. The surface is covered with peat, 1.5 m or less often to 5 m thick. Below there lies a fluviolacustrine section of intricately alternating loamy sand, loam, and sand, the latter being water-saturated. Furthermore, older (presumably Salehard stage) loam, from a few to 10-15 m thick, which may bear frost heaves, lies near the surface. We studied a hummocky flat surface of terrace III, often swampy, where heaves and hummocky peatbogs occupy more than 70 % of the area. The heaves are high, other things being equal, in the case of near-surface loam swelled cryogenically in a zone of maximum temperature gradients. Flat peatland formed with minor or no participation of segregation ice.

The origin of heaves along the southern margin of the permafrost zone is most often attributed to frost jacking. In this interpretation, heaving results from moisture flow toward the coldest parts of peatbogs. The classical view is that the heave height depends on the total thickness of segregation ice lenses within the depth interval 8-13 m which is the most favorable for ice of this kind.

However, there is a model which suggests a thermokarst origin for some heaves interpreted as remnant hills (outliers) that rise above the surrounding surface subsided as ground ice beneath it has thawed out [*Timofeev & Vtyurina 1983*]. Peatland with large heaves forms by erosion of polygonal ground (Piavchenko, Pers. Commun.). The presence of heaves as thermokarst remnants in northern taiga of West Siberia was reported in [*Tyrtikov 1979*].

The studies were performed at two geomorphically different sites, with 6.6 m and 2 m high heaves, those at the first site having larger base diameters. Possible indicators of the thermokarst origin of some heaves were observed at site 1. It was, namely, their inconsistent morphology, with relatively flat surfaces, which abruptly slope down, instead of dome shapes as signature of heaving.

A heave which was difficult to interpret from its morphology was traversed by a special drilling profile. Drill holes in the heave slope and on the nearby flat peatland stripped sections almost fully consisting of sand (Fig. 1), except for one hole on the top where ice-rich loam was found. The shallow position of the latter during freezing led to segregation ice accumulation that shows up as a heave on the surface. Correspondingly, ice layers became widespread due to loam. The volumetric ice content at the account of ice lenses in the stripped portion of the loam section is 35 %. The total ice thickness in the upper part of loam drilled in the heave axial part is 110 cm while the heave itself is 6.6 m high. According to the classical point of view (that the heave height is defined by the total thickness of segregation ice within the depths 8-13 m), this structure cannot be a frost heave. However, there is evidence [*Vasilchuk 1983*] that some heaves may have their ice cores lying deeper than 12-15 m. Thus, the ice-rich core at a depth below 10 m may influence the heave height as well.

Assuming the 35 vol.% ice content in loam to be depthward uniform, the depth to the bottom of the ice-rich layer that controls the heave height can be estimated at about 25 m. This depth lies within the active layer (to 20-30 m) where moisture flow may influence the surface pattern. Therefore, the studied landform is most likely a frost heave. Without the layer with the maximum ice content in loam, the true thickness of the swelled loam would be much less than 25 m, i.e., no more than 18-21 m. Furthermore, the total thickness of ice may be underestimated as a part of ice is lost on core retrieval.

In most cases, heaves have their heights greater than the total thickness of ice lenses, the difference occasionally reaching 4 or 6 m [*Vasilchuk 1983*].

The total ice thickness estimates from the stripped part of loam (borehole 3) do not contradict the idea that the studied landform may result from frost heaving but does not rule its origin as a thermal erosion outlier.

Frost heaving is supported by the conformable bedding of loamy sand and sand immediately beneath peat in the upper section (Fig. 1).

Another flat peatbog (site 2) was drilled 1 km away from the profile. The loam top was stripped at the depth 6.7 m but the total thickness of ice lenses between 6.7 and 10.2 m deep was 40 cm (12 vol. % ice content). In this case, no considerable heaving occurred though loam lied relatively close to the surface (possibly, because of low soil moisture). The 2 m high heave at the site is located near the flat peatland. According to field reports, the total ice thickness in the drilled section (3.75-10.5 m) reaches 120 cm, the ice lenses making up about 17 vol. %.

As drilling shows, the heaves are higher where swelling loam lies closer to the surface, but this regularity is restricted to small areas similar in water content. High heaves with the most ice-rich soil may lie over deeper buried swelling loam.

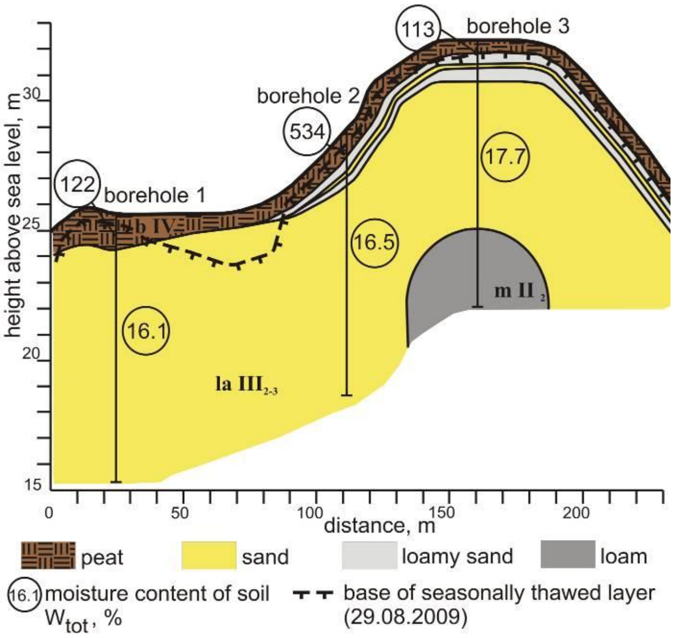

Fig. 1. Engineering-cryological cross section

Heaves (and peat) show no strict correlation of their heights with the total thickness of segregation ice lenses, but they all correlate with the volumetric ice content.

The origin of some heaves with ambiguous geomorphic features has to be inferred taking into account the total thickness of ice lenses, but reliable interpretation requires drilling deeper than 10 m. Nevertheless, shallow drilling data allow extrapolations of ice contents onto larger depths within the active layer (to 20-30 m) and estimating approximately the missed total segregation ice thickness which may show up in the terrain pattern.

Acknowledgments

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Study of the Far North Landscapes Dynamics Using Modern Methods of the Earth Remote Sensing

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There are enormous hydrocarbon reserves in the Far North of Russia, but its production is associated with extremely harsh environmental conditions of the region. The largest hydrocarbon reserves are concentrated in Yamal-Nenets Autonomous District (YNAD), with many elements of its landscapes being of cryogenic origin. The YNAD landscapes are relatively stable. However, due to an active industrial development of these areas in recent years, there is a problem of monitoring them in order to ensure industrial safety of oil and gas facilities.

Among the indicators of cryogenic phenomena being manifested in the landscapes the most important are geomorphological indicators such as thermokarst, patterned grounds, and frost heave. They are the main ones in permafrost area. The change of permafrost state in the first place affects the processes of termokarst (the distribution of thermokarst lakes). Therefore they can be regarded as the main indicator of thawing of frozen ground, hence, the key indicator of landscape change.

Both activation and fading of geocryological processes is primarily associated with the index of the heat exchange intensity (energy exchange) above the roof of permafrost and in its upper layers (down to the depth of 10-20 m). As a rule, the anthropogenic impact increases the heat exchange and disturbs the state of dynamic balance in permafrost. As a consequence, the activation and emergence of geocryological processes occur. The degree of activation largely depends on the nature of anthropogenic impact and the state of permafrost.

The change of heat exchange rate can be identified by examining the thermal channel of satellite images. When comparing images taken at different time, temperature anomalies are identified, their origin is analyzed, and some conclusions about possible temperature dynamics are drawn.

In order to identify thermokarst subsidence, it is reasonable to use the differential radar interferometry method. It can help to detect the subsidences and uplifts of the earth's surface with an accuracy of about 1 cm.

The use of materials of aero and space imagery is suitable for obtaining not only quick and objective information about the state of natural and anthropogenic sites, but also for the organization of the monitoring of the northern landscapes changes. Since thermokarst lakes are well displayed in the satellite images and the methods of their interpretation are thoroughly studied, aerospace topographic monitoring is the most appropriate method to monitor their dynamics (and hence the dynamics of landscapes).

Topographic monitoring is a technique of periodic and continuous observations of the changes of natural or anthropogenic sites located on the earth's surface and possessing defined and undefined borders, the presentation of the information on a site's changes in satellite images or on a topographic basis, as well as the classification of changes and the creation of a database containing information on such changes. However, the use of only visual interpretation is not sufficient. It is necessary to use additional processing techniques for the data of remote sensing for more accurate estimate of the changes of natural and anthropogenic sites (hence, also the landscapes). Such techniques are the ones described above: the analysis of temperature anomalies in the area, the differential radar interferometry method, etc. The combination of all techniques gives a complete picture of the situation and allows to carry out a detailed analysis of landscape dynamics and to predict future situations. It is advisable to combine the techniques through a geographic information system (GIS) that will include the following: measurements taken, cartographic materials, satellite and aerial photographs, and other related information. The final result is a prediction map of the Far North landscapes dynamics in the study area.

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Hydrogeological and Geocryological Conditions in the North of West Siberia (Within the Area of the Yamalo-Nenets Autonomous District)

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The Yamalo-Nenets Autonomous District is located in the arctic zone of the West Siberian Plain, with more than half of it being outside the polar circle. The district is one of the main oil and gas bearing regions of Russia. It provides up to 15% of all oil reserves and 91% of all gas production in Russia [*Beshentsev 2006*].

The district's area is hydrogeologically referred to the northern extremity of the West Siberian megabasin consisting of three independent complex superimposed hydrogeological basins: Cenozoic, Mesozoic and Paleozoic [*Matusevich 1986*]. The Cenozoic basin (its first hydrogeological complex, to be more exact) is frozen in different degrees. The hydrogeological complex is represented with the Cenozoic-Cretaceous system of drainage basins [*Matusevich & Smolentsev 1998*].

Five hydrogeological regions (Fig. 1) were identified in the basin based on the peculiarities of permafrost distribution and permafrost structure and on the subsurface runoff modulus.

Figure 1. Zonation of the Yamalo-Nenets Autonomous District's area based on the peculiarities of permafrost distribution and on the peculiarities of the subsurface runoff modulus
1, 2, 3, 4, 5 – the numbers of hydrogeological regions

10-30% of permafrost is typical of the first region with the subsurface runoff modulus equaling 3.5 l/sec km^2. These characteristics make up from 30 to 70% and 2.5 l/sec km^2 respectively in the second region. In the third region, the percentage of permafrost increases up to 90% with the runoff modulus decreasing down to 1.5 l/sec km^2. In the fourth region, the permafrost makes up 90-100% with the runoff modulus equaling about 0.5 l/sec km^2. The zone with the 100% content of homogeneous permafrost without segregated ice is spread in the Far North, with almost no subsurface runoff (<0.05 l/sec km^2) [*Ivanov & Beshentsev 2005*]. The West Siberian permafrost is characterized with latitudinal zonation. The latitudinal zonation occurs in the distribution of permafrost thickness and permafrost temperature, in the permafrost structure and in its ice content as well as in the permafrost relief of the earth's surface. Three main permafrost zones were formed on the territory of the West Siberian Plain from north to south due to the combined impact of paleohydrogeological factors and contemporary ones [*Beshentsev, Ivanov, Beshentseva 2005*].

1) the zone of continuous bedding of thick modern and ancient permafrost – it occupies the northern half of the plain part of the region (approximately to the north from 66°) as well as the Polar Urals and the Pre-Urals;

2) the zone of discontinuous bedding of modern and ancient permafrost – it is located in the southern part of the area under study;

3) the zone of deep bedding of ancient permafrost - it is developed on the limited area in the valley of the Ob River, from the southern boundary of the District (the village of Kazym-Mys) to the confluence of the Great and the Little Ob Rivers, and it is also developed in the upper reaches of the Kunovat River.

The presence of thick and complex permafrost excluded a significant part of the geological profile of the North of West Siberia from water exchange and influenced the formation and the regime of subpermafrost, intrapermafrost and suprapermafrost waters. The indicated regime is almost entirely determined by geocryological conditions on the research territory. Seasonally thawed, suprapermafrost, subpermafrost waters and open talik waters are formed here.

Groundwater is alimented by means of infiltration of rain, snow and river groundwater. The waters are discharged into the nearest watercourses. There is no inflow of groundwater from remote regions on most of the area due to the fact that the ground water-bearing systems of some river basins are disconnected.

The regional distribution of low-mineralized (70-150 mg/dm^3) ultrafresh waters is a typical feature of fresh groundwaters of the Yamalo-Nenets Autonomous District that are associated with the sandy and clayey unconsolidated sediments of the Eocene and Quaternary Period. The main components of general mineralization of groundwater include the salts brought by precipitation, the salts leached by water from water-hosting grounds and from the soil layer and the ions synthesized from water and from carbon dioxide. The groundwater is characterized with low concentrations of such main salt-forming components as calcium (from 3 to 50 mg/dm^3) and magnesium (from 2 to 40 mg/dm^3). The high content of iron ions (from 1.4 to 6.5 mg/dm^3), manganese ions (from 0.01 to 2.2 mg/dm^3) and silicic acid ions (from 2.4 to 35 mg/dm^3) sharply stands out against the background of the low values of these ions.

The chemical composition, the mode of occurrence and the hydrogeological parameters of the groundwater of the Eocene and Quaternary sediments reflect the history of landscape development and the paleohydrogeological history both in the general mineralization and in other hydrochemical characteristics. Besides, the indicated groundwater is subject to the regular latitudinal-concentric zonation. The in-depth study into the impact of permafrost-hydrogeological and paleogeographical factors on the formation and distribution conditions of the fresh groundwater of the cryolithozone will allow us to more purposefully approach the search and exploration of groundwater deposits as well as to forecast the change in the groundwater composition at operating water intake stations.

The following conclusion can be drawn on the basis of the geological history of drainage basins development: the processes of cryogenic metamorphization of groundwater occurring due to repeated freezing and thawing of the sediments of the Eocene-Oligocene-Quaternary hydrogeological complex represent the main factor of low mineralization and latitudinal-concentric zonation of groundwater from fresh to ultrafresh [*Beshentsev, Ivanov, Beshentseva 2005*].

The groundwater was repeatedly frozen during the Early Zyrianka and the Late Zyrianka Ice Ages and was washed by thaw and flood waters in the interglacial periods, when the system of northern rivers' runoff and, therefore, the system of subsurface runoff of this region was almost completely formed at the end of the Pleistocene - the beginning of the Holocene.

Repeated processes of metamorphization of the chemical composition of freezing and thaw waters occurred in the course of formation of the groundwater chemical composition at the described area. They included [*Ivanov & Beshentsev 2005*]:

a) cryogenic concentration (the gradual growth of the mineralization value of the freezing water);

b) directional change in the chemical composition of ice and water that underwent at least one freeze-thaw cycle; c) seasonal redistribution and reduction of the ion (chemical) runoff of rivers as a result of the chemical sedimentation of cryogenic sediments (minerals in the form of salts, hydroxides and organocomplex compounds);

d) ice desalination in the process of thawing;

e) the formation of hydrochemical stratification in continental and marine water bodies in the process of their ice cover thawing;

f) the accumulation of $CaCO_3$ and of soluble compounds in marine ice, icing ice, glacier ice and ground ice;

g) the salinity fluctuations of the World Ocean waters in a thousand-year cycle as a result of the glaciation state variability.

As a result, clearly expressed hydrochemical zonation of the groundwater of the Yamalo-Nenets Autonomous District is observed against the general background of low mineralization (70-150 mg/dm^3).

The amount of permafrost grows and the ground permeability falls from south to north. This increases the period of water interaction with the grounds and leads to more intensive leaching of cations under the conditions of a more complicated water exchange. Besides, the impact of lower temperatures increases this factor, which, as is known, leads to calcium carbonate sedimentation and magnesium carbonate accumulation in the solution [*Ivanov & Beshentsev 2005*].

The growth of the sulfate and chlorine content is also observed in the northern direction. These elements serve as indicators of direct cryogenesis processes according to the research results [*Beshentsev, Ivanov, Beshentseva 2005*]. The direct cryogenic freezing-out traces in the vertical profile can also be seen in the increased salt content in the lower part of the Upper Cretaceous - Quaternary water-bearing level. In a number of cases, the groundwater mineralization here grows up to 0.7-1.5 g/dm^3 in the relatively water-bearing Upper Paleocene horizon (the tibeysalinskaya suite). Consequently, the increase in the relative content of sodium and magnesium ions and the decrease in the groundwater mineralization with the reduction of the water exchange intensity convincingly demonstrate the role of cryogenesis processes in the formation of the hydrochemical conditions of the cryolithozone in the north of the West Siberian megabasin.

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Sources of Environment Risks in the Yamal-Nenets Autonomous Area

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Abstract

The Yamal territory is subject to high anthropogenic loads as a result of intense and large-scale nature management. Main environment risks come from drilling and works associated with transport and primary processing of petroleum, which pollutes the ground surface, surface and ground waters and causes changes to landscapes (degradation of vegetation, acceleration of erosion, etc.).

Keywords: Anthropogenic loads; chemistry of groundwater; environment; fresh groundwater; permafrost conditions; permafrost monitoring.

The Yamal territory is subject to high anthropogenic loads as a result of intense and large-scale nature management. Since the late 1980s the Yamal-Nenets Autonomous Area has been among world largest gas producers yielding more than 90% of gas and 12% of oil and condensate in Russia. The greatest impact is on the most highly developed and richest Pur district. The Polar Urals, the highland part of the area, is a province of active chromite mining, and other mineral deposits (manganese, base metals, gold, PGE, gemstones) are being explored there. Sand and gravel quarries are operated all over the area to supply material for laying roads and construction. There are many modern cities and villages (Nadym, Novyi Urengoi, Noyabrsk, Muravlenko, Gubkinsky, Tarko-Sale, Vyngapurovsky, Purpe, Yamburg, etc.), more than 1000 km of rail ways and 4000 km of motor roads, and thousands kilometers of gas and oil pipelines and power lines. Extraction and use of groundwater and surface waters has been ever increasing.

The greatest environment impact in areas of petroleum production is from drilling and works associated with transportation and primary processing of petroleum, which pollutes the ground surface, surface and ground waters and causes changes to landscapes (degradation of vegetation, acceleration of erosion, etc.).

Urban load is another major source of environment risks, after petroleum production and transportation, especially the impact on Eocene-Oligocene-Quaternary aquifers. About 60 million cubic meters of waste water is discharged annually in water bodies: about 90 % into rivers and lakes and 10% into the subsurface. Sewage water pollution consists of industrial (50%), household (47 %), and other (3%) components. Rivers of the Pur catchment are being especially heavily polluted. In 2002, 47.2 mln m^3 of sewage water was discharged (37.9 mln m^3 or 80% into waters and 9.2 mln m^3 or 20 % into quarries and storage basins in the watershed territory).

The watershed area of the Pur catchment has been polluted with tons of waste products: petroleum (34.2), suspended matter (586), dry residue (2430), synthetic surfactants (11.2), sulfates (0.26), chlorides (0.32), ammonium nitrogen (69), phosphorus (0.18), diethylene glycol (343), methanol (2880). Non-treated wastes dumped onto the ground surface become washed off by spring waters and thus pollute both surface water bodies and underground aquifers.

Annual emissions into air exceed 0.8 mln ton, mainly from permanent sources of petroleum production objects. The emitted gases are mostly carbon oxide (54%), hydrocarbons (39.0%), and nitric oxide (7%, as NO_2).

Burning tremendous amounts of gas in flares (more than 1500 in the area) causes irreversible damage to the environment: e.g., 4.2 billion cubic meters of gas was burnt in 2004.

The company *Gazprom Dobycha Nadym* Ltd. is developing the Medvezhie, Yubileinoye, and Yamsoveiskoye deposits in the central Yamal-Pur interfluve. Medvezhie, the northernmost one, stretches for 120 km in the N—S direction across two landscape-climate zones of northern forest tundra and tundra, with continuous permafrost. Two other deposits are located in the zone of Holocene sporadic permafrost, where frozen layers are often separated by unfrozen rocks. The temperature of permafrost varies from 0 to -3° C.

The development of the territory has changed its permafrost-geological conditions. The seasonal thaw depth became 40-70% greater as a result of soil cover removal and changes to snow accumulation conditions and soil composition at development sites. Deformation of foundations mostly results from precipitation associated with warming and permafrost thawing, from heaving of cooling soil and high temperature gradients, as well as from increasing soil moisture. The situation aggravates because of growing water saturation of soils at some industrial sites.

Principal measures undertaken at enterprises to maintain the carrying capacity of foundations include decreasing ground temperatures with various cooling systems and piling.

Large-scale temperature monitoring at tens of specially equipped wells in oil fields is being run by *Nadymgasprom*. In 2004 the Subarctic Research and Education Station was set into operation where research activities are performed in addition to training students. There are three 30 m deep geothermal holes within the Yubileinoye field drilled in natural landscape conditions. Two holes are near sand dumps where clusters of gas wells are located and the third one is rather far away, in an open tundra area. The temperature logging is automatic, with readings at every six hours.

The coldest temperature is -2.3°C throughout the drilled depth in the undisturbed part of tundra while mean annual ground temperature at the base of the active layer approaches 0°C, and the ground is mostly unfrozen. The ground temperature in the upper section, about the depth of the active layer base, may reach 2°C and is within negative temperatures in hole 2. There may be two reasons for the latter fact: (i) infiltration of melt and rain waters in the sand dump which makes the groundwater table shallower and increases heat flow in areas of water transit thus warming up the ground; (ii) different positions of the holes with respect to the dump. The head of well 1 is below the site level, and a thick snow cover accumulates there, which prevents soils from cooling in the cold season.

Thus, the underground hydrosphere is suffering the greatest impact, especially the most valuable freshwater of the Eocene-Quaternary aquifer which is the principal source of drinking and household water in the Yamal area, as well as in the entire Tyumen region. The anthropogenic loads change the conditions of groundwater circulation and cause transformations of waters and hydrogeological systems.

Preventing further pollution of various kinds requires continuous monitoring of environment at urban and isolated water supply points, which has to address water intake, position of the dynamic level, groundwater chemistry, and the state of boreholes and drinking water protective areas.

There is one important control of groundwater quality and composition in West Siberia, which often remains beyond consideration. This is namely the permafrost dynamics, especially, permafrost degradation as a result of global warming. Water withdrawal stations in the permafrost zone exist in special conditions where the state of frozen ground that acts as ion-exchange shields and filters is a factor of protection. In addition to hydrodynamic and geochemical observations, the monitoring program in the area has to include development of methodological recommendations for temperature monitoring of ground conditions, water at well heads, and the water budget within the area where useful groundwater resources originate. This will allow constraining the correlation between permafrost and hydrogeological parameters and predicting possible changes to water quality.

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Mechanism of Water and Salt Migration in soil during Cyclic Freeze-thaw

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Water and salt movement during freeze-thaw is one of the fundamental problems in geocryology, and the former president of International Permafrost Association Pewe [*1983*] pointed out that founding out the law of water and salt transfer during freeze-thaw is a new way for controlling salinization. Due to the subjective influence and instrument condition, the study on freeze-thaw affected on salinization is not available.

Influencing factors on water movement in soil during freeze-thaw

Water movement in frozen ground is due to the comprehensive effect of manifold causes. Research on the influencing factors have indicated that water movement is predominantly affected by temperature, the initial moisture content of soil, salt content and the structure of the soil.

Temperature gradient: Temperature is one of the external agents of the soil water movement. During freezing under a temperature gradient the unfrozen water potential induces pore water to transform from the unfrozen zone to the freezing zone. So temperature gradient is the key inducing factors on water migration, or some other factors change due to the changing of temperature gradient, and the factors are influencing water migration.

Initial moisture content: When the initial moisture content of the soil is big, there is enough water for ice growth and forming continuous ice lens, so the ability of water migration is weaker in a denser massive frozen zone. The initial moisture content may affect frozen depth of the soil, the frozen depth is shallower to the soil with bigger initial water content [*Pikul et al.1991*].

Salt content: Salt has a substantial impact on water pressure, unfrozen water content and water movement. The presence of salt will lower the freezing temperature to temperature below 0°C, and different salt type and concentration have different influence on the freezing point [*Bing & Ma 2011*]. At the same temperature the unfrozen water content in saline soil is bigger than that in soil of salt free.

Soil structure: The water migration depends not only on the external condition, but also largely upon the physical structure of soil, the variation of dry density has a significant influence on the flux of water migration. Under the freezing state, the water permeability to the soil with coarse particle is stronger than that of fine-grained soil, but the ability of water movement is weaker.

Influencing factors on salt migration in soil during freeze-thaw

Solute moves with water since we know water is one of the main factors to salt migration. The denser of initial solute concentration and the quicker of freezing velocity, the fewer of transfer salt. Water is not only the solvent of salt, but the transfer carrier of salt as well. So water transfer controls the salt migration except the salt variation for the physical and physicochemical causes.

In the process of salt migration following various physical, chemical and biological processes, the amount of salt migration is fluctuating in soil profiles due to the stochastic distribution of micro structure of soil and its variance at time and space [*Celia & Bouloutas 1990*]. Salt migrates from freezing zone to unfrozen zone in high permeable medium like sandy soil; however, the direction is reverse to the medium of low permeability. And the process is more complete provide that the permeability is higher and freezing ratio is slower. During freezing salt can transfer with water, but their transfer become more and more difficult due to the occupied access, thus the main direction of the transfer is to the freezing zone.

Given all that, the salt migration is complex during freezing which influenced by the soil type, initial moisture content, salt content, temperature, temperature gradient, and cooling rate. So the migration process is the result of the various factors mentioned earlier.

Mechanism of salt and water movement in soil during freeze-thaw

Three types of experiments were performed with the same soil, all with a bottom boundary temperature of +2°C: (i) unidirectional freezing with the upper surface of the sample at -10°C; (ii) cyclic freeze-thaw with the upper surface temperature varying sinusoidally from -10°C to +10°C and (iii) cyclic freeze-thaw with the upper surface temperature varying sinusoidally from -10°C to 0°C (Figure 1a, b and c). The three experiments had a sodium sulfate solution reservoir connected to the sample through the bottom cap so that provide an open system during freezing and thawing. At the end of the experiments the samples were divided into 1 cm thick discs to measure moisture content and dry density.

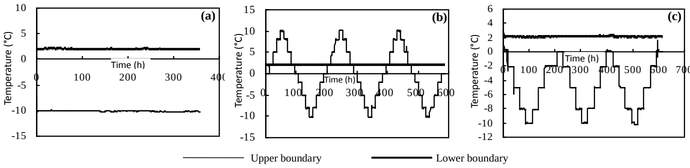

Fig.1 Boundary temperatures during the experiments: (a) during unidirectional freezing; (b) during cyclic freeze-thaw from -10°C to +10°C; (c) during cyclic freeze-thaw from -10°C to 0°C.

Fig.2 and Fig.3 shows the moisture and salt content profiles after the experiments. In the unidirectional freezing experiment, the unfrozen moisture potential induced water to move from the unfrozen zone to the freezing zone, causing increased moisture contents in the freezing zones and reduced values in the unfrozen zones (Figure 2a). It should be pointed out that the upper part of the soil remained frozen at the end of the experiment. The two cyclic freeze-thaw experiments, which ended with thawed soils, developed high moisture contents further up the profile. This was especially true of the soil cycled from -10°C to 0°C at the surface which showed the maximum moisture content in near-surface layer (Figure 2b and c).

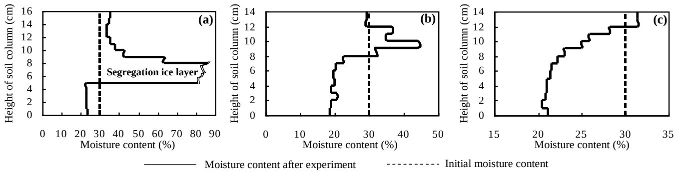

Fig.2 Moisture content profiles after the experiments: (a) following unidirectional freezing; (b) following cyclic freeze-thaw from -10°C to +10°C; (c) following cyclic freeze-thaw from -10°C to 0°C.

To unidirectional freezing, the unfrozen water potential induces pore water to transform from the unfrozen zone to the freezing zone. The ice lens (segregational ice) developed when freezing front drove forward. The maximum moisture content layer was lower compared to the second experiment (Fig.2b). During the freezing water migrated from the lower section to the upper, which leads to the drainage of the all soil column and a lower permeability. Thus, water cannot infiltrate to the original site when thawing. So there is a thawing interlayer causing moisture retention and with a greater moisture content after several cycles. But when the soil is only experienced freezing and thawing actions at minus temperature, there has not interlayer water accumulated, segregational ice layer and the unfrozen water potential gradient exists at all times. Thus, water continues to migrate to the upper layer.

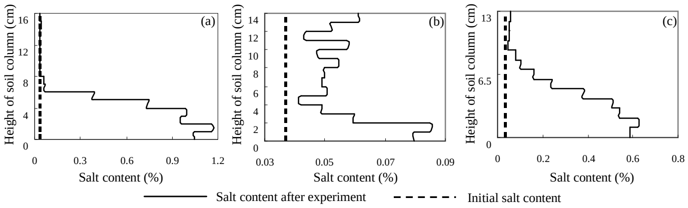

Fig.3 Salt content profiles after the experiments: (a) following unidirectional freezing; (b) following cyclic freeze-thaw from -10°C to +10°C; (c) following cyclic freeze-thaw from -10°C to 0°C.

Due to the ice self-purification during the unidirectional freezing, the freezing front serves as a partition layer to salt, so the amount of salt migration in frozen zone is very little though the moisture content in the zone is great. To the unfrozen zone, salt migrates with water and the amount of salt migration decreases at the soil column. So salt migrates for convection. When the soil experienced freezing and thawing, the temperature gradient varies. The trend of the moisture content in unfrozen zone is the same as the unidirectional freezing; the moisture content after the experiment is smaller than the initial for the drainage and the consolidation. And the biggest moisture content exists at the middle of the soil column. At the beginning of the action, the pore of the soil, particle grain size and mineral composition is random; the migration access has not yet formed, so the migration is taken place in local soil sample. With increase cyclic freeze-thaw numbers the access for salt and water migrating forms. At thawing the water migrated can not thoroughly back to the original place under the influence of gravity, so water migrates at the first cyclic freeze-thaw. With increase cyclic freeze-thaw number, the amount of migrated water increase, thus making a big amount of water at the middle of the soil. The amount of salt content is bigger at the detention layer of the water, partly because the salt source for the convection at the early stage applies salt to move up, making a bigger salt content at the top of the soil column, for one reason or another that there is a concentration gradient between the upper part of the soil with bigger salt content and the lower part soil water, which makes diffusion of salt to the lower part of the soil.

The unfrozen water potential exists all the time to the soil experienced cyclic freeze-thaw from -10°C to 0°C, but it is various, so water migrates to the upper part of the soil column, making a bigger water content at the top of the soil. Compared with the unidirectional freezing, the salt content increases in the unfrozen zone because of the supplement. However, water takes salt to migrate up for the existing temperature gradient. Though the temperature at the top is -10°C, the temperature is given stage by stage, the freezing front at the early stage formed at the higher of the soil column and forward slower, so the salt content is bigger.

Conclusions

Water migration during freeze-thaw is influenced by temperature gradient, initial moisture content, concentration gradient and soil structure. Temperature gradient is one of the external agents of the soil water movement. Water is not only the solvent of salt, but also carrier of the salt, so salt migration is influenced by factor influencing water movement besides various physical and physicochemical matters. So the mechanism of water movement determines a large extent the mechanism of salt migration. Salt migration is controlled by concentration gradient and temperature gradient. Salt migrates with water for convection accompanying diffusion for concentration gradient.

Acknowledgments

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Origin and Evolution of Subsea Ice-bearing Permafrost on the Canadian Beaufort Shelf: Implications from a 500m Deep Borehole

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The Quaternary section of the Canadian Beaufort Shelf consists of a sediment wedge in excess of 800 metres in thickness that accumulated in the subsiding Tertiary age Beaufort-Mackenzie sedimentary basin [*Blasco et al, 1990*]. In 1988 ConocoPhillips Limited completed a 500 m deep borehole in 32 m water depth [*Ruffel, 1990*] on the southern margin of the Quaternary depocentre of the Beaufort-Mackenzie sedimentary basin on the central Beaufort Shelf. Sediment samples recovered from the deep borehole were analyzed for permafrost, sedimentological, biostratigraphic and geochemical characteristics.Borehole stratigraphy indicates the inner shelf is composed of a thick section of eight regressive/transgressive sediment cycles consisting of sea level lowstand deposits of thick clastics and sea level highstand deposits of thin marine muds [*Blasco, 1995*].

The clastic sediment layers are characterized by thick, low density fine sand containing fresh pore waters of glaciofluvial origin, terrestrial pollen assemblages and macrofossils. Primary depositional structures such as laminations and trough cross-bedding are preserved. In contrast the marine muds contain saline pore waters and marine microfossils. Permafrost consists of pore ice, vein ice, reticulate and massive ice. Ice fabric indicates rapid crystal formation at shallow depths with no evidence of degradation, deformation or reformation.

Interpretation of this stratigraphy suggests the Beaufort Shelf was not subject to deltaic progradational processes associated with proto-Mackenzie River discharge over geologic time. During glacial maxima and low sea level the Beaufort Shelf was subaerially exposed and sediment starved as the Mackenzie River drainage basin was blocked by ice sheets. Initial deglaciation was accompanied by major meltwater events (catastrophic?) that flooded the shelf with thick glaciofluvial clastic outwash sediments. The deposition of meltwater sediments on the exposed shelf was rapid. During interglacial periods rising sea levels resulted in the deposition of thin marine muds as Mackenzie River sediment discharge mostly bypassed the inner shelf.

This stratigraphic model explains the observed distribution of ice-bearing permafrost. During sea level lowstands associated with glaciation the shelf was exposed to subzero temperatures that maintained underlying previously frozen ice-bearing sediments. Catastrophic? sediment laden meltwater discharge across the shelf resulted in the rapid subaerial deposition of clastic sediments with contemporaneous aggregation of ice-bearing permafrost. Subsequent rising sea levels associated with deglaciation flooded the shelf accompanied by the deposition of marine muds. During interglacial periods seawater warmed the subsurface to -1.5°C. Insufficient heat was available to melt the ice in the sediments. A subsequent glaciation and resulting drop in sea level exposed the shelf again and resulted in the freezing of the now exposed marine muds and dropping the temperature of underlying still frozen sediments below -1.5°C. Deglaciation led to the rapid deposition of another layer of glaciofluvial outwash that quickly froze in the cold subaerial environment. Rising sea levels again resulted in the deposition of another layer of marine muds. In this manner the 8 cycles of ice-bearing sediments accumulated on the shelf as the Tertiary age basin continued to subside.

The age of the section sampled in the borehole is not clear but a decomposed undated tephra at the base of the core is normally magnetized suggesting the section post dates the last magnetic reversal and would be younger than 780,000 years.

At no time during interglacial periods did seabed temperatures rise above 0°C, thus preventing widespread thawing of the ice-bearing permafrost . Significant thawing of these low density clastic sediments would have resulted in dewatering, densification of the lose sands, the deformation of sediments and the loss of primary depositional structures such as trough cross-bedding. Localized thawing occurred only where warm Mackenzie River outflow exposed the seabed to a positive temperature regime. This model accounts for the observed occurrence of ice-bearing sediments on the shelf.

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Carbon Dioxide Production and Labile Organic Matter of Cryogenic Soils in North Taiga Ecosystems of Western Siberia

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Introduction

According to the existing world assessments, the planetary maximum of mean annual carbon dioxide concentrations is not above tropic forests and not between 20° and 60° N where 95% of the produced fossil fuel is burned. It is at 70° N – above tundra and northern forests. It is northern ecosystems that represent the main source of carbon dioxide and provide its planetary maximum in the atmosphere.

Most of the authors showed that the organic carbon content has the greatest impact on the value of greenhouse gas emissions from frozen soils. Nonetheless, the qualitative composition of the soil organic matter was not examined. However, there is no doubt in the fact that this composition determines the availability of the organic matter to microorganisms and the mobilization speed. The additional carbon emission into the atmosphere in the form of greenhouse gases will strengthen the greenhouse effect in the future based on the feedback principle and can become comparable with the annual technogenic increase in these gases in the atmosphere.

The problem of the direct impact of cryogenesis both on the qualitative composition of the soil organic matter from the perspective of its availability to microorganisms and on gas behavior in the soil profile remains understudied at present.

Area of Research

The area of research is located in the north of Western Siberia (Nadymsky District, Tyumen Region and Yamalo-Nenets Autonomous District of the Russian Federation) within the northern boundary of north taiga, in the contour part of the 3rd lacustrine-fluvial plain of the Nadym River.

According to the soil-geographic zoning [*Dobrovolsky & Urusevskaya 2004*], this area is referred to the Nizhneobskaya province of the cold long-freezing soil facies of the subzone of the gley podzolic and podzolic soils belonging to the north taiga of the European-West Siberian taiga-forest region of the boreal belt.

The area under study is located in the zone of permafrost islands. The permafrost is discontinuous, being absent under forest land islands and bogs, and is confined to peatlands, frost mounds and ridges. Landscapes of different ages characterized with a various degree of cryogenesis manifestation are widely developed in the area at present.

Objects and Methods

The research was carried out at three sites: the forest site, the flat-topped polygonal peatland and the degrading peatland.

The forest site represents hummocky dish lichen pine forest. No permafrost was discovered in the soil cover. The soil forming in the conditions of deep permafrost bedding was classified as the illuvial-ferriferous finely light-colored sandy silt podzol.

The flat-topped polygonal peatland represents flat and slightly inclined large-hillocky main surfaces of peatlands with cloudberry-ledum-sphagnum-lichen cover. The active layer is represented in this case by a peaty horizon underlain by a mineral stratum. Permafrost occurs below 55 cm on average. The following type of soil was identified: peat flow-humic fine-peaty sandy silt-light clayey silt cryosoil.

The degrading peatland represents small-mound ridge surfaces consisting of mounds raised above the bog level. It is characterized with locally developed bare peat spots, sparse vegetation and permafrost at the depth of 60 cm on average in the peat layer. Degrading peatlands are relict formations. The soil is classified as peat oligotrophic destructive permafrost.

The following studies were conducted in field conditions: regime monitoring of the carbon dioxide emission from the soil surface with a chamber method [*Smagin 2005*] and regime monitoring of the carbon dioxide concentration in soil horizons with a "tube method". Hermetically sealed tubes of a 1 cm diameter leading to the surface were placed in the soil at the depth of 20, 40, and 60 cm to fulfill this task. Concentration measurements in both methods were made with the help of the portable DX6210 Gas Analyzer. Also, regime monitoring of the temperature was conducted with the help of Thermochron iButton^{TM} .

All measurements were fulfilled many times every day during a month, during the peak of the vegetation period and during three field seasons of 2009-2011.

The content of the general carbon and the content of the carbon of labile (water-soluble) organic matter of the soil were determined in laboratory conditions. The first one was measured with the help of the AN-7529 express-analyzer.

Results and discussion

It can be concluded on the basis of the received averaged data (Table 1) that the values of carbon dioxide emission are low in this region. This testifies to low biological activity of all investigated soils. The soils of forest ecosystems are characterized with maximum emission values. This is associated both with lack of the permafrost roof in the soil profile and with microclimatic peculiarities. The monitoring showed that the heat income to the forest soil surface is higher. The lowest emission values are typical of the degrading peatland soils. This is associated with close bedding of permafrost soils and with the substrate quality – this is ancient almost completely processed peat.

The clear daily dynamics of gas emission was identified. It is associated with the daily air temperature dynamics.

Among research objects, the forest site and the flat-topped polygonal peatland are characterized with maximum averaged values of carbon dioxide concentration in soil horizons. The general trend of the change in the carbon dioxide concentration and emission over the objects is preserved because it depends on the closeness of bedding of permafrost soils.

It is established that the soils under study function in different temperature regimes dependent on the presence or absence of permafrost in the profile. Cryosoils of the flat-topped polygonal peatland can be regarded as "cold", while the podzols of forest ecosystems with no permafrost in the soil profile can be regarded as "warm".

Table 1. Carbon dioxide production by soils

Soil	Emission, $mgCO_2/m^2hr$	CO_2 concentration,% 20 cm	40 cm	60 cm
Peat-cryosoil	116	0.30	0.29	0.3
Peat oligotrophic destructive permafrost	42	0.10	0.16	NA
Illuvial-ferriferous podzol	205	0.15	0.31	0.23

It was found out on the basis of the received data (Table 2) that the following is typical of the peat-cryosoil of the flat-topped polygonal peatland: a high content of general carbon in the peat horizon, with abrupt reduction in mineral horizons and further increase in the suprapermafrost horizon. This confirms the humus retinization theory.

The soils of the degrading peatland are characterized with the highest general carbon content within the entire profile among all soils under research, with the lowest values of biological activity. We think that this is associated with the low content of labile organic matter.

The highest content of water-soluble organic matter was discovered in the organogenic horizon of podzol at the forest site and of peat-cryosoil of the flat-topped polygonal peatland. The highest biological activity values are typical of the forest ecosystem soils. This testifies to favorable conditions of organic matter transformation, as compared to other objects.

Table 2. General and water-soluble carbon content

Soil	Horizon (thickness, cm)	C gen,%	C water-sol, % of soil	C water-sol, % of C gen
Peat--cryosoil	O (0-6)	36.77	0.670	1.822
	T (6-12)	42.85	0.789	1.841
	B1 (12-16)	1.26	0.039	3.105
	Bh (16-24)	1.33	0.027	2.037
	B3 (24-35)	0.93	0.025	2.678
	BC (35-43)	5.06	0.024	0.474
Peat oligotrophic destructive permafrost	T1 (0-17)	50.10	0.232	0.463
	T2 (17-33)	49.73	0.236	0.474
	T3 (33-48)	50.19	0.274	0.546
Illuvial-ferriferous podzol	OT (0-11)	42.43	1.093	2.576
	E (11-16)	1.16	0.051	4.394
	B (16-35)	0.58	0.019	3.254
	BC (35-61)	0.23	0.012	5.221

The interrelation between the content of water-soluble organic matter in the upper organogenic soil horizon and the values of carbon dioxide emission was identified.

Thus, the value of carbon dioxide emission for the soils under study is determined both by hydrothermal and geocryological conditions, and by the organic matter composition, particularly by the labile fractions content.

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The Regularities of Temperature Formation in the Grounds of the Western Part of the Lama Lake Basin

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Introduction

The Lama Lake area is unique in terms of its natural conditions and serves as a recreational zone for the residents of the Norilsk region. The geocryological conditions of this area were hardly studied before. The geocryological studies in which the authors participated were carried out by the Expedition of the Geocryology Department of Moscow State University (1991-1993) and the Russian-German Expedition (1997). The annual mean ground temperature is the main characteristic of geocryological conditions in any area, and the analysis of specific and general regularities in its formation is of primary importance.

Description of the area

The Lama Lake basin is located at the foot of the western part of the Putorana Plateau. The area is located outside the polar circle; its climate is elevated continental with the annual mean air temperature of -9.3 °C. The annual mean amount of precipitation makes up 429 mm including 236 mm falling in the form of snow. The area is referred to the north taiga subzone and is mainly covered with forest consisting of fir, larch and birch as well as of light forest. The research area covers the plain territory of the northern and the southern shore of Lake Lama (the absolute heights are 45-175 m). The plain territory includes lake terraces, the Mikchangda River terraces and the highest level of glacial genesis. Permafrost is discontinuous and forms islands according to geophysical research data.

Research methods

The special landscape microzoning of the territory was made and the corresponding map was prepared to evaluate the impact of natural factors on the ground temperature formation. We chose the following zoning indicators: the relief and the microrelief of the surface, the composition of the grounds in the upper part of the section and the nature of vegetation that represent the main temperature forming factors. At several points of each identified microzone, the surface conditions were described, the seasonal thawing depth was measured, the section of deposits was studied and the frozen and seasonally thawed grounds were sampled for determination of the moisture content as well as of the volume weight of the ground skeleton. 2 thermometric wells were drilled in peatlands during the fieldwork in 1991. The annual mean ground temperature was determined to be within the range from -1.5°C to -2°C.

Since the data of the direct thermometric monitoring are limited, we estimated the impact of various natural factors on the ground temperature and on the thickness of the seasonally thawed or the seasonally frozen layer with the help of S.N. Buldovich's method [*2001*] in order to determine the regularities in the formation of the annual mean ground temperature. This methodology is based on the analysis of the connection between the thermal regime of grounds and the level of annual heat exchange in them. The calculation is conducted through the value of annual heatturns defined by a whole series of landscape-climatic and geological factors, by the annual mean ground temperature and by the thickness of the seasonally thawed layer (seasonally frozen layer). In addition to the annual mean ground temperature at the bottom of the seasonal thawing or freezing layer (t_ξ), we estimated the impact of the components of the radiation-heat balance and the impact of the snow cover and of the soil vegetation cover. We also calculated the temperature shift occurring due to the difference between grounds' heat conductivity coefficients in the thawed and the frozen states. All these procedures were performed for each microzone. The temperature map of the western part of the Lama Lake basin was drawn on the basis of calculation results.

Research results

Impact of the radiation-heat balance

The annual mean temperature of the day surface differs from the annual mean air temperature by the radiation correction value (Δt_R). Δt_R makes up on average 1.0 °C for open forestless parts of the area under study, and it makes up -0.2 ° for forested surfaces (under the forest cover).

Impact of the snow cover

The snow cover is one of the most important temperature-forming factors. The impact of snow (Δt_{sn}) is defined not only by its thermal resistance but also depends much on the value of heatturns passing through the soil surface. We should emphasize the irregular distribution of the snow cover in height and density within the area of research that causes differences in Δt_{sn}. A thick snow cover up to 0.8-1.1 m (sometimes reaching 1.5 m) is accumulated in the forests with undergrowth and thick bushes. High snow thickness (up to 2 m) is also observed in inter-ridge depressions typical of dissected glacial surfaces. The snow thickness varies from 0.2 to 0.6 m in open forestless areas. The Δt_{sn} values in different microzones are within the range from 5.0 to 8.5°C. The snow warming impact grows regularly with the increase in the snow cover thickness. The highest Δt_{sn} values (from 8.1 to 8.5°C) are observed in the microzones covered with forest or thick bushes and in inter-ridge depressions. The lowest value of Δtsn is registered on the islands with no vegetation in the Mikchangda River's delta with a thin snow cover (0.3 m).

Impact of the soil vegetation cover

The impact of the wood and bush cover, as is shown above, is expressed in the change of the components of the surface radiation-heat balance and in the redistribution of the snow cover. Being heat insulators, the moss-lichen and green moss soil vegetation covers impede the summer warming of the soil and, at the same time, reduce heat emission from the soil surface in winter. The calculation results showed that soil covers have a cooling impact on t_ξ (Δt_p from -0.1 to -0.7 °C). The higher the thickness of the moss cover is, the greater impact it exerts on t_ξ. Thick green moss covers on the low lake terrace have the highest cooling impact (from -0.6 to -0.7°C). The higher the moisture content of the soil cover is, the greater cooling impact this cover exerts in summer and the lower warming impact it exerts in winter. The Δt_p value is almost twice as high for moist moss as that of low-moisture moss.

The impact of factors determining t_ξ is interdependent. The amplitude of monthly mean temperature fluctuations increases at the surface of vegetation cover when the snow cover decreases. This leads to the increase in the value of heatturns and to the increase in the cooling impact of vegetation. The heatturns' value and the impact of soil vegetation covers go down when the snow cover thickness increases. For example, Δt_p fell by 0.1°C at the low terrace of Lake Lama within the site composed of clayey silts when the snow cover thickness increased by 0.1 m. However, the quantitative input of the snow warming impact under the same climatic conditions significantly exceeds the cooling impact of soil vegetation covers.

Impact of grounds' composition and properties

The composition of grounds in the seasonal thawing (freezing) layer is distinguished with a great diversity: from pebble-boulder deposits with sandy and sandy silt filling to clayey silts and peat. The temperature shift (Δt_λ) caused by the difference in the heat conductivity coefficients of grounds in the frozen and in the thawed state rises with the increase in the difference of the heat conductivity coefficients and depends on the ice content of grounds. The Δt_λ values from -0.1 to -2.1°C were obtained as a result of calculations. The highest Δt_λ values are reached in peats; Δt_λ in clayey silt varies from -0.4 to -1.4°C, and in sands and gravel-pebble deposits it ranges from -0.1 to -0.4°C.

Ground temperature formation under the impact of the complex of factors

The formation of t_ξ occurs under the impact of the complex of natural factors. Besides, the change in the impact of one factor leads to the alteration of the impact of all other factors because the heatturn is altered. A complex combination of factors in different microzones results in the variety of t_ξ on the territory. The lowest temperature microzones (t_ξ reaches -2.1°C) are referred to peatlands with the highest Δt_λ. t_ξ from -0.3 to -1.3°C is formed on glacial deposits. The lowest temperature was obtained for inter-ridge depressions composed of dusty sandy silt and covered with a peat layer. The close t_ξ (-0.3 to -1.7°C) values are observed at lake terraces where the highest temperatures are typical of low-moisture sand grounds with a thick snow cover, while t_ξ = -1.7°C was obtained for open sites with a low amount of snow that are composed of sandy and clayey silts. The positive t_ξ values can be formed on water-glacial sand-pebble deposits at the sites with a high snow accumulation. Complex temperature conditions are formed on the floodplain islands in the Mikchangda River's delta that are composed of sandy silt and silty sand. t_ξ is about -3°C at these sites with no vegetation. This is mainly associated with a low thickness of the snow cover and with its higher density resulting from strong wind loads. The positive t_ξ values (0.4°C) are formed on the islands covered with thick bushes that intercept loose snow.

Conclusions

The temperature conditions abnormal for high latitude developed in the area of research. Thawed grounds and high temperature permafrost are developed here. The t_ξ values vary from +0.4 to -3.3°C. The snow cover has the greatest impact on the t_ξ formation. Its thickness and density vary much within the area under study. The impact of the bush and wood vegetation manifests in the snow accumulation conditions. In the forest the temperature at the day surface is lower by comparison with forestless lands. Soil covers have a low cooling effect and thick moss covers reduce the warming impact of snow in a number of cases. The temperature shift is negative and considerably reduces t_ξ especially on peatlands.

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Establishment of New Economic Region on the Basis of Central Arctic Resource Potential

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Russian economy stability in XXIst century will be mostly relied on development of hydrocarbon reserves of Arctic shelf. Unique resource potential allows considering Central Arctic as a region guarantying long-term national energy security.

The area of the region is 2.5 mkm^2, 1.4 mkm^2 are onshore and 1.1 mkm^2 in marine shelf. The Central Arctic consists of Yamal and Gydansky peninsulas (YaNAO), Taimyr peninsula (Krasnoyarsk District), system of gulfs and Kara sea.

Total initial reserves of the region are estimated over 100 billion TOE with significant dominance of gas reserves amounting about 85%. Approved estimations of the recent assessment amount over 90 billion TOE seeing underestimated in Gydan petroleum province (NGO) and Severo-Karskaya SPNGO.

As of 01.01.2011 , 51 onshore hydrocarbon fields discovered in the region: 26 in Yamal peninsula, 12 in Gydansky peninsula, 14 in Enisey-Khatangskaya NGO. Two fields – Rusanovskoe and Leningradskoe – discovered in the South-Kara shelf, four fields – in the Gulf of Ob. Major part is multilayer fields, gas accumulations dominated/

Geological and geophysical knowledge of the Central Arctic region differs depending on situation. Onshore drilling acquaintance measured by 1.5 thousand deep wells taped completely only Cretaceous part of section. Some wells were drilled in marine conditions: 2 in Rusanovskoe and 2 in Leningradskoe fields, 3 in Bely Island, 1 in Sverdrup Island. 22 wells drilled in the Gulf of Ob.

Volume of seismic profiles in the Kara Sea shelf amounts to 113.99 thousand lin.m.

On the basis of geological and geophysical survey deep structure of sedimentation mantle is studied at a depths of 11-17 km, main tectonic elements are specified and 84 local structures are identified.

Seismic surveys performed in Gydansky peninsula and in the northern part of Kara Sea in recent five years allow forecasting significant prospects of these territories; underestimated reserves assessment of these territories becomes clear in a view of new data and requires correction on a basis of complexion of acquainted results and development of complex geological model of onshore and offshore areas of Central Arctic Region.

Hydrocarbon field development in the Central Arctic plays important economical and geopolitical role for Russia. Industrial development of the territory allows further extension to other Russian Arctic Regions. Russia could settle in Arctic shelf in a safe manner and long-term basis.

Yamal peninsula has unique potential for industrial development. Prepared for commercial production natural gas reserves of Yamal peninsula allow to forecast annual gas production 300 bcm during 50-70 years.

Construction of the biggest Russian LNG capacities is projected in the north of Yamal peninsula. Potential LNG plant production capacities should be over 40 million tones. Selling of LNG requires building of large sea port which exploitation should support renovation and further development of the Northern Sea Route. Construction of sea port will result in diversification of hydrocarbon supplies as liquefied natural gas could be shipped by tankers both to Europe and Asia.

Development of oil and gas fields in Central Arctic Region requires utilization of innovative technologies saving fragile ecology balance of Arctic and giving the opportunity to indigenous ethnic communities of the North to live on their traditional way (nomadic reindeer herding).

Due to development of oil and gas fields in Central Arctic a great number of social problems arising in single-industrial towns during production decline could be resolved. Such town could get “second life” and become the base for exploration of Central Arctic potential.

Progress of the region will require huge capital investments, but it is absolutely substantiated giving unique reserves volume and constantly rising world hydrocarbon demand in a long-term prospect.

Hydro-Climatic Change Indications of Arctic Permafrost Thawing

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Introduction

Climate change in the Arctic will significantly affect the physical environment over the coming decades, to a large degree through changes in the hydrological cycle. Along with permafrost thawing, increased surface water flows, rising groundwater contribution to streamflow and increased precipitation are some changes that so far have been observed in the Arctic and also may have direct and substantial effects on the environment and infrastructure in the region.

Climate projections provide information on expected future changes to key atmospheric parameters such as air temperature, precipitation, and wind speed. However, practical adaptation of society also requires information on how such changes are propagated further through the terrestrial ice-water system, changing permafrost and water flows. Here, we extract and summarize some permafrost-indicative findings in our recent study [*Bring & Destouni, 2011*] where we investigated a recent period of observed climate and concurrent river discharge changes in the Arctic. We use the nature of the physical watershed as a natural boundary for water flow and compare precipitation-runoff change relations that indicate considerable permafrost changes across the largest Arctic basins.

Method

From the Regional, Hydrometeorological Data Network for the Pan-Arctic Region (R-ArcticNET) database of river discharge, we identified 13 independent drainage basins for which the most downstream hydrological monitoring station covered an upstream drainage area of more than 200,000 km^2 and for which recent discharge data was accessible. For these basins, we combined observed distributed precipitation data from the CRU TS 2.1 dataset, and observed discharge data from the Water Survey of Canada, the Arctic Rapid Integrated Monitoring System (ArcticRIMS), and the R-ArcticNET. We compared the reference period 1961-1990 with the more recent period 1991-2002, the latest for which distributed CRU data were available.

Results and discussion

Changes to precipitation and discharge for the 13 basins between 1961-1990 and 1991-2002 are shown in Figure 1.

In the figure, 1:1 changes are indicated with a solid line, on which all basins would fall if all change to precipitation translated directly to a corresponding change in runoff. Such a situation would require that evapotranspiration and water storage in the drainage basins remained constant under climate and other changes in the region. Most basins instead fall above this line, indicating a considerably greater increase (or smaller decrease) in runoff than the increase (or decrease) in precipitation.

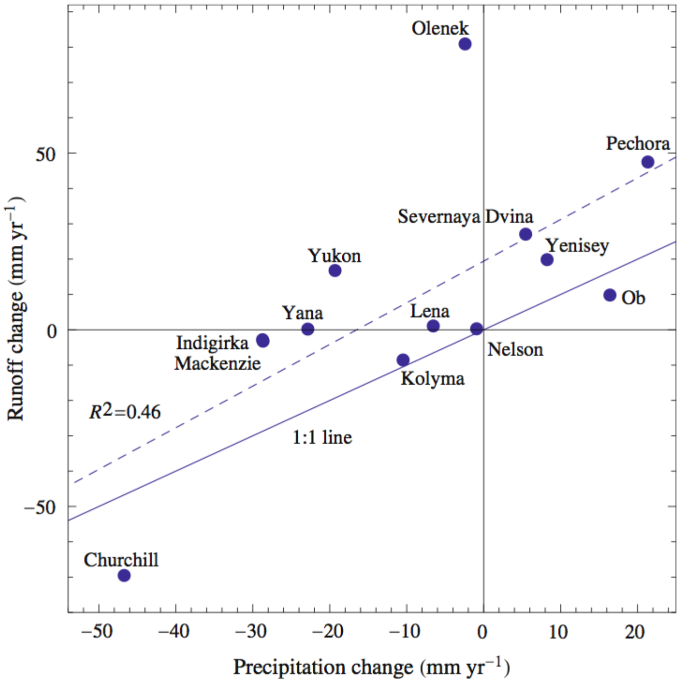

Figure 1. Changes to precipitation and runoff from 1961-1990 to 1991-2002 for 13 major Arctic basins. From Bring & Destouni (2011).

Establishing the source of this excess water is important both for a full process understanding of climate-hydrology interactions in Arctic basins and for relevant transformation of climate model projections into reliable hydrological projections, of importance for local and regional adaptation to climate change.

Other studies have also indicated increased discharge to the Arctic Ocean, in several cases identifying precipitation as the main driver. However, several of our study basins exhibit contradictory historic changes, with increased discharge even through precipitation has decreased or remained stable. A partial explanation to the observed excess discharge water may be gauge undercatch in combination with reported increases in snowfall, which would tend to increase the portion of underestimated solid precipitation during the year. Other contributing factors may be anthropogenic water-use changes that have changed evapotranspiration, in combination with changes in snow and groundwater storage. However, part of the explanation may also be permafrost degradation.

Simulations have shown that climate change in cold regions with permafrost entails complex and non-linear changes to the precipitation-runoff relation [*Bosson et al, in press*]. A combination of mechanisms may then contribute to the excess water in major Arctic watersheds, with the relative importance of permafrost thawing along with different other processes varying from basin to basin [*Adam and Lettenmaier 2008*].

In comparison to relying only on large-scale climate model results, a multi-model approach that links such results to hydrological modeling, which can better resolve and represent permafrost storage changes, along with groundwater, evapotranspiration and other runoff-affecting processes would enable better distinction, understanding and projections of permafrost-related hydrological change.

Conclusions

We analyzed and compared basin-wise changes to precipitation and river discharge across 13 major Arctic basins between the periods 1961-1990 and 1991-2002. Results indicate a general pattern of excess discharge compared with changes in precipitation. A combination of factors, including permafrost degradation, along with measurement errors and changes in groundwater storage and evapotranspiration can explain this result. Fully resolving the relative importance and contributions of these factors to the found complex, non-intuitive relation between (e.g., decreasing-stable) precipitation and (increasing) discharge changes requires further, physically based and well-resolved model studies of regional hydrology under climate change.

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Characterisation and Monitoring of an Active Rock Glacier in the Swiss Alps

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Introduction

Degrading Alpine Permafrost

Cryogenic features in the high mountains of the Alps react sensitively to global climate change. Rising temperatures in mountain permafrost zones caused by heavy rainfall events contribute to degradation, which can lead to accelerations of the ground within a rock glacier [*Arenson et al., 2010; Springman et al., 2012*]. The consequences can extend to initiation of landslides, causing hazards to human life and infrastructure.

Fundamental knowledge about the expected behaviour of a rock glacier is essential to predict whether instabilities are likely to develop. Coupling between mechanics, hydrology and temperature of a rock glacier is not well understood. Research efforts are necessary to gain a better system understanding, which can help to initiate preventive steps to protect the population from natural hazards.

Research collaboration

Three Institutes of the Swiss Federal Institute of Technology of Zürich (ETHZ) collaborate in this project. The research group consists of the Institutes for Geotechnical Engineering, of Geophysics and of Environmental Engineering (hydraulics). The research programme consists of three main parts: characterisation, monitoring and modelling of the rock glacier.

Goal of the project

The interaction between geotechnics, hydrology and thermal regime, together with the time dependent behaviour of the frozen soil, is not well understood. The goal of this project is to combine these four parts in one constitutive model and to embed this in a numerical model. Such numerical simulations can be developed to analyze the response and obtain a more detailed view of the different processes. Ground parameters from laboratory tests, as well as displacement and temperature measurements directly from the field, are indispensable in calibrating parameters and in validating the numerical model.

Method

Characterisation and long term monitoring

Long term monitoring showed numerous rock glaciers in the Turtmann valley (Valais, Switzerland) are exhibiting thermally degrading zones accompanied by acceleration of the surface displacements over the last 40 years [*Roer et al., 2005; Kääb et al., 2007; Roer et al., 2008*]. A rock glacier below the Furggwanghorn was chosen as a site for field characterisation and long term monitoring. Locations for boreholes were defined in summer 2010 in cooperation with the Institute of Geophysics and with reference to geomorphological aspects. The boreholes should give clear information about the availability of permafrost. Five boreholes (139 mm diameter) were drilled to a depth of 25 m. All boreholes are located in the upper part of the rock glacier, where thermal degradation was expected. A change in the thermal conditions and the growth of thermokarst could explain why the rock glacier shows increasing irregular creep behaviour. Formation of crevasses confirms this trend. Borehole F1, F2, F3 and F4 are arranged along one of the principal axes of the rock glacier. The distance between F1 and F4 is 26 m. Borehole F5 is located around 5 m from F4, transverse to the axis.

Percussion drilling with high pressure air cooling delivered some information about the different soil characteristics through the material blown out, although this was not ideal. Rocky blocks, with dimensions greater than the drill diameter, also made the drilling campaign more difficult. The ground was very heterogeneous, with no consistent layers. The top 2-3 m were covered with blocks of loose granular material. The soil below was a mixture of frozen silty sand and big blocks.

Instrumentation

Thermistor chains (Typ MEAS 44031) were installed in four of these boreholes (F1, F2, F3, F4) to measure the temperature distribution within the rock glacier. Each chain contains 30 temperature sensors that were fixed at different depths. The distance between the sensors is 0.5 m in the upper 5 m and 1.0 m in the lower part. Ten supplementary temperature sensors were placed on the surface around the boreholes F1, F2, F3 and F4. A chain inclinometer was installed in the fifth borehole F5. The inclinometer consists of 48 stiff segments (Shape Accel Array, Measurand, Canada), which are connected with a hinge that rotates through 360°. Each of these 50 cm long segments measures the inclination in two vertical directions. The displacement of the rock glacier can be determined by integration of the inclination over the whole instrument length and assuming there was no displacement at the base. The position of the borehole on the surface has to surveyed by a stationary reference point to convert the movements measured into absolute displacements.

The data collection occurs automatically so it is possible to monitor data over the whole year, even when the boreholes are covered with a thick layer of snow and hands-on measurements are not possible. The measurement interval of the thermistor chains and the inclinometer is six hours.

The subsurface measurements were supplemented by a meteorological station. Meteorological parameters such as precipitation, air temperature, snow depth and radiation are especially important to be able to form the energy equation. Details about the different measuring parameters are given in Table 1. Meteorological data are collected every 5 minutes and are recorded on data loggers. The electricity supply to all instruments is achieved through solar charged batteries.

Table 1. Summary of the measuring instruments

Description	Measuring range
Air Temperature	-40°C to +60°C
Humidity	0-100 % rel. humidity
Short & long wave radiation	305 to 2800 nm
Snow depth	0.5 m-10 m
Precipitation	0 to 50 mm/min or 0 to 3000 mm/h
Wind direction	mechanical 360°,electrical 355°
Wind speed	Max. accuracy between 1 m/s to 60 m/s,

Results

Field Monitoring

The drilling campaign revealed ice at some depths. The temperature measurements in the four boreholes confirm that permafrost can be identified on average below 3 m although readings only extend to 10 months. All boreholes show a similar temperature distribution below the active layer. The temperatures stay mostly constant and very close to 0°C, without any obvious seasonal effect for the first year of monitoring.

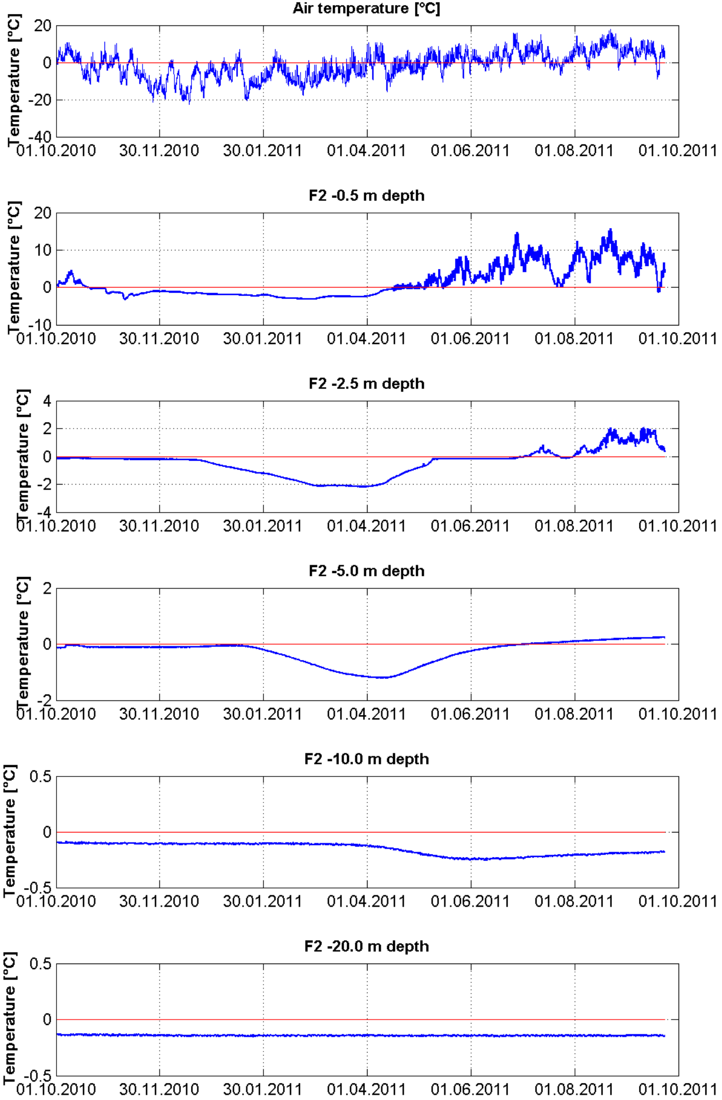

Figure 1. Temperature distribution in borehole F2

The temperatures are above the melting point at some depths, especially in borehole F3. This could also be identified during the drilling campaign, when liquid water was blown out with the cooled air. Borehole F1 contains permafrost until a depth of around 22 m. The permafrost base could not be reached at a depth of 25m in the other three boreholes.

The active layer depths were interpreted from the boreholes with the thermistors. The active layer in F1 is around 2 m and 6 m in F2 (Fig. 1). F1, F2 and F3 show clear signs of a winter cooling effect. Time lag up to a depth of 12 m can be seen in F2. Heat transport superimposes temperatures below zero in the active layer after the snow has disappeared in the spring. A corresponding effect cannot be found in borehole F4. Figure 1 shows the temperature distribution in Borehole F2 at different depths. The uppermost graph illustrates the measured air temperature at the meteorological station on the rock glacier.

The displacement measurements in borehole F5 are of major interest for the numerical simulation. As expected, the inclinometer broke as result of the large movements in this area. Nevertheless the results obtained over nine months show significant deformation rates with depth during the whole period.

Conclusion

Fieldwork 2011and outlook

Field data collected over approximately one year confirm the existence of permafrost in this rock glacier. This was a first important step to achieving a combined numerical model. Two new boreholes were planned and were drilled in August 2011 more or less on the same axis and below the others. Various types of pressuremeter tests were carried out to measure the in situ response to constant strain rate and constant stress creep tests. A thermistor chain as well as an inclinometer was installed in each borehole. The field characterisation and monitoring will be supplemented with geotechnical tests in the laboratory.

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Thermal Conductivity of Gas-Saturated Sediments during Gas Hydrate Formation at Negative and Positive Temperatures

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Introduction

The first evidence of anomalously low thermal conductivity in methane hydrate was obtained in 1979, and was supported and updated through later studies by different authors. Generally, thermal conductivities of pure monolith gas hydrates have been quite well documented today. According to experimental data, gas hydrates have their thermal conductivity (~0.6 W/m*K) about that of water (~0.6 W/m*K) and almost 4 times lower than in ice (~2.23 W/m*K) [*Groysman, 1985; Wright et al. 2005; Bukhanov et al. 2008*].

However, unlike pure gas hydrates, thermal conductivities of their sedimentary hosts remain quite poorly studied. The reason is that hydrate-bearing sediments have complex element and phase compositions and diverse macro- and microscopic structures.

Much attention has been given lately to gas-hydrate exploration in different areas of the subsurface, including permafrost, as well as to technologies for gas extraction from natural accumulations of gas hydrates. However, no solution is possible without minute investigation into physical (and thermal) properties of sediments. This knowledge is also important for development of classical deposits of natural gas in Arctic areas and in permafrost where producing formations lie close to the permafrost base and to zones of hydrate stability, and have rather low temperatures. The temperature of rocks near well bottoms may approach that of hydrate formation.

Therefore, the behavior of thermal conductivity in gas-saturated sediments where gas hydrates are forming at low positive and negative temperatures has important implications.

Method

The thermophysical studies were carried out using a specially designed test system which allows measuring thermal conductivities of wet gas-saturated fine-grained sediments in a pressure chamber during formation of gas hydrates in their pore space, at both positive and negative temperatures.

The system consists of a cooling box, which maintains the required temperature, a 200 cm^3 pressure chamber, a 300 cm^3 gas container, supply tubes, and a thermal conductivity meter mounted directly into the pressure chamber. The latter configuration allows measurements in pressurized gas-saturated samples. The instrument error is within 5%.

Thermal conductivities were measured in sediment samples of different grain-size compositions: fine quartz sand, silt-size loamy sand sampled from permafrost (Vorkuta region), and silt-size sand from the Laptev Sea shelf. The grain-size data are summarized in Table 1.

Methane was used as the hydrate-forming gas (99.98%).

The experimental procedure included the following steps: conditioning of samples with a given water content and charging them into the pressure chamber, sealing and vacuuming the pressure chamber with charged samples, filling the chamber with the hydrate-forming gas (CH_4), and creating conditions for hydrate formation in the pore space of sediments. Note that hydrate saturation of samples occurred at both positive and negative temperatures [*Chuvilin & Kozlova 2005; Chuvilin et al. 2011*].

Table 1. Particle sizes of tested sediment samples

Sediment	Particle size distribution, %		
	1-0.05 mm	0.05-0.001 m	<0.001 mm
fine sand	94.8	3.1	2.1
silt-size sand	89.4	10.6	---
loamy sand	41.8	53.7	4.5

Thermal conductivities of samples, as well as temperatures and pressures in the chamber, were recorded at each step. There were several cycles of hydrate saturation for each sediment type. In addition, the samples in the chamber were frozen and thawed both at ambient and high (up to 3-4 MPa) pressures, for comparison. The pressure was created by nitrogen (N_2) which did not form hydrates at the conditions of the experiment.

The parameters of phase transition in the soil samples were inferred from PT changes in the pressure chamber in the course of hydrate formation, using the PVT method. Namely, hydrate saturation (Sh), volumetric hydrate content (Hv), and hydrate coefficient (Kh, share of pore water transformed into hydrate) were derived from measured pressures and temperatures [*Chuvilin & Kozlova, 2005; Chuvilin et al. 2011*].

Results and Discussion

Thermal conductivities of the tested sediment samples (Fig. 1a) showed quite moderate changes during hydrate saturation at low positive temperatures (+1…2 °C).

A notable thermal conductivity increase was observed in gas-saturated samples at high Kh (more than 0.5). For example, in a fine sand sample (W = 16%) it grew from 1.80 W/m*K to 1.96 W/m*K, or almost 10%. This may be due to local re-distribution of water in pores during hydrate formation, which influences thermal interactions in the samples.

As for the thermal conductivity behavior at negative-temperature hydrate formation (Fig. 1 b), samples with higher hydrate saturation showed lower thermal conductivities.

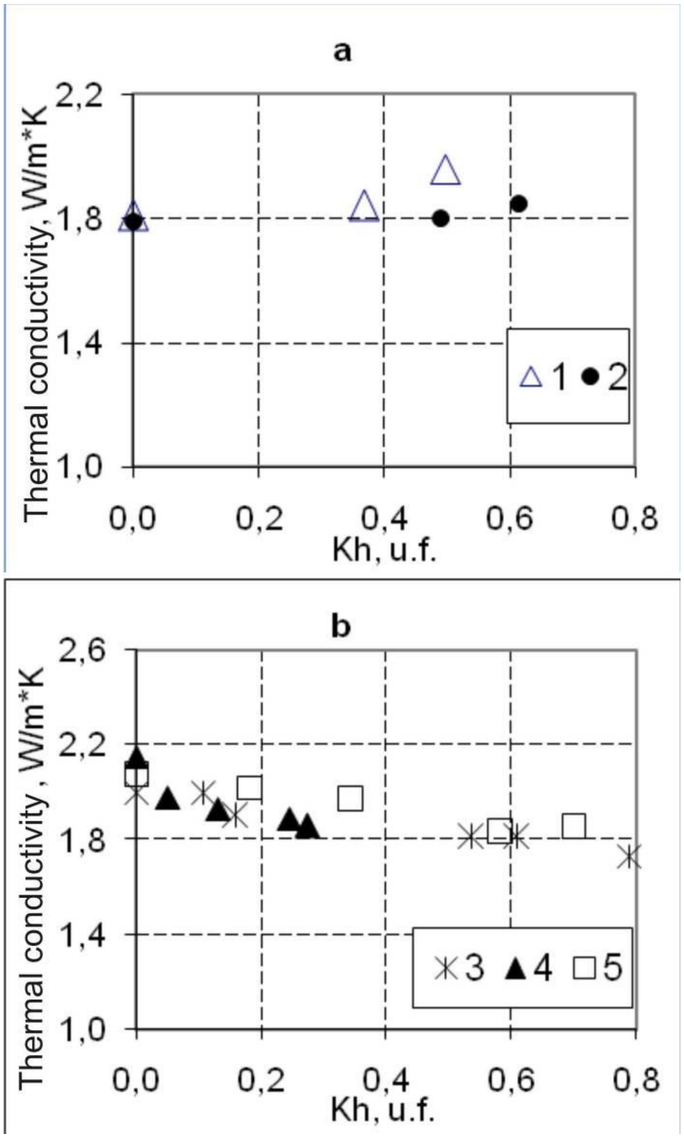

Fig. 1. Behavior of thermal conductivity during hydrate saturation at t = + 1…2 °C (a); t = -6…-4 °C (b).
1- fine sand, W=16%; 2 – loamy sand, W=16%; 3 – fine sand, W=22%; 4 – silt-size sand, W=15%; 5 – loamy sand, W=22%

For instance, the thermal conductivity of silt-size sand (W = 15%) decreased from 2.15 W/m*K to 1.89 W/m*K (for 12%) as Kh grew to 0.25. This tendency of thermal conductivity decrease in the course of hydrate saturation may be due to changes in the shares of pore ice and pore hydrate, specifically, to a greater share of the hydrate component which has a 4 times lower thermal conductivity.

Thus, as methane hydrate accumulates in the pore space of sediments, the latter change their thermal conductivity, in different ways depending on the phase state of the pore water. Thermal conductivities decrease at temperatures below 0°C, when pore water exists mostly in the form of ice and slightly increase with hydrate saturation at positive temperatures.

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Phytometers of Chemical Pollution of Ecosystems in Cryolithozone Regions of Western Siberia

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Today the problem of new efficient methods search for assessment of environmental pollution and the biota state at all levels of its organization is very acute. The ecosystem state analysis is required for provision of the environmental safety of regions with potential oil fields, pipeline construction and the areas of other associated engineering structures, where significant technogenic impact on the natural environment is formed. Permafrost zones arouse special concern. Here oil pollution can cause serious transformation of physical and chemical soil, water bodies and atmosphere conditions. This in turn can lead to plant cover degradation. The permafrost state is changed as a result. The use of the phytometering method allows to identify the species capable of growing on oil-polluted lands, serving as phytomeliorants that can be used for oil-polluted land reclamation. They can be also used for diagnostics of the soil biological activity and its pollution monitoring.

Hydrocarbon environmental pollution in the northern regions of Russia becomes a serious environmental problem due to the development of the trunk pipelines network. Permafrost zones arouse specific interest and concern. This is preconditioned by the peculiarities of the cryolithozone hydrocabon pollution. Oil pollution influences adversely not only cryolithozone soils and grounds, but also the plant cover. This impact is studied very poorly yet, and this is preconditioned by the complexity of its transformation in the biosphere and the variety of the ways of impact on plants. Consequently, the assessment of the current state of the plant cover in oil production and transportation regions, determination of vegetation responses with regard to impact doses (chronic or impulse) and forms, and determination of main indicators of the integral chemical pollution are the required tasks for solution to a number of ecological and economic-production tasks.

The peculiarities of the geographical location of oil fields in Western Siberia and the abundance of wide bogs preconditioned the unusual location of field facilities and the unusual labor organization for their servicing. The maximum environmental impact of technogenic factors is usually observed in industrial zones of oil gathering and delivery points concentration, where natural landscapes turn to be completely destructed. While pollution of natural ecosystems frequently occurs in linear structure zones, the species composition of plant communities is changed, transpiration falls and the surface runoff is slowed down as a result. This intensifies swamp formation processes, and the area albedo is changed. This leads to change of the permafrost state.

Since vegetation is an easily disturbed component of geosystems in case of external impact and it is capable of self-restoration, the dose, the power and the duration of this impact can be defined on the basis of its state. Nonetheless, the impact of oil fields on the plant cover remains understudied yet. This is preconditioned by the multi-component composition of toxicants, the complexity of their transformation in the biosphere and the variety of the ways of impact on plants. This is why the modern phytometering studies are mainly aimed at searching non-specific indicators of the total chemical impact on plants, both from the air and through the soil.

The work describes the analysis of the current state of plant complexes in the area of one of the largest fields in Western Siberia – Samotlor – with the purpose of detection of chemical pollution phytometers. The Samotlor oil field is located in the southern part of the middle taiga subzone. Fir-cedar forests with abies, sometimes cedar-fir, short grass-red bilberry-green moss forests are typical of it. They occupy relatively well-drained fields. The soils under them are podsolic, eluvial-gleyic on middle and light clayey silts or eluvial-gleyic non-podsolic long-seasonally frozen on heavy-clayey silt deposits. Nonetheless, forest vegetation ranks significantly behind non-zonal bog communities in area (field bogginess is approximately 90%); the area covered with lakes makes up 12%. With regard to this peculiarity, the analysis of the species variety and the vegetation classification were carried out with the Brown-Blanke method, independently for forest and bog communities. Special attention was paid to the list of underbrush species, the grass-bush and the moss layers, taking into account the irregular sensitivity to pollution and its transformation speed for different ecological and life forms of plants.

Multiple oil spillages are observed within the field, mainly along pipelines. Most frequently they are restricted by sites stripped of forest, but oil is accumulated in great quantities in linear depressions together with surface waters or intrudes into adjoining bog or forest plant communities. The response of plants and plant communities depends on habitats and on a pollutant. The following vegetation response trends can be identified within the Samotlor field for all types of chemical pollution. 1. Almost all vegetation dies in case of surface oil spillage. First plants growing on toxic soils, depending on the moisture content, include: reed (in places oversaturated with water), marsh sedge, moss crop, mace reed, rush, persicaria, water plantain, woodreed and meadow foxtail. The domination of these species in plant communities currently testifies to the fact that vegetation restoration occurs very slowly. 2. Alteration of the anatomic-morphologic parameters of plants occurring in the form of needle necrosis and chlorosis can be considered the external evidence for the oil and its decomposition products' impact on plants. These phenomena are most evident on pine in bogs and on pine undergrowth in well-drained habitats. In general, 50% of needles are exposed to necrosis and chlorosis, and this is developed everywhere. 3. Woody plants are the first ones to suffer from oil spillage. They die immediately at the spillage center. The analysis of the undergrowth linear increment showed that its significant reduction is observed, as compared with the maximum possible for this area. For example, the increment values were noted for the most widely developed coniferous species: cedar – 2-3 cm (with the background value of 10 cm), fir tree – 3-5 cm (with the background value of 12 cm), abies – 4-5 cm, and pine – 6-7 cm.

Therefore, needle chlorosis and necrosis are easily observed total pollution indicators, while the reduction of the increment of all coniferous species undergrowth, especially of cedar (the main forest-forming species) is an easily observed chronic pollution indicator. The results received allow to predict the development of the field vegetation in the future. It is safe to say that reduction of the increment of the main forest-forming species undergrowth will continue even in case of complete removal of the chemical load. Moreover, forest restoration will get worse, because toxic substances accumulated in the soil.

Plant restoration processes within toxic habitats are rather problematic because chemical impact is supplemented by a physical one (underflooding and flooding) and in some cases by mechanical destruction near the sites, on the sites, along the power transmission line, and along pipelines. The identified species – the first plants that are capable of growing on toxic soils – can serve as phytomeliorants. They can be used for reclamation of oil-polluted soils.

Uncertainties in the Global Mean Temperature Change Caused by Permafrost Degradation and Carbon Release

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Introduction

Permafrost soils contain ~1672 Pg of organic carbon [*Tarnocai et al., 2009*], much of which is relatively inert and not currently included within the global carbon cycle. Under increased temperatures permafrost degrades and a proportion of this old permafrost carbon becomes more vulnerable to decomposition and subsequent release into the climate system. Like fossil fuel burning this is an irreversible process which will cause a further increase in greenhouse gases in the atmosphere and hence have a positive carbon climate feedback [*Schuur et al., 2008*]. This paper estimates global temperature change caused by permafrost carbon release (P-GMT) that might be calculated by the Hadley Centre Climate model if permafrost carbon release were included [*Burke et al., 2012*].

Approach

Simple framework for calculating P-GMT

A highly simplistic large-scale model for the release of permafrost carbon to the atmosphere is proposed here.

1. Physical changes in the near-surface permafrost were quantified using Hadley Centre Climate model (HadGEM2-ES) AR5 simulations [*Jones et al., 2011*] for a range of representative CO_2 pathways (RCP).

2. These physical changes were combined with knowledge of the distribution of Arctic soil carbon [*Tarnocai et al., 2009*] to assess the amount of carbon in the thawed permafrost made vulnerable to decomposition.

3. The vulnerable carbon was assigned to three pools: a passive pool which is not released over the timescale of this study; an active pool which decomposes almost immediately the permafrost thaws; and a slow pool which decomposes slowly over time.

4. The amount and form of slow carbon released to the atmosphere was estimated given representative CO_2 and CH_4 decomposition rates; CH_4 oxidation rates; CH_4 transport pathways; and knowledge of the Arctic land cover.

5. The impact of the released CO_2 and CH_4 on the global temperature was quantified using a simple climate energy balance model tuned to replicate the behavior of HadGEM2-ES.

Uncertainties

There are large uncertainties in the future RCP pathway, the decomposition model parameters, and the distribution and amount of soil organic carbon (SOC). Therefore, for each RCP pathway, 4000 Monte Carlo simulations of P-GMT were estimated with the parameters sampled from the range of values shown in Table 1 and the SOC sampled from uncertainties estimated from Tarnocai et al. [*2009*]. This gives the plausible spread in P-GMT.

Table 1. Spread of parameter values for the large scale permafrost carbon decomposition model.

Parameter	Min.	Max.
Slow pool (% total SOC)	10	60
Fast pool (% total SOC)	0	5
Aerobic decomp. (mg C g C^{-1} day^{-1})	0.03	0.5
Anaerobic decomp. CO_2 (μg C g C^{-1} day^{-1})	5	70
Anaerobic decomp. CH_4 (μg C g C^{-1} day^{-1})	0.1	15
Lowland proportion respired aerobic	0.0	0.3
Upland proportion respired aerobic	0.7	1.0
Proportion methane oxidized wetlands	0.1	0.7
Proportion methane oxidized lakes	0.0	0.3
Proportion methane oxidized mesic	0.5	1.0
SOC in 1-2 m as fraction of 0-1 m	0.5	0.9
SOC in 2-3 m as fraction of 1-2 m	0.4	0.8

Results

Simulation of P-GMT

HadGEM2-ES simulates a loss of near-surface permafrost of between 25 % and 65 % and an increase in the active layer of between 24 and 59 cm, depending on the RCP pathway. This causes an increase in carbon vulnerable to decomposition from a few Pg up to 870 Pg. This wide range of values reflects the large uncertainty in our knowledge of the distribution of SOC.

The proportion of this vulnerable carbon added to the carbon cycle each year mainly depends on the decomposition of the slow carbon pool. At the beginning of the 21st century the slow pool is small and the majority of emitted carbon is from the active pool. As the slow pool grows in size the amount of emitted carbon increases rapidly. By 2100 CO_2 emission rates are between 0.02 and 4 Pg C yr^{-1} (5th – 95th percentile range) depending on RCP scenario. Maximum CH_4 emission rates are around 60 Tg CH_4 yr^{-1}. Although this represents a relatively small amount of carbon, CH_4 is a much more effective greenhouse gas than CO_2 and by 2100 a quarter of P-GMT is caused by CH_4.

The large uncertainties in the input data result in large uncertainties in P-GMT which varies between 0.01 and 0.3 °C by 2100 (5th to 95th percentile), although values up to 0.6 °C cannot be ruled out. Overall P-GMT is about 2 – 4 % of the temperature increase simulated by HadGEM2-ES without permafrost carbon release.

Uncertainty assessment

The Monte-Carlo simulations were used to determine the relative importance of the different processes/parameters on the value of P-GMT. Any differences between the RCP scenarios near the beginning of the 21st century are small. However, by 2060 they begin to dominate the uncertainties. Since the future CO_2 pathway is hard to determine, and depends on many unpredictable factors, this uncertainty is difficult to reduce.

Figure 1 shows how the relative uncertainty caused by: (1) the distribution of the soil organic carbon; (2) the quality of the carbon; (3) and the decomposition model parameters, impacts the spread in P-GMT over time. These uncertainties can be reduced through further observational-based analyses.

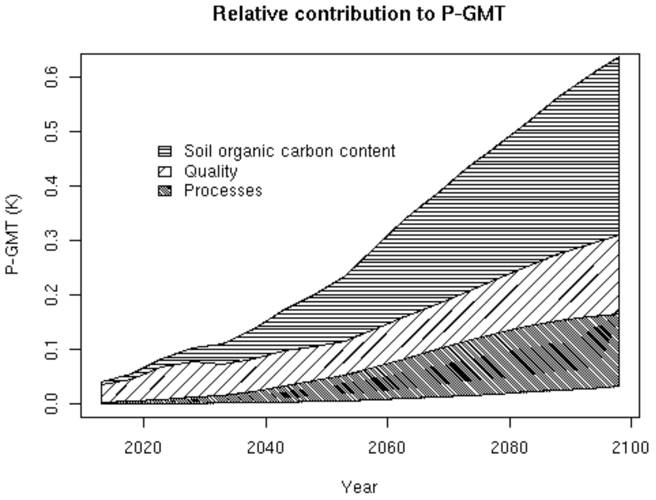

Figure 1. The sensitivity of the spread in P-GMT to the permafrost processes for the high CO_2 concentration pathway. The proportion of the spread in P-GMT attributable to each process is defined by the difference between the characteristics of the whole ensemble and those of sub-ensembles with the parameter ranges limited.

At the beginning of the 21st century, when the temperature change is smallest, knowing the quality of the available carbon is most important and contributes to over 80 % of the spread in P-GMT. The spread in P-GMT caused by uncertainties in the quality of the available carbon change little over time. However its contribution to the total spread decreases over time. As the amount of soil carbon builds up in the slow pool the importance of knowing the soil organic carbon content and the parameterization of the decomposition model increases. By the end of the 21st century about half the spread in P-GMT is caused by uncertainties in the soil carbon distribution, a quarter caused by the quality of the soil, and a quarter by the parameterization of the soil decomposition model.

Conclusions

If permafrost carbon release were included within HadGEM2-ES, there would be an additional increase in temperature of between 0.05 and 0.6 °C by the end of the 21st century for the high CO_2 concentration pathway. The proportion of this temperature increase caused by the release of methane is ~0.25.

By the end of the 21st century, of the permafrost related processes considered, the distribution of soil organic carbon contributes to about half of the spread in P-GMT with the soil decomposition model and the quality of the organic carbon contributing a quarter each. A reduction of these uncertainties though improved observational-based analysis will improve our estimates of P-GMT. Additional uncertainties caused by biases in the simulation of the active layer thickness have not been considered here but are likely to have some impact on P-GMT.

There are many other processes such as thermokarst development; fire; the formation of ice wedges within the permafrost; cryoturbation; the presence of peat soils; and self-sustaining heat generation by microbial activity, which could additionally be included to refine estimates of P-GMT. Again future observations will help determine which of these processes are potentially significant and need to be included within a modeling framework.

This simple model of permafrost carbon release can be used as a tool to develop an understanding of the impact of permafrost carbon on the global climate system and help develop an appropriate representation of the permafrost climate feedback within a global circulation model.

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Geophysical Surveys in Permafrost

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Abstract

The optimal methods of exploring the permafrost zone are induction and seismic surveys. The reported study is an experience of combining the two survey methods.

Keywords: Frozen soil; geophysical surveys; permafrost; permafrost section; seismic exploration.

Problems of data acquisition in permafrost

Anomalous physical properties of frozen ground

Permafrost has always posed problems to geophysical surveys though frozen ground has prominent anomalous physical properties. Although it may appear paradoxical, it is the anomalous behavior of permafrost relative to unfrozen ground that causes ambiguity in geophysical models. Contrasts in geophysical parameters would be expected to make the surveys especially efficient but, on the other hand, the changeability of permafrost states and its high lithological diversity, along with hard acquisition conditions almost cancel the advantages and make it difficult to relate interfaces to specific geological causes.

Methods of electromagnetic induction soundings

According to the available experience, the problems of geophysical surveys in permafrost are generally resolvable, but special approaches to technologies and methods of data acquisition and processing may be required.

Resistivity and seismic measurements in winter seasons in frozen ground have their specificity. In seismic exploration this is, namely, the presence of a high-velocity zone in the upper section which screens seismic waves off the layers below. The classical resistivity surveys may face serious problems with earthing the transmitter and receiver electrodes, and it is better to collect data by unearthed lines. Linear measurements may imply studying a certain strip of land along the profile (100-150 m wide), which allows some freedom in choosing the line position depending on engineering-geological and geodetic settings. In view of large lengths of profiles, additional array surveys have to be very high-performance and cheap.

The necessity of integrating several methods is associated with non-uniqueness in the correlation of geophysical parameters with the permafrost state. The non-uniqueness of resistivity data may be due to the fact that soils of different states (e.g., frozen loam and unfrozen loamy sand) may have similar resistivities. In seismic exploration, high-velocity reflections may be produced either by dense rocks or by permafrost. In this respect, joint processing of data from different methods increases the reliability of geophysical models. To sum up, joint processing of induction resistivity and seismic data appears to be a promising way of geophysical profiling in permafrost. Electromagnetic induction measurements without earthing are of a very high performance and are highly sensitive to the state of frozen ground. Furthermore, there exist modern technologies of both surface and remote electromagnetic scanning (GPR or ground penetrating radar). The powerful GPR technologies (8–10 km/hr on the surface and 120 km/hr from air) allow scanning permafrost to a depth of 150–180 m at every 0.2–0.5 m and 10–15 m, respectively. Seismic exploration integrated with electromagnetic scanning has to be applied at local sites in order to specify the cryogenic conditions of soils, check and correct electromagnetic data, study the dynamic properties of soils, and to make the inferred predictions more reliable.

GPR electromagnetic surveys

Aerial surveys were performed as continuous scanning on the basis of time-domain GPR measurements. The method was chosen for its high performance and cheap costs (compared to the surface analogs), and for high spatial and depth resolution with respect to resistivity.

The technology was first applied in West Siberia by *Sibgeotech* Ltd. in 2006 at the prospected oil pipeline Khar'yaga – Indiga in the Yamal-Nenetsk Autonomous Area. In 2007, similar work was undertaken at some Olympic objects in Krasnaya Polyana (Sochi).

The possibility of using the GPR techniques arose due to research and development studies at the Siberian Research Institute of Geology, Geophysics, and Mineral Resources (SNIIGGIMS, Novosibirsk) and *Sibgeotech* Ltd. This line of research extends the helicopter surveys broadly used in western countries. The helicopter platforms have better technical characteristics than the aircraft systems due to novel technological solutions for special carrying structures, a powerful electromagnetic channel, and a closer position of sensors to the object of study.

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The Study of Thermoerosional Processes and Ravine Formation in Natural-Technical Systems of Gas Fields in the Cryolithozone

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Keywords: hydrophysical and geophysical factors of technogenic ravine formation; natural-technical system; thermal erosion.

The intensive industrial development of the cryolithozone area in the process of hydrocarbon field development and operation, together with the increase in climatic characteristics fluctuations in the Subarctic, led to the activation and the development of hazardous geocryological processes in natural-technical systems. Thermoerosional processes are the leading slope processes of destructive technogenesis in natural-technical systems. The development of technogenic ravine formation integrates the results of interaction of slope geocryological processes: thermal erosion, thermokarst, solifluction, landslides and falls of ground etc. The necessity to develop methods for geotechnical monitoring of slope processes in the cryolithozone is an acute problem in the aspect of a complex system of monitoring, control, hazard evaluation and forecast of thermoerosional and ravine formation processes, with the purpose of control of the state of natural-technical systems.

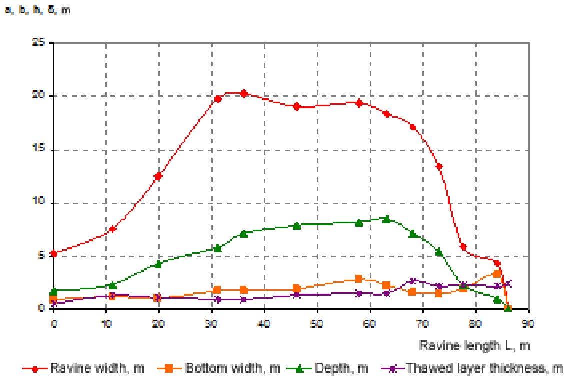
Stationary studies of the dynamics and the regularities of thermoerosional processes and ravine formation development in natural conditions were conducted in 2008-2011 in the process of execution of the project documentation "Liquidation of ravine formation in the area of gas processing facility UKPG-1V at the Yamburg oil and gas condensate field", and during subsequent monitoring of design facilities. Seven ravine systems located in the area of gas field GP-1V of the Yamburg oil and gas condensate field are the objects of the research into thermoerosional processes and ravine formation.

Monitoring methods and methodologies

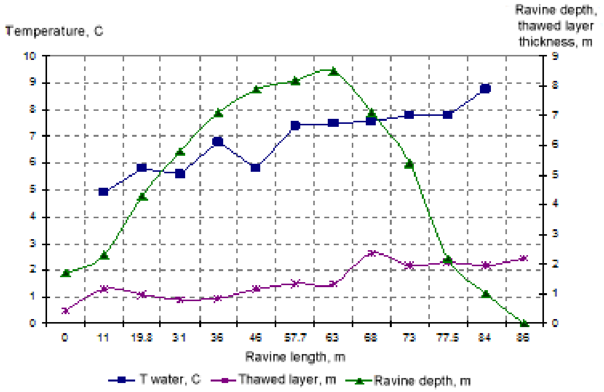
1. Measurements of morphometric parameters of ravine systems and the watercourse temperature.

Monitoring time period: the linear measurements of ravine systems are conducted in the 1st-2nd ten days of July (those changes are registered that occurred in the ravine during the spring snow melting period) and in the 3rd ten days of August - 1st ten days of September according to the method of water section line division [*Lobastova 1990*]. The large-scale topographic survey was used for results comparison. Reference points were chosen with an interval the value of which depends on the dimensions of ravine formation. The following was measured for the identified ravine cross-sections: length along the valley bottom, width, bottom width and the depth of the ravine; the thickness of the seasonally thawed layer; watercourse temperature; the position of the washout and thaw fronts; the areas and the dimensions of fracture formation were registered along the edges and near-top zones.

The field measurement results are given in the database in the numeric and the graphical forms (Fig. 1).



a) morphometric parameters;



b) watercourse temperature.

Figure 1. Field measurements: Ravine No. 1 of KGS 117V

The quantitative characteristics of thermoerosional processes and ravine formation received on the basis of measurement results include volume of the disturbed ground $V=V(a,b,h,L)$ and its annual increment coefficient $K=K(V,T)$, intensity of bottom washout $J_h=J_h\ (h, L, T)$ and of side washout $J_a= J_a\ (a, L, T)$. [Lobastova 1990]. *Hydrothermal monitoring at the natural objects of thermoerosional processes and ravine formation* was conducted for the first time in August 2011 with the purpose of identification of the watercourse heat and mechanical energy input into thermoerosional processes during the period of liquid precipitation fallout. The watercourse temperature was measured in the bed of ravine systems with simultaneous registration of the thickness of the thawed interlayer δ. Thawing intensity $J_\delta = J_\delta\ (\delta, L, T)$ is the estimated quantitative characteristic.

2. Snow-metering observations and the methodology of determination of runoff hydrophysical parameters.

Snow-metering observations for thermoerosional processes and ravine formation in natural-technical systems were conducted for the first time in April 2009. Height h and density of the snow cover ρ are measured in the 1st ten days of November and the 3rd ten days of April in accordance with the developed methodology: in the natural area of the catchment basin, in the catchment basin area occupied by the technosphere, and in the ravine system.

The snow cover distribution in the ravine system body with different types of snow accumulation is represented in the numerical and the graphical forms. Water reserve in the snow S (cm), water runoff layer H (cm) and water runoff volume W (m^3) are estimated on the basis of the average values of snow height and density.

Water discharge during the snow melting period in the ravine $Q=Q(W, V_{сн}, t)$ *is the main quantitative hydrophysical characteristic in the thermoerosional processes and ravine formation dynamics*.

Runoff layer H is defined according to the empirical Formula calculated by means of natural observations in Central Yamal *[Baranov 1999]*.

Runoff volume W (cm^3) from the catchment basin area:

$$W = (F_{np} \cdot H_{np}) + (F_{mex} \cdot H_{mex}) \,, \qquad (1)$$

where F_{nat}, F_{tech} – natural area of the catchment basin and the technosphere area, m^2.

The water volume in the ravine is estimated in the following way:

$$V_{в} = \frac{\rho_{сн}}{\rho_{в}} . V_{сн} \qquad (2)$$

V_w - snow volume in the ravine, cm^3, ρ_{sn} – snow density in the ravine, ρ_w - water density, g/cm^3.

The averaged water discharge for the snow melting period is calculated according to Formula (4):

$$\overline{Q} = \frac{W + V_{в}}{\bar{t}} \qquad (3)$$

where W - the runoff volume from the catchment basin area, cm^3, t - the mean statistical period of snow melting, also including the time of snow melting in the ravine.

The main hydrophysical characteristics are estimated for the natural site of the catchment basin, the technosphere and the ravine as such. Altogether, this allows us to evaluate the input of the corresponding watercourses into the dynamics of thermoerosional processes and of ravine formation.

3. *Research results*

The thermoerosion and ravine formation model with regard to the annual cyclicity of hydrophysical and geophysical factors is developed on the basis of multi-year studies. The following periods are identified within the annual cycle on the basis of hydrophysical and hydrological parameters of slope processes: *I. The zone of formation of factors of thermoerosional processes and ravine formation and II. The zone of development of thermoerosional processes and ravine formation.* The process intensity is defined by the factors of thermoerosional hazard that are formed during the fall and the winter periods of the annual cycle. The activation of thermoerosional processes and of ravine formation in natural-technical systems occurs in spring, summer and fall during 42% of the total year time in the research area.

The input of thermoerosional processes into ravine formation is defined by the mechanism of watercourse concentration in the ravine valley bottom. The water reserve in the snow and the runoff volume at the elements of the catchment basin area form the main watercourse source during the snow melting period (Fig. 2).

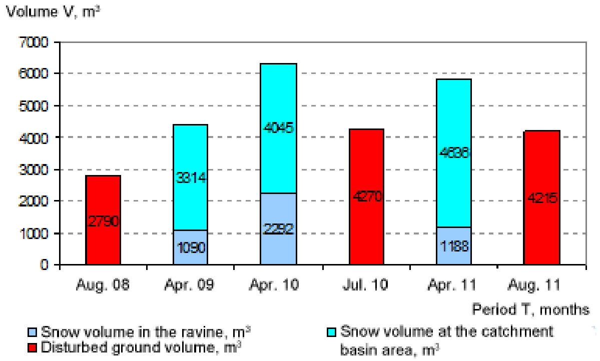


Figure 2. Dynamics of the volume of erosional disturbances and the snow accumulation volume for ravine No. 1 of KGS 117V.

The calculations of hydrophysical parameters on the basis of the snow-metering observations data (the case of seven objects of thermoerosional processes and of ravine formation) showed the significant excess of the height of the snow cover in the ravine, as compared to the catchment basin area, $h_{rav} > h_w$. The excessive height of the snow cover is formed $-\Delta h_{add} = h_{rav} - h_w$. This provides for the additional water reserve in the ravine body ΔS_{add} and increases the snow melting period by time Δt_{add}.. In this case the additional runoff layer goes along the ravine valley bottom the area of which is by tens of times smaller than the ravine area along the edge. For ravine systems at the active development stage, the input of hydrophysical parameters of the ravine as such into the thermoerosional processes by 100-150 times exceeds the input of the watercourse from the catchment basin area.

The period of the main snow melting for the catchment basin is about 26 days. This includes the period of snow melting in the ravine after snow melting is complete at the catchment basin. The average period of *additional snow melting* Δt_{add} can make up 20-30% of the main one. The specific water reserve in Δt_{add} will by 50 times exceed the specific reserve from the catchment basin in relation to the ravine valley bottom area.

The zones of runoff concentration are formed in the ravine system as a result of irregular accumulation of the snow cover in the ravine body. These zones are characterized by a significant seasonally thawed layer thickness and high temperatures of base grounds. These are the zones providing for the increment of the ravine system in summer.

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Frost Heaves

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Introduction

Perennial frost heaves located on the 5th Salekhard plain, in the Nadym-Pur interfluve (40 km to the west of Novy Urengoy) were investigated in July, 2009.A frost heave is a convex form of a cryogenic terrain with an ice or an ice-ground core which forms in seasonally frozen and perennial frozen ground areas due to irregular ice formation in the grounds [*General Geocryology 1978*]. There are three heave groups with different ice formation type, namely, the segregation, the intrusion and the intrusion and segregation group [*Popov, Rozenbaum, Tumel 1985*]. The heaves are up to several tens of meters high, their foundation diameters being up to several hundreds of meters large. As to lifetime, there are seasonal and perennial frost heaves. Seasonal frost heaves are usually located in southern and relatively continental permafrost areas where deep seasonal thawing conditions are present. Ice accumulations in such heaves are often constituted by frozen water of the seasonally thawed layer which is pressed between the freezing grounds and the permafrost table [*General Geocryology 1978*]. Seasonal frost heaves are not large. In spring, they either settle or explode which is accompanied by flow of the intrusive water onto the surface. Nevertheless, their lifetime can sometimes reach a few years. Perennial frost heaves are rather widespread in the Arctic regions that are notable for their severe permafrost and climatic conditions. These large terrain forms dominate over flat plains being good reference points. They may be up to 90 m high, their foundation diameters reaching up to 300 m. Formation of perennial frost heaves is to a great extent associated with intrusive ice formation. There are, however, frost heaves of segregated and intrusive-segregated origin. Intrusive and/or intrusive-segregated frost heaves are often confined to terrain depressions which are partially filled with water (e.g. alases).

Research Methodology

The field study included route descriptions of the depression and ridge terrain genetically associated with ground ice thawing-out (thermokarst), morphometric measurements of the frost heaves, cleanup of the outcrops, ice and soil sampling for laboratory investigations, measurements of the seasonally thawed layer's depths depending on the microlandscape conditions on the surfaces of the heaves.

Results and Discussion

Within the area studied (the 5th Salekhard marine terrace), there are perennial frost heaves of the intrusive-segregated origin. The deposits of the terrace were formed during the cold sea transgression period in the end of the Middle Pleistocene and transformed later (subaerial conditions, erosion and cryogenic processes) [*Popov, Rozenbaum, Tumel 1985*]. The modern appearance of the terrace was especially influenced by the cold Sartan time and the Holocene optimum warming (5-7 thousand years ago).

Formation of the large frost heaves is associated with the cooling which has been taking place during the last six thousand years after the Holocene optimum and, locally, with discharge of the large thermokarst lakes. It should be also noted that the 5th Salekhard marine terrace has the highest elevation levels within the area studied (the absolute elevations are 70-90 m).

A frost heave located 40 km to the west of Lake Nashe-to is rather typical, see Figure 1. It is situated in the middle of a vast alas being slightly displaced to the south. The surface of the alas is bogged and covered with lakes. The lakes located on the alas are up to 100-200 m large, have irregular shape and low coasts. In this region, we have found 13 frost heaves on an area of 60 km^2. We have named the heave studied Vershinin-pingo. It stretches from the north-east to the south-west being 7.2 m high.

Figure 1. A frost heave within the 5th Salekhard marine terrace near Novy Urengoy

Intensive fissuring and active slope and other cryogenic processes may indicate that the heave keeps on growing. Intensive solifluction and formation of spot medallions on the solifluction terraces were noted. An irregular ground heave which occurs during freezing of the seasonally thawed layer causes formation of straightly stretching furrows and dikes. An active grading of the ground material is taking place. The surface of the spot medallions is covered with gravel and pebble. Individual small boulders are also present. The fragmentary material is well rounded. It is of the glacial-marine origin. The large (up to 2.5 m) ground spots in the top of the frost heave resemble sandy-clayey bulges. Apparently, aeolian processes are of significance for them as well (in addition to cryogenic and erosion processes). The surface of the heave is hummocky and has a lot of solifluction mudflows and peaty knolls associated with an irregular heave of the seasonally thawed layer's grounds. A significant variation in the surface heat transfer conditions has caused a significant variation in the seasonal ground thawing depth: 36 cm, 39 cm, 82 cm on the knolls, 27 cm, 29 cm, 40 cm between the knolls, 115 cm, 104 cm and 120 cm on the ground spots (July 15, 2009). Different drainage conditions and variations in snow accumulation have caused variations in the vegetative cover: the depressions around the heave are occupied by sedge-moss communities, the lower part of the heave is occupied by dwarf birch thickets, and the top of the hill is occupied by shrub-moss communities and sparse larch trees.

Relatively small (up to 2.2 m - 2.5 m high, with a diameter of up to 7 m - 10 m) growing segregated-intrusive frost heaves surrounded by bogged and flooded moss and sedge tundra areas were also found at the site and described. Drilling of one of these heaves performed under the supervision of A.V. Boytsov, an associate professor at Tyumen State Oil and Gas University, demonstrated that the upper 2.5 m thick layer consists of ice-rich peat with varying decomposition degree, whereas inclusions of mineral substrate in the peat appear at a depth of at least 2 m – 2.2 m. Large areas with hummocky microtopography or heaved peatlands which snow is blown away from in winter are rather typical for the territory within the alas regions. Evidently, some of these formations are kind of "cold areas" and able to cause development of perennial segregation frost heaves.

Conclusions

Perennial frost heaves are a common type of cryogenic terrain in the relatively southern areas of the cryolithozone of the north of West Siberia: in the Tazov Peninsula, the Nadym-Pur interfluve and so on. The field observations have revealed that the frost heaves located within the bogged alas areas at the place of drained-off thermokarst lakes are growing despite the regional climate warming trends.

Acknowledgments

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"Russia - United States Thermal State of Permafrost": Permafrost Monitoring Internet Data Portal

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Introduction

Due to the high sensitivity of permafrost to changes in climate, long-term monitoring of its thermal state has become important over the last few decades. A network of the permafrost observations can serve as a fundamental informational base both for the Arctic ecosystem evolution scenarios and engineering purposes.

One of the keys to any kind of large monitoring system is data storage and distribution to a broader community [*Pavlov, 2008*]. One of the most convenient ways of providing data access is through internet data portals.

This abstract describes an internet data portal established for the NSF funded project "Russian – USA Thermal State of Permafrost" (TSP).

Thermal State of Permafrost project

The "Russian - United States Thermal State of Permafrost" was initiated in 2007 as a part of the International Permafrost Association IPY project #50 "Thermal State of Permafrost" [*Brown et al., 2010*] in order to develop a better understanding of the response of permafrost to climate changes in the Alaska and Northern Eurasia. The project is aimed at establishing a network of boreholes, instrumented for permafrost temperature observations. Currently the network consists of over 860 boreholes [*Brown et al., 2010*], including 60 points of observation in Alaska and 160 points of observation in Russia [*Romanovsky et al., 2010a, b*].

TSP website structure

The TSP internet data portal is located on the website of the Permafrost Laboratory, Geophysical Institute, University of Alaska Fairbanks (http://permafrost.gi.alaska.edu). The website is running on Drupal, an open source content management system, and a MySQL database is used as a backend to store the content used to create the webpages.

The website provides two ways of navigation: an interactive map and a list of observation stations. The interactive map uses Google's map as a base and has four base layer options (Satellite, Hybrid, Normal, and Physical). In addition other data layers such as permafrost extent, ground ice content, or Kenji Yoshikawa's borehole sites can be enabled for Alaska. From the map or list view there is also an option to download the sites as a KML file for viewing in Google Earth on local computers. The main structural unit of the portal is an individual webpage for each observation point (Figure 1).

Webpage layout

The webpage contains three types of data: textual (metadata, site description, etc.); graphic (maps, images of research sites, plots with data); and numerical (tables with results of observations). All of the information is organized in the following sections:

Site webpage sections:

Site Name; Site Code (The 3 character code for the site); BoreholeID (Unique code assigned to the borehole for the TSP project); Borehole Depth (in meters); and Borehole Class (Classified as surface (SU) <10 m, shallow (SH) 10-25 m, intermediate (IB) 25-125 m, and deep (DB) >125 m according to the Global Terrestrial Network for Permafrost (GTN-P) classification).

The Description section contains a brief description of the natural conditions at observation site (landscape type, vegetation, etc.) and information about the organization and researcher conducting the observations at the site, including contact information.

The Site Location shows a zoom-able map, geographic coordinates and observation point elevation.

The Measurements section lists the measurements being taken at the site.

The Data section contains links to observation data files stored at the CADIS portal and at the CALM web site (for selected points of observations) as well as to data files stored on our own server.

The Other Resources section provides information about ongoing research projects that are being carried out at the site and links to the corresponding web resources if available.

The Images section has pictures of the observation site and some plots of the observed data.

Real-Time Data

In addition to providing archived data as mentioned above we are also starting to provide near real-time data for some of our sites. Due to the remote nature and large area covered by our sites acquiring real-time data requires a variety of technologies. For the most remote sites we are using Iridium satellite transceivers to collect the data once per week. In areas where cellular telephone coverage is available we are using cellphone modems to collect the data once per day. Additionally, we are also taking advantage of existing radio communications networks to collect data where we can. The data is all collected using Loggernet software from Campbell Scientific Inc. and stored on a local computer. Recently we have started to use a software package, Vista Data Vision, to archive and provide web access to this real-time data (http://permafrost.gi.alaska.edu/VDV). We hope to also populate this software package with historical data to provide an interface for exploring the existing datasets.

Conclusions

The presented system provides a brief but informative look at the permafrost temperature monitoring in Alaska and Northern Eurasia. It has a user-friendly interface and provides easy access to the measurement data and reflects interaction with other permafrost related research projects.

Acknowledgments

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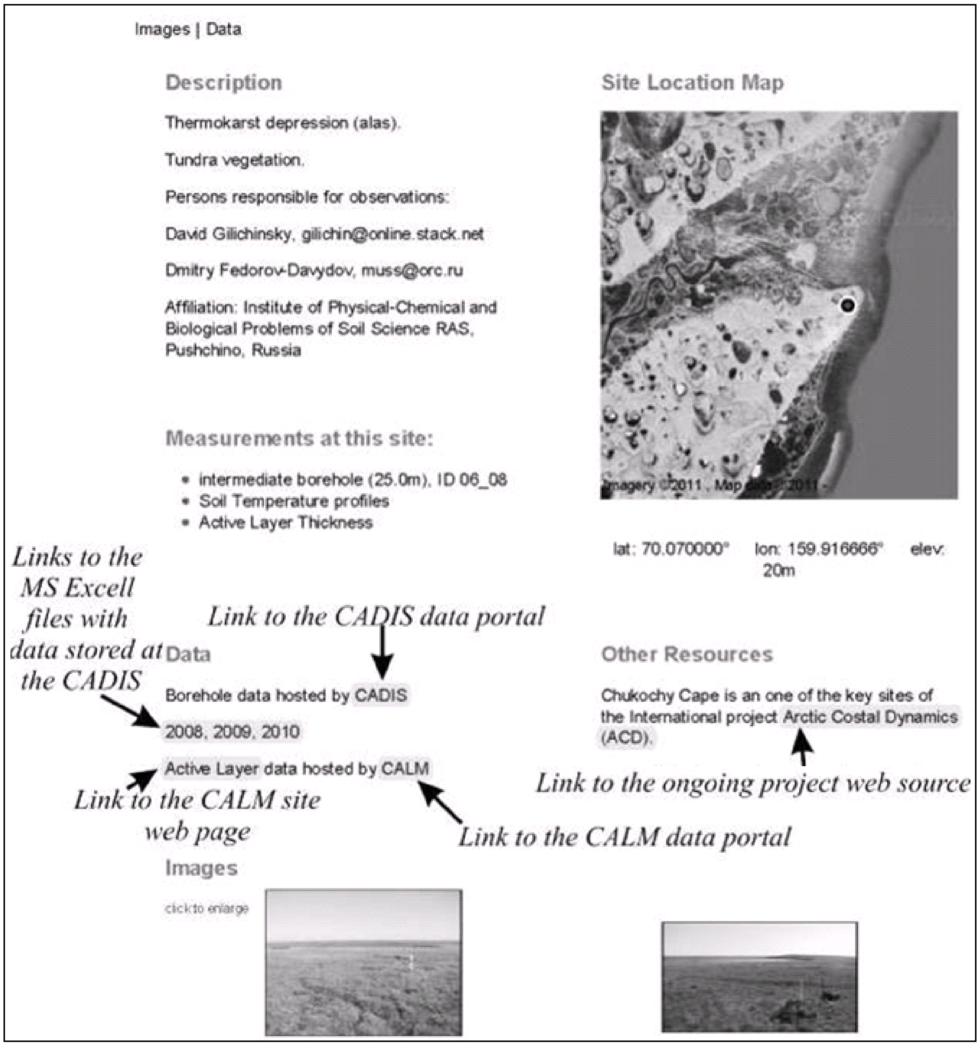

Images | Data

Description

Thermokarst depression (alas).

Tundra vegetation.

Persons responsible for observations:

David Gilichinsky, gilichin@online.stack.net

Dmitry Fedorov-Davydov, muss@orc.ru

Affiliation: Institute of Physical-Chemical and Biological Problems of Soil Science RAS, Pushchino, Russia

Measurements at this site:

- intermediate borehole (25.0m), ID 06_08
- Soil Temperature profiles
- Active Layer Thickness

Site Location Map

lat: 70.070000° lon: 159.916666° elev: 20m

Data

Borehole data hosted by CADIS

2008, 2009, 2010

Active Layer data hosted by CALM

Other Resources

Chukochy Cape is an one of the key sites of the International project Arctic Costal Dynamics (ACD).

Images

click to enlarge

Links to the MS Excell files with data stored at the CADIS

Link to the CADIS data portal

Link to the CALM site web page

Link to the CALM data portal

Link to the ongoing project web source

Figure 1. Layout of an individual observation site webpage

The Methods of Selection of the Best Location for Oil Pipeline Route on the Terrain Based on the Use of Engineering-Geocryological Cost Maps (The Case of the Above-ground Vankor-Purpe Oil Pipeline Section)

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Introduction

Numerous accidents on oil pipelines in the cryolithozone are caused by insufficient consideration of permafrost-geological conditions of pipeline routes at the design stage, by missing assessment of reliability of design solutions and by the absence of forecasting methods for potential hazards and cost of risk. This work describes the approach to assessment and optimization of reliability of geotechnical system "oil pipeline - environment", which will result in an increase in its quality on the basis of developed methods of analyzing permafrost-geological conditions when designing oil pipelines with the use of reliability theory provisions.

Probability-statistical calculations are aimed at forecasting, evaluation and control of geotechnical system reliability. The calculations employ analytical method of reliability assessment. Reliability of oil pipeline system to a large extent depends on the method of pipe laying. The work describes the methodology of selecting the best pipeline route arrangement on the terrain and pipeline laying method, using engineering-geocryological cost maps.

Terminology

Geotechnical system means an engineering structure and geological environment interacting with it. The reliability of oil pipeline system is understood as the system capability to withstand all external impacts (natural and climatic, anthropogenic, thermal and mechanical) within the specified period with normal operation (serviceability) of the system. It is evaluated by the system no-failure (no-accident) probability within the specified service life. Breakdown hazard is also a random value that is measured by complementation to a unit of reliability. Mathematically expected costs for liquidation of an accident and ecological consequences associated with it is called a cost of risk.

Task formulation

Thus, the solution to the assigned task includes the following stages:

1. Analytical method of reliability calculation
2. Reliability optimization
3. Preparation of an engineering-geocryological cost map.

Selection of the best route for laying an above-ground pipeline based on the example of the Vankor-Purpe pipeline section

Let us consider a section of the existing oil pipeline route "Vankorskoye Field – NPS Purpe" having the length of about 10 km. The selected oil pipeline section "Vankorskoye Field – NPS Purpe" is located in Tyumen Region and starts at the north-east at the distance of about 20 km from the border of Tyumen Region with Krasnoyarsk Krai. The section of the designed oil pipeline route is located in a zone of thick permafrost (up to 200-400 m). This section belongs to the Taz-Yenisey area. One of the peculiarities of the area is its extremely high number of swamps and lakes. The average annual temperature of grounds varies from minus 2.4°C to minus 0.1°C. The site is characterized by mainly discontinuous spread of permafrost. According to the results of geotechnical site investigations, the continuous length of the sites composed of thawed grounds reaches 0.5-1.3 km. The distribution of permafrost along the profile varies from 75 to 90 %. On individual, rather long sections of the route, permafrost does not adjoin the layer of seasonal freezing, i.e. there are areas with deepened permafrost table. The project provides for above-ground laying of oil pipeline on pile foundations.

The territory, through which the oil pipeline in question runs, is subdivided into 12 engineering-geocryological sites (on the map the number of a site designates a type of lithological section, hatch – permafrost depth, a letter – temperature of grounds). For each of the distinguished sites the best total cost is calculated. In addition, on the basis of this cost the calculations are made for foundation reliability, depth of preliminary freezing of the ground and the length of a pile. These are main governing parameters of the foundation (The example of the calculation is given in the article "Methods of estimation of the reliability of oil-trunk pipelines", L.N. Khrustalev, M.Yu. Cherbunina. Kriosfera Zemli, 2010, Vol. XIV, No. 3, 69-76).

Each site is marked with the Total minimum cost (Ctotal), reliability (R), Depth of preliminary freezing-thawing of the ground (Hfr), pile length (l) (Fig. 1). Then, the best solution for laying of a pipeline is selected by applying different route options to the map. The best routing option is then selected.

Conclusions

The proposed method of assessing reliability of main oil pipelines in the cryolithozone allows one to take into account the stochastic non-uniformity of the system "oil pipeline –

permafrost foundation ground" and loads affecting such system, to control the quality of this system, foresee system possible failures and evaluate their consequences materially (in conventional units).

The task for optimization was formulated: the sum of costs for system creation and the cost of risk tends to minimum. The solution for this task makes it possible to find the best way of pipeline laying and respective design parameters.

This work proposes the method of making cost maps for selection of the best solutions when laying oil pipeline in the cryolithozone.

Based on the example of the Vankor-Purpe route section, the best alternative route for oil pipeline laying and its design parameters were selected.

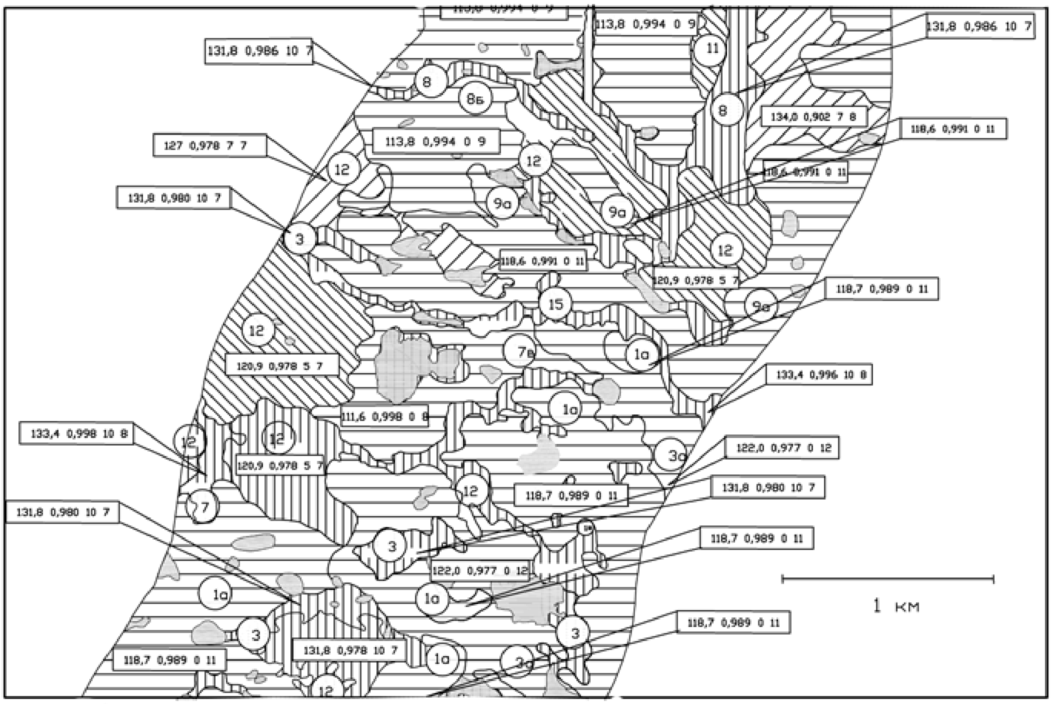

Fig. 1 The fragment of the engineering-geocryological cost map of the Vankor-Purpe oil pipeline section.

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Experience in Application of Borehole Geophysics Methods for Studying the Thawing of Permafrost Located Near Production Oil Wells at the Multiple Well Platforms of the Fields in Western Siberia

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Oil in the Far North regions is produced by multiple drilling method. Injection wells participate in the production cycle. Heated solution with the temperature of 120 °C is pumped through their wellheads. The process of such facility operation is accompanied by thermal interaction with grounds, which causes the changes in geocryological conditions. This results in formation of a thawing zone that can transform into a thermokarst pit. Merging of such zones around production wells is not permitted, as this is an extremely adverse factor for stability and long service life of the multiple well platform facilities.

The report surveys the results of using a set of borehole geophysics methods. During the period from 2010 to 2011 the research and production company Radionda LLC conducted works at some producing fields located within Krasnoyarsk Krai and Yamalo-Nenets Autonomous District, beyond the Arctic Circle, for studying geocryological composition of the upper part of the section and assessing a thawing process of permafrost at the multiple well platforms of producing fields.

Geophysical investigations included:

Well temperature survey;

Gamma-ray logging;

Electromagnetic well logging by method of one-hole radio-wave profiling (ORWP);

Interwell space examination by method of radio-wave geointroscopy (RWGI)

On the multiple well platform of the first field the fact of thawing was confirmed by positive temperature anomalies in the inspection well located in the immediate vicinity of a high-temperature injection well. For other investigation wells located at a distance from the heat source, the temperature was negative (Fig. 1a). Figure 3 presents a layout of wells.

For lithologic differentiation of rocks the gamma-ray logging was used. It detected great differences of strata by clay content. Natural radioactivity value (γ) does not depend on the frozen-thawed condition of rocks.

OWRP is a high-frequency electromagnetic method, but, unlike electric resistivity logging, it can be used in dry wells or wells with polyethylene pipe casing, and, if compared with the induction logging, it has a wider range towards high resistances, therefore it can be used for permafrost studies.

When comparing the OWRP data and the gamma-ray logging data, a close correlation between electric properties and clay content was found. In the wells where a thawing process was detected, abnormal increase in electrical conductivity is registered (red area in Fig. 1b) Thus, electric characteristics of grounds depend not only on the lithological type of grounds but also on their physical state.

The interwell space was studied by method of radio-wave geointroscopy (RWGI) based on evaluation of the rate of radio-wave energy absorption by grounds located on the wave propagation path from the source to the receiver (grounds with low values of $w\rho_{eff}$ and ε_{eff} are characterized by more intensive radio-wave absorption). Fan-shaped layout of measuring equipment ensures high density of studies (Fig. 2).

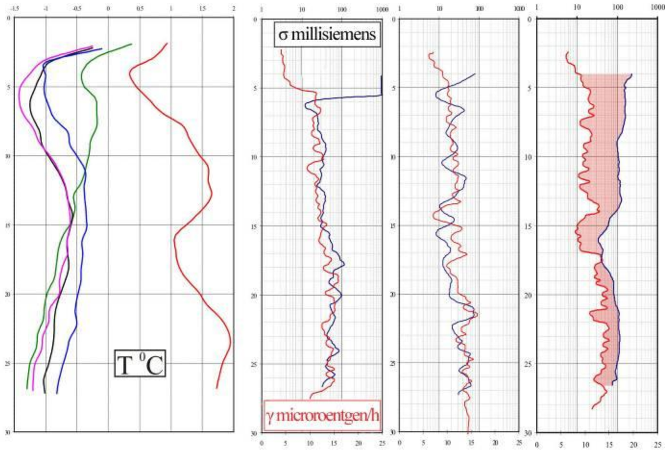

Figure 1. Data comparison of: well temperature survey (1a); gamma-ray logging and OWRP (1b).

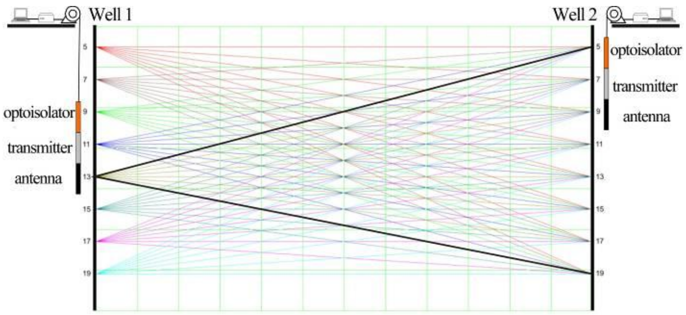

Figure 2.Fan-shaped layout of measurement.

During interpretation the interwell space was divided into equal cells. Multiple ray intersection within each cell makes it possible to calculate effective electrical resistance.

RWGI data are processed by known methods [*Radcliffe 1979*] with the help of software package developed by Radionda LLC.

Figure 3 depicts the instance of fragments taken from a 3D geoelectrical map created with wave algorithm of data processing. Comparison of the RWGI data with logging data makes it possible to relate low-resistivity regions (T) to the area of spread of thawed grounds near the high-temperature injection well.

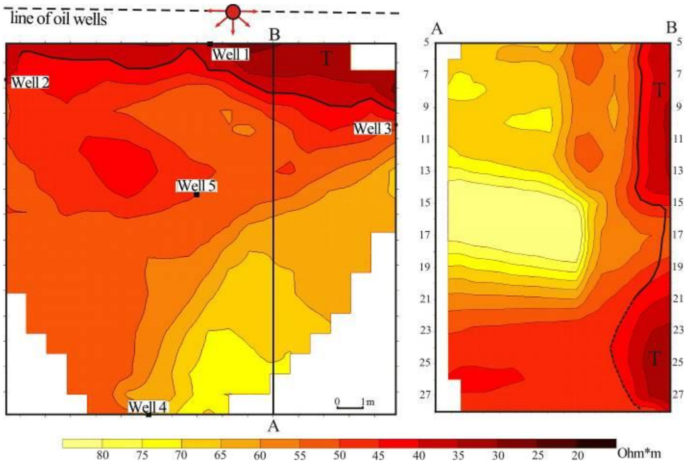

Figure 3. Fragments of the 3D geoelectrical map (horizontal plan at the depth of 13 m and section along the AB line).

Measurements with the use of RWGI method within the frequency range of 5 ÷ 31 MHz, when jointly processed, made it possible for the first time to make a 3D map of specific inductive capacity (Fig. 4). As is known, ε of water and ice differ 40-fold in such frequency range, which allows one to use this parameter for evaluation of frozen-thawed condition of the grounds at the foundation of multiple well platforms.

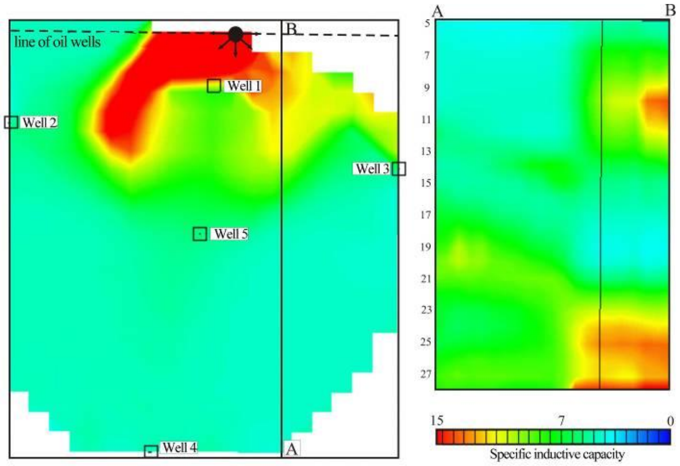

Figure 4. Fragments of 3D map of specific inductive capacity. (horizontal plan at the depth of 10 m and section along the AB line)

At another field, when conducting investigations for multiple well platforms, the described complex was accompanied by collecting of core samples for subsequent laboratory analysis of petrophysical and thermophysical properties in the frozen and thawed states (thermal diffusivity coefficient (a), thermal conductivity coefficient (λ), volumetric heat capacity (Cρ)). The analysis of the population of obtained data made it possible to find out correspondence among individual engineering-geological elements (EGE) and geophysical data (ρ_{eff}, ε_{eff}, γ). (S.V. Bomkin)

Table 1. Parameters of engineering-geological elements

	ρ_κ Ohm•m	ε	γ micro-roentgen per hour	ρ g/cm3	a m^2/s	λ W/m •K	C J/m^3 K
EGE1	400	6	6	1.96	1.14	2.15	2.59
EGE2	30	30	13	1.97	0.63	1.46	3.01
EGE3	90	10	10	2.24	0.86	1.92	2.87

On the basis of these data and RWGI data, a real three-dimensional thermophysical model of the designed working site was created, which became the material for calculation of a thawing process during operation of a facility with the help of numerical mathematical methods.

Summarizing the results of the performed works, it is possible to draw basic conclusions that the proposed complex:

- Enables assessment of frozen-thawed state of grounds at multiple well platforms in conditions of complex geology of the permafrost upper layer;
- Three-dimensional study of grounds in the direct vicinity of producing wells will make it possible to monitor the condition of multiple well platforms and to track the dynamics and spatial spread of a thawing process;
- The information obtained through interwell methods is necessary for mathematical modeling of changing thermal conditions near producing wells.

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Assessment of the Damage Caused by Cryogenic Processes and the Issue of Insurance against the Consequences of these Processes for the Territory of the Russian Federation

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On average, 250 emergency situations related to hazardous natural processes occur on the territory of the Russian Federation for a year.

We performed expert assessments of values of the average multi-year damage caused by the most hazardous processes for the whole territory of Russia. For example, Figure 1 shows these values for the Northern economic region.

After analyzing 13 major damage-causing processes on the territory of the Russian Federation, we concluded that the average multi-year damage caused by them is about 15 billion dollars (Table 1).

Table 1. The values of the average multi-year damage caused by the main hazardous natural processes on the territory of the Russian Federation.

Processes	Damage, in millions of $ US
Floods	2793.6
Cryogenic processes	2478.0
Landslides, rockfalls	2160.0
Earthquakes	1720.0
Hurricanes, cyclones	320.0
Tsunamis	40.0
Avalanches	13.2
Mudflows	40.0
Abrasion	47.0
Karst	676.0
Erosion	364.0
Waterlogging	3546.0
Land subsidence	454.0
Total:	14652.0

According to the previous studies [*Koff & Chesnokova 1998*], it was determined that the extent of damage depends primarily on the confinement of the corresponding economic region or a constituent entity territory of the Russian Federation to certain ground masses and, secondly, on the intensity and the extent of technogenic processes. The most damage-causing processes prevail in economic regions with specific classes of characteristic massifs. This primarily relates to seismic and permafrost areas.

Analysis of composition peculiarities, structure and properties of characteristic massifs as well as analysis of the damage origination determined by characteristic massifs and manifested during the interaction of technogenesis with them, shows that the latter are distinguished by some invariant properties of the geological environment. These distinctions are presented in the form of property ratings. Their first place reflects the maximum, and the last one - the minimum manifestation of the corresponding property.

The analysis of expert assessments of social-economic damages formed within economic regions is a complex scientific task. This is explained by the fact that some damage assessments correspond to the observed actual damages, while other assessments are only forecasts. Damage caused by many processes, especially geocryological ones, is prevented stepwise, this is why the final assessment of losses is often very undersized. Analysis and calculation of indirect damage and damage caused by secondary impacts are carried out very rarely. This also reduces the overall assessment of damage. Not only losses but also manifestations of hazardous geocryological processes are not monitored within a number of difficult areas. This also deprives the obtained results of a sufficient factual basis.

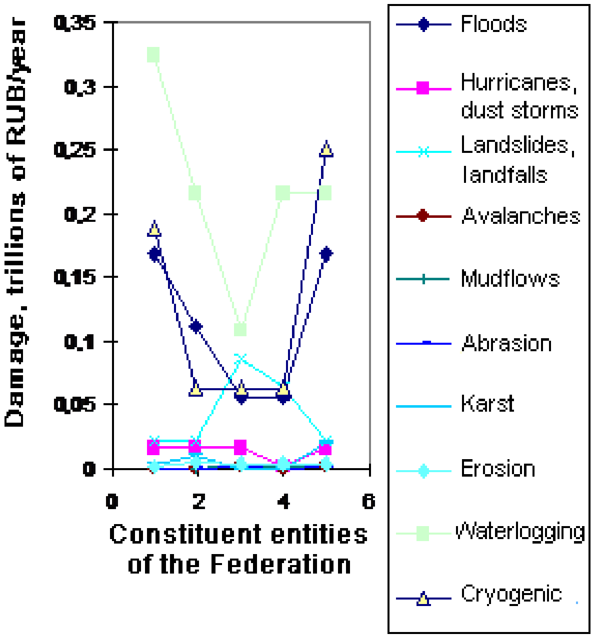

Figure 1. The average multi-year social-economic damage caused by the consequences of hazardous natural processes in the Northern economic region. 1 - Arkhangelsk region, 2- Vologda region, 3- Murmansk region, 4 - the Republic of Karelia, 5 - The Republic of Komi

It should also be noted that the damages formation is connected with various operational errors. Therefore, the losses are usually determined not only by the initial "configuration" of the interaction between technogenesis and a set of massifs, but also by the trajectory of the territory's social-economic development, including environmental management. The latter is determined by people when they develop building regulations, rules and projects, and reflect massifs properties and results of their interaction with technogenesis objects in a way in which they understand them at the time of planning, design and research.

The principled position during this work is the territory differentiation according to the degree of social-economic value. The steps of such assessment can be presented as follows.

1. General geocryological assessment of the territory.
2. Social-economic assessment of the territory.
3. Economic assessment of the territory - the assessment of damages caused by separate hazardous processes.
4. Assessment of the territories based on the total risk.
5. Determination of the territories insurance ratings.

Considering the territory of Russia as land and territory resources, we approach the determination of corresponding insurance indexes of the territory. The insurance index primarily reflects the (risk) probability degree of activation of hazardous processes, including extreme geocryological ones, on the given territory and the degree of its stability (sensitivity) in relation to these processes. More specifically, the degree of probability that these processes would cause damage to the main industrial funds and to the population. Since the industry and the population are unevenly distributed over the territory, the insurance indexes are determined primarily for large units (centers, focal points etc.) of settlement in economic regions of Russia. These include urban agglomerations and economic regions centers.

Considering exomorphodynamic and geocryological conditions of the territories, the risk values for industrial funds and population and the set of the most damage-causing processes, we can speak about the territory's insurance index that reflects the risk degree and the insurance rate value. It also determines the order of regions (territories) that need safety measures and insurance against the most damage-causing geocryological processes.

Collection, organization and analysis of the data concerning hazardous geocryological processes manifestation allow the insurer to determine the danger extent for each region and the acceptable level of risk that corresponds to the tariff and the resources of the insurance fund.

As we already noted, the regions located in the zones of high seismic activity and in the zones where 30-50% of the territory is subject to hazardous and potentially hazardous permafrost processes (insurance index I-II) primarily need safety measures.

Another important problem is the problem of sensitivity. And, while we have an integral idea concerning geological environment and technogenesis, the problem of sociosphere sensitivity (to hazardous geocryological processes) is still poorly studied. It is closely connected with the problem of people's attitude towards natural risk. People's attitude towards risks that is derived from their views and life circumstances is analyzed in the works of sociologists.

Economic mechanisms reducing the risk of social losses, destruction of buildings and structures and environmental pollution during the development of a set of hazardous geocryological processes should be oriented, on the one hand, towards the decrease in risk level and, on the other hand, they should be oriented towards creating new and efficient sources of financing of corresponding measures in northern regions.

The need to solve the problems of the informational base of insurance against the consequences of hazardous geocryological processes requires the use of geographic information systems, not only to visualize the acquired information' but also to solve the certain scientific and practical issues.

The informational base is primarily required to obtain specific results for urban territories [*Chesnokova 2011*]. It includes information on the following main groups of indicators:

- data on the territory's seismic hazard with regard to its regional and local features; information on structural-tectonic structure and activity;
- information on engineering and geological, hydrogeological and geocryological conditions;
- information on the sensitivity of the city's territory as a whole, on the sensitivity of individual buildings and structures, on engineering infrastructure in relation to hazardous processes, including the information on potential secondary anthropogenic influences, their extent and manifestation conditions;
- information on the social characteristics of an urban environment, population number and population density, age, professions, daily and seasonal migration, the level of readiness for hazardous processes and on the composition and arrangement of saving and life-support forces;
- information on individual and integral risk indicators, including a probabilistic assessment of consequences of hazardous processes.

In conclusion, the following should be noted:

- insurance against the consequences of hazardous geocryological processes is a modern and a very urgent issue as well as an interesting subject for scientific research;
- insurance against hazardous processes is an international problem;
- no other area of insurance brings together so many scientists and specialists of different professions (geocryologists, geologists, seismologists, economists, construction workers, insurance experts and others);
- the social significance of insurance against hazardous geocryological processes is very high. It enables rapid restoration of buildings, economy, and most importantly, restoration of normal human life.

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Hydrological and Hydrochemical Features of Lakes of Polygonal Wetlands Area of the Lena River Delta, Eastern Siberia, Russia

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Arctic and Antarctic Research Institute (AARI), St.-Petersburg, Russia
T.M. Potapova
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J. Boike
Alfred Wegener Institute for Polar and Marine Research (AWI) Potsdam, Germany

Instructions

The Lena River is one of the main Russian rivers flowing to the Arctic Ocean. River mouth of the Lena River is one of the biggest Russian Arctic deltas. It has more than 800 channels and cross horns with the total length of about 6500 km. The total area of the Lena delta is 25000 sq km if the top of the delta is Stolb Island and 32000 sq km – from Tit-Ari Island where the first channel Bulkurskaya branches off [*Geoecological state…, 2007*]. At presents time the Lena delta consists of 1500 islands [*Are and Reimnitz, 2000*] and 60 000 lakes of different forms and sizes mainly thermokarst and polygonal lakes with area less than 10 sq km. The Lena River basin lakes like other objects of permafrost zone have not studied enough. Morphometrical and hydrological data are available for only about 800 lakes or 0.2% of all lake catchments. A standard hydrometrical lake net is very poor.

Samoylov Island is situated on the first terrace of Holocene alluvium sediments genesis with 10-13 m height and 7 000 yr BP [*Makarov 2009*]. Samoylov Island is the mark point of environment studies including hydrographical net formation of this region. Every year investigations hydrological and hydrochemical regimes of the island lakes and channels of the delta are being carried out. Observations of polygons and their water features are considerably importance.

Study area

Field work was conducted at the Samoylov island (72°22’N, 126°29’E), situated on the first terrace of the Lena River in 2008-2010. Two different parts of the island can be allocated – high part (first terrace) and low part – alluvial part.

The main factors of formation of island lakes are thermoerosion and river influence and that in also a basis for the recognizing of the main types of Samoylov osland lakes: thermokarst lakes, polygonal lakes and flood-former riverbed lakes. There are a lot of different types of lakes could be find out on the island: thermokarst lakes, flood-formed riverbed lakes, polygonal lakes and lakes of mixed types. Most part of the island is occupied by polygonal lakes or ponds. Thermokarst and formed riverbed-thermokarst lakes are the biggest lakes located on the noth-west of the island.

Results and discussion

Determined hydrophysical and hydrochemical characteristics of lakes depend on features of their formation. The result of field measurements in June-July 2009 and August 2008, 2010 and laboratory analyses (Table 1) are hydrochemical characteristics of water objects of Samoylov island and Olenekskaya channel of the Lena River.

Table 1. Hydrochemical characteristics of island lakes and Olenekskaya channel of the Lena River Delta (June-August, 2009-2010).

Type of lakes	P-PO_4 mg/l	Si, mg/l	t, °C	pH
Flood-former riverbed	0,02-0,03	1,7-2,2	6,4-11,6	7,2-7,7
Former riverbed–thermokarst	<0,01-0,03	0,04-0,9	7,7-9,7	6,7-7,6
Thermokarst	0,01-0,05	0,02-1,5	5-10,4	7,1-7,6
Polygonal-termokarst	0,01-0,05	0,04-1,2	7,2-10,3	7,1-7,7
Lena River, le-nekskaya channel	0,03-0,05	1,5-2,2	14,5	6,7-7,6

Water temperature

Temperature regime of the studied lakes largely depend on an air temperature but it is also depend on morphmetrical characteristics: more shallow lakes had a temperature up to 14 C, temperature of termokarst and flood-former riverbed lakes was 6-8 C on the surface in August 2008.

Summer water temperature (June-July, 2009) was vary from 5 to 10,7 C in early July, it was not higher 7,6 C at the end but could reach 10,7 C even at depth.

Main hydrochemical characteristics

Hydrochemical data are conformed to previous obtained values for small polygonal ponds [*Wettrich, 2007*]. It has been determined that all ponds are oligotrophic and have neutral water. However, we have marked quit high concentrations of phosphates (up to 6 mg/l) that is probable connected with different time of sampling. Mineralization is less than 100mg/l and varied during the field work season from 5.3 to 11.3 mg/l (from 34 to 68 mg/l according to our results), conductivity was varying from 27 to 254 µS/ cm, or all water bodies have low-mineralized water with dominance of calcium (magnum) and hydrocarbonate ions that also correlate with our results. Lakes have colorized water - less than 10 degrees of coloration, 6,7-7,7 pH values or neutral and alkalescent water.

Phosphates varied from <0,01 mg/l to 0,07 mg/l, concentrations of Si varied up to few milligrams per liter. The reason of elevated concentrations of Si is cryogenic processes typical for arctic regions. The variability of nutrients for the most water bodies is characterized by elevated concentrations phosphates and Si during the period (July-August).

Geochemical characteristics of lakes bottom sediments

Research of geochemical composition of island lake sediments, which are under influence of the Lena River, in future will permit a possibility to estimate the self-cleaning ability of lake ecosystems and their stability to the anthropogenic affect. It is shown that concentrations of trace elements in lakes sediments don’t exceed the concentrations of their Clarks in the Earth crust [*Viogradov 1962*]. Distribution of elements along cores quite progressively increases without abnormal picks. That fact supports a conclusion about nature geochemical composition of lacustrine cores of the Samoylov Island and all delta lakes, potentially. Concentrations of main petrogenic elements correspond to their natural values in soils and rocks of the Lena River catchment.

Sediments of considered lakes have a high (for north regions) capacity of cation exchange (16-58 mg eqv./100 gACB). It could be assumed, that lakes of Samoylov Island have a possibility to self-cleaning due to high accumulative ability of sediments and also due to an intensity of exchange reaction with water. But the level of self-cleaning ability of ecosystem is individual and depends on many factors such as geographical location (intensity and set of abiotic processes), concentration of elements influencing biodiversity progression (content of nutrients, trace elements, toxicants, pollutants and ect.), and efficiency of substances utilization due to photosynthesis and restructuring of the diversity of alga complexes. Geochemical transformation of substances in the system also can be a criterion of self-cleaning.

Conclusions

Comparison and analysis of hydrological, hydrochemical and hydrobiological field measurements and laboratory data of the lake water and sediments from one of the many islands of the Lena River delta allows us to obtain some new results about the current state of arctic water bodies.

Hydrochemical composition of lakes and geochemical characteristics of sediments depend on changes taking place on the lake catchments, for instance, an increase of biogenic element input due to an increase of seasonable melting layer, and also they depend on extend of the influence of river water that inflows an island of a channel.

Further research of geochemical composition of island lake sediments, which are under influence of the Lena River, in future will permit a possibility to estimate the self-cleaning ability of lake ecosystems and their stability to the anthropogenic affect. Additional observations on low-investigated elements of water and mineral balances of Samoylov Island lakes are in the scheme of future research such as ground influx of water and nutrients elements from catchments, water exchange between sediments and lake water, a circulation of biogenic elements in the trophic lake chain and etc.

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Creation and Maintenance of a Spatial Database During the Geotechnical Monitoring of Pipeline Transport

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The background

A significant volume of data on geotechnical and geocryological processes influencing the engineering state of gas pipelines and the associated infrastructure was received in the process of geotechnical monitoring of the Zapolyarnoe-Urengoy trunk gas pipeline system in 2006-2011.

Spatial systematization of the data reflecting the spatial association of processes was necessary to improve the quality of management of the geotechnical system "gas pipeline - environment". This was required for further work, specifically for correction of the project "Reconstruction of the 1st, 2nd and 3rd Branches of the Zapolyarnoe-Urengoy Gas Pipeline System. Water Disposal and Flood Alleviation".

Work performance

The available information on the state of the pipeline geotechnical system for the observed period (2006-2011) and engineering investigation materials were gathered and analyzed at the first stage. The result of the first stage was the summary register of the state of the facility under study in the MS Excel format as well as the systematized photo material.

The second stage included the georeference of the prepared summary register of the study object's state that was realized with the help of the problem of linear coordinates (ESRI ArcGIS). Remote sensing materials were chosen with the help of the spatial organization of the database on the geotechnical system state. They included satellite images of high spatial resolution (0.5 m, "WorldView-1,2", "GeoEye-1"), coordinates system UTM-WGS84/44 and actualization of the period from Autumn 2010 to Autumn 2011.

The georeference of the description of the sites, registers and images of monitoring was the result of this stage. Moreover, helicopter flight images of the report period (more than 5 thousand images) were georeferenced.

The third stage consisted in determination of the pipeline system state by employing the method of interpretation of remote sensing materials. The assumed mapping methodology generally consists of the following operational sequence: detection of causes and consequences of spatial differentiation of geosystems with regard to the field materials analysis → identification of homogeneous sections of the gas pipeline route with the adjoining territory → interpretation and tabulation of the attributes of the data on the research site state → verification and generalization of the data on the gas pipeline route state.

Homogeneous sections of the gas pipeline route were detected in accordance with the concepts of geotechnical systems of an oil and gas complex [*Kozin, Marshinin, Osipov 2008*] on the basis of the landscape analysis. Meanwhile, we considered not only the current state of the geotechnical system but also the retrospective analysis of the operation of the hosting geosystems as well as the development forecast of the geotechnical system.

The analysis of the situation for the previous years and the interpretation data allowed us to make a classification of the states of the geotechnical system sections that consists of sections' types, sections' groups and kinds of sections.

A type of the section state is a position in the sequence of the state change from the designed to the disturbed one.

A group of the section state is defined by the nature of change in the given gas pipeline position.

A kind of sections is defined by the intensity of the process that isolates them.

In total, four types of section states were singled out for the gas pipeline geotechnical system:

- within deviation norms;
- position disturbance;
- position restoration (repaired);
- repeated position disturbance.

A type of the state of sections with disturbed positions includes five groups of section states for the gas pipeline geotechnical system:

- the group with embankment erosion;
- the group with the deepening lesser than the designed one;
- the group of aerial crossings with the deviation from the designed position;
- the group with the development of slope thermal erosion and of thermokarst on the temporary technological passages along gas pipelines;
- the group of embankment deflation.

Each group of sections is subdivided into kinds of the state of the gas pipeline geotechnical system on the basis of the process intensity. For example, aerial crossing sections with the deviations from the designed position are represented with the following types:

- the aerial crossing with arch development;
- the aerial crossing with bend development;
- the aerial crossing with the rise of the pipe bottom less than 1 m from the land level;
- the aerial crossing with destruction of slopes at the points where a gas pipeline comes out from the ground;

The data on gas pipeline sections were included in the state table by homogeneous sections with continuous description. The ending of the previous section was the beginning of the next one.

Results

The spatial database of the pipeline system state in MapInfo/ArcGIS formats was the result of the work. This made it possible to:

- improve the quality of management solutions for pipelines reconstruction;
- trace the dynamics of exogenous processes, trace their spatial interaction and calculate the rate and the prospects of development;
- maintain the data bank of the state of the gas transport geotechnical system, enriching it after every helicopter flight and surface investigation;
- identify the sections for top-priority repair and monitoring, such as: erosion processes, underflooding, thermokarst, and unauthorized actions of the outside economic entities in the zone of responsibility of the gas transport enterprise.

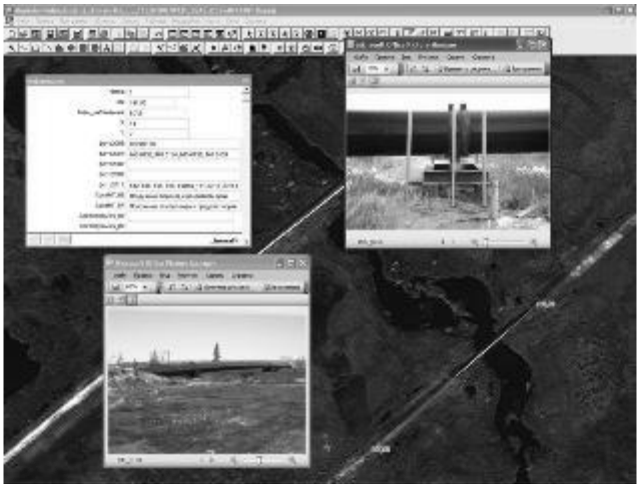

Figure 1. Example of GIS application in the analysis of the vertical bend of an aerial crossing at the gas pipeline

The work results were applied in correction of the project "Reconstruction of the 1st, 2nd and 3rd branches of the Zapolyarnoe-Urengoy gas pipeline system. Water disposal and flood alleviation" for the work period of the winters of 2011-2012.

Prospects

Involvement of new data on the natural and technical environment into the spatial database of the gas pipeline geotechnical system as well as completion of user's versions on the basis of the user-friendly interface for thematic consumers.

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The Impact of Low Air Temperatures on the Fuel Consumption of Automobiles Working on Compressed Natural Gas and Gasoline

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Abstract

This work considers the issues of influence of ambient air low temperatures on fuel consumption of automobiles operating on compressed natural gas and gasoline. Graphical dependences were obtained. Mathematical models describing these dependences were proposed. The conclusion was drawn regarding the issue which of the considered fuels is less sensitive to changes in air temperature from the perspective of fuel efficiency.

Keywords: compressed natural gas; fuel consumption; gasoline; low air temperatures.

Nowadays more and more vehicles are fitted with gas cylinder equipment operating on compressed natural gas that represents the most promising developing trend, as regards economy of traditional oil motor fuels. Besides, natural gas, when combusted in engines, emits a less amount of harmful substances with exhaust gases, as compared with oil motor fuels.

There is a certain time period until large-scale gasification of transportation means in our country. But the problems that are faced when using natural gas as a motor fuel require solutions already now.

For example, when operating transportation means in Russia, much attention is paid to natural-climatic factors. The cold climate zone occupies the biggest part of our country – about 70% (central and northern parts of Russia, Western Siberia, Eastern Siberia and the Far East), therefore low air temperatures dominate on significant part of Russia.

In particular, when vehicles are operated at low temperatures, fuel consumption changes. These changes lead to improper correction of standards and norms of technical operation, including fuel consumption norms. The more adequate correction of fuel consumption norms can be obtained on the basis of adaptiveness of compressed natural gas and gasoline-operated vehicles to low temperature conditions. This evaluation will make it possible to find out, with which fuel (gasoline or natural gas) a vehicle is more adapted to the temperature change in operation conditions.

Rig tests were conducted at the Department "Vehicle Transport Operation" of the Tyumen State Oil and Gas University for engine ZMZ-4062.10 (with a brake unit consisting of balancing stand AKB 92-4 (DC motor-generator), weighing device VKM-32, type RP-10 SH13, and liquid rheostat) operating on gasoline and compressed natural gas. This engine as the subject matter of analysis is selected based on the fact that it is mounted in microbuses of GAZel line, in particular, in GAZ-32213. This vehicle is widely used in our country for transportation of passengers and goods.

Gasoline consumption was measured by a flow meter consisting of a measuring flask built in a gasoline pipe. Natural gas consumption was calculated according to reference data [*RD 3112199-1095-03 2002*].

Based on the processed results of rig tests, we built the graphical dependencies reflecting the influence of ambient air temperature on fuel consumption (Fig. 1-3). They allow us to draw the conclusion that: the minimum gasoline consumption is reached at air temperatures from -5 to +15 °C, and the minimum natural gas consumption – at air temperatures from -10 to +15 °C, depending on the engine operation mode. When deviating from the optimum, fuel consumption increases. It should be also noted that under other equal conditions consumption of compressed gas is slightly higher than that of gasoline. Instruction [*Instruction… 2008*] specifies that 1 l of gasoline corresponds to 1 +/- 0.1 m^3 of compressed natural gas (depending on the natural gas properties). Therefore, this small growth of gas consumption can be explained by its chemical composition.

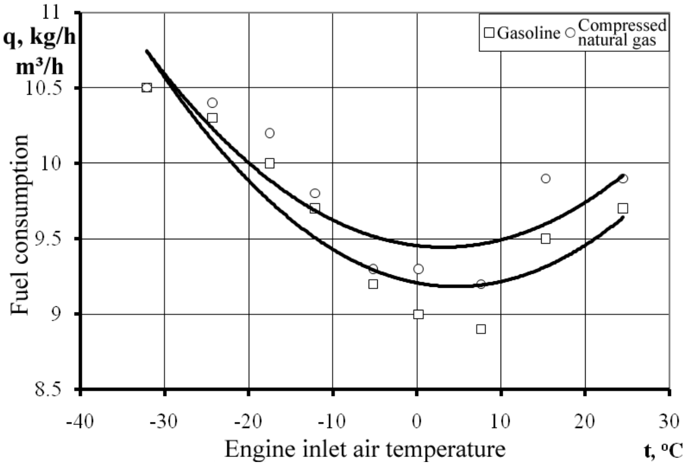

Figure 1. The fuel consumption change vs. engine inlet air temperature curve at P = 26.4 kWatt, n = 2500 min^{-1}

Processing of experimental data resulted in numeric values of parameters included in mathematical models (with the help of the "Regress 2.5" program) describing the influence of engine inlet air temperature on the change in fuel consumption.

If engine load (P) = 26.4 kWatt and crankshaft rotation speed is (n) = 2500 min^{-1}, fuel consumption change equations take the form (Fig. 1):

for gasoline:

$$q_m = 9{,}18 + 1{,}16 \cdot 10^{-3} \cdot \left(t_{ф} - 5\right)^2, \qquad (1)$$

for compressed natural gas:

$$q_m = 9{,}44 + 1{,}05 \cdot 10^{-3} \cdot \left(t_{\text{ф}} - 3\right)^2. \qquad (2)$$

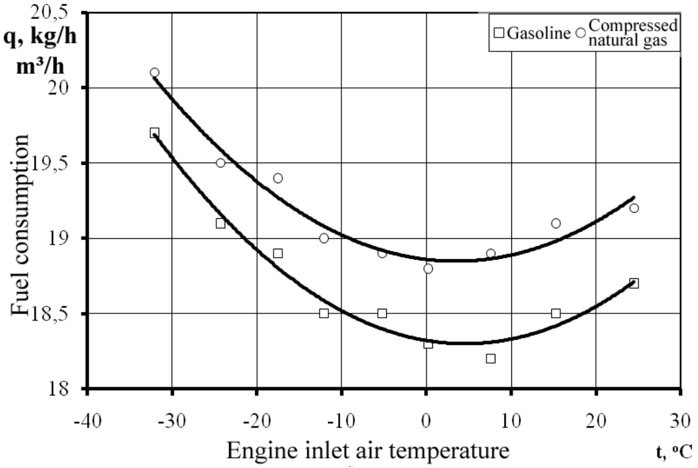

Figure 2. The fuel consumption change vs. engine inlet air temperature curve at P = 57.2 kWatt, n = 2650 min^{-1}

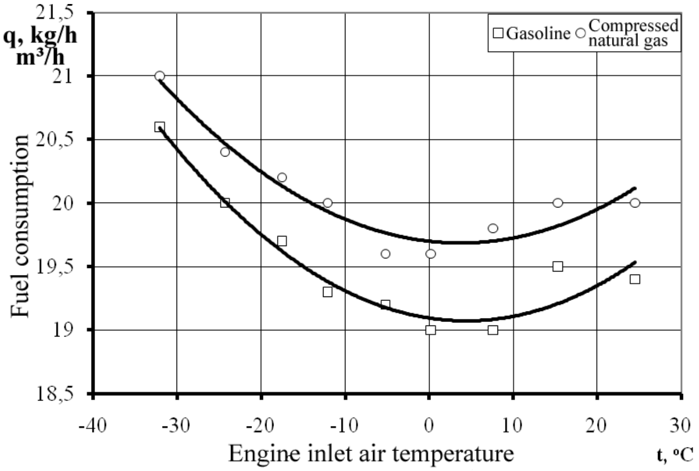

Figure 3. The fuel consumption change vs. engine inlet air temperature curve at P = 64.7 kWatt, n = 3000 min^{-1}

If P=57.2 kWatt, n=2650 min^{-1} (Fig. 2), the equations take the form:

for gasoline:

$$q_m = 18{,}30 + 1{,}03 \cdot 10^{-3} \cdot \left(t_{\text{ф}} - 5\right)^2, \qquad (3)$$

for compressed natural gas:

$$q_m = 18{,}85 + 9{,}60 \cdot 10^{-4} \cdot \left(t_{\text{ф}} - 3\right)^2. \qquad (4)$$

If P=64.7 kWatt, n=3000 min^{-1} (Fig. 3), the equations take the form:

for gasoline:

$$q_m = 19{,}07 + 1{,}14 \cdot 10^{-3} \cdot \left(t_{\text{ф}} - 4\right)^2, \qquad (5)$$

for compressed natural gas:

$$q_m = 19{,}69 + 9{,}98 \cdot 10^{-4} \cdot \left(t_{\text{ф}} - 4\right)^2. \qquad (6)$$

Numeric values of correlation coefficients of fuel consumption change equations for different engine operation modes are as follows: q – 0.85...0.98, and the determination coefficient value for q – 0.76...0.98.

The works of L.G. Reznik, V.N. Karnaukhov, D.A. Zakharov and others present U-shaped fuel consumption vs. ambient temperature curves for gasoline engines. This study presents similar curves obtained for compressed natural gas.

After analyzing these curves, the following conclusion can be drawn: since compressed natural gas graphical dependences do not have such pronounced U-form as gasoline-related curves, then natural gas is less sensitive to changes in ambient air temperature than gasoline from the perspective of fuel economy. And this means that the GAZel vehicles with the ZMZ-4062.10 engine operating on compressed natural gas, under other equal conditions, adapt better to change in temperature conditions than those operating on gasoline.

Acknowledgments

I would like to express my deep gratitude to Ilya Aleksandrovich Anisimov for his assistance in conducting experimental research.

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The influence of snow and frozen ground on seasonal rockslide deformation in marginal permafrost areas, Northern Norway

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Introduction

Rockslides pose a significant geohazard in periglacial landscapes with frozen ground. Focus has been on mapping and detecting large rockslope instabilities due to their potential large risk related to the initiation of destructive tsunamis, particularly in steep fjord landscapes, with coastal settlements. However, processes linked to melting, refreezing and temperature changes in ice in the rockslopes have been much less investigated, and their influence on driving mechanisms for observed displacements is less well understood.

Here we use a case study from northern Norway of one of most active rockslides, the Jettan rockslide, to expand our understanding of the influence of frozen ground on rockslope dynamics. In the Jettan rockslide an extensive monitoring system provide seasonal displacement, and in addition systematic studies of the ground thermal and snow regime has been performed to understand seasonal freezing and permafrost conditions.

The Jettan Rockslide

Large parts of the north Norwegian fjord landscapes are located in the arctic zone with altitudinal permafrost. The permafrost regional limit is descending from app. 990 m asl. in the west, to 550 m in the interior in the east of N Norway [*Christiansen et al., 2010*]. This means that the Jettan rockslide area, extending from 400 m to 800 m asl., is located somewhere at the regional modern permafrost limit. However, the irregular topography of the rockslide area, with deep open fractures, a complex fracture geometry and snow accumulation pattern, creates special local terrain and subsurface conditions. This complex topographic setting being located within the permafrost border zone, is thought to significantly influence the rockslide deformation.

The first geological studies of the Jettan rockslide were initiated by the Geological Survey of Norway (NGU) in 1999, and have been continued using different investigation methods, in addition to the implementation of a continuous monitoring network [*Braathen et al., 2004*]. The investigations have included detailed structural and geomorphological mapping, geophysical measurements (2D resistivity and refraction seismics), LIDAR scanning and analysis of satellite-based InSAR and widespread air, ground and crack temperature and snow monitoring.

The Jettan rockslide consists of a volume possibly up to 17 million m^3, and parts are moving with velocities of more than 50 mm/yr [*Blikra et al., 2009; Nordvik et al., 2010*].The unstable area is detached from the intact bedrock at its rear by large normal faults, and internally this area is characterized by a series of extensional fractures, some of which can be traced as up to 300 m long surface depressions. The large active back fracture, delimiting the active area, is about 300 m long, up to 10 m wide and deeper than 25 m. Due to the large and open structure, visual observations of the back fractures lower parts were possible using climbing techniques in early September.

Results

Displacement

The displacements in the active area indicate annual displacements between 1 and 5 cm based on continuous measurements since 2007. There is a strong seasonal control on the displacement rates, with a coherent increase in velocities in early spring (May), and a decrease only in the early winter (December). The velocity is reduced even more in mid winter (February) [*Nordvik et al., 2010*].There is no correlation between the displacement pattern and the precipitation record, and even though the increased displacements start during snowmelt, it does not slow down again after the snowmelt has finished. This indicates a totally different driving mechanism than water pressure alone for the overall deformation.

Snow dynamics

A perennial snowpatch exist in the bottom of the active back fracture. This snowpatch is at minimum size in end of summer, and grows through the winter to reach it maximum size only in April. Melting of snow takes place from May until the end of summer. Large amounts of snow can accumulate during snowstorms, when the open fracture catches snow. But it is only towards mid winter that the fracture is significantly filled. Thus cold air can drain into the fracture during the first part of the winter.

Air, ground and crack thermal regimes

The mean annual air temperature for the study period 1 September 2009 to 1 September 2011 are respectively -1°C and0,3°C. The air temperature is largely negative from October to April, and reaching 15-20°C in summer (Fig. 1 upper panel). Correspondingly, the air temperature of the active fracture (Fig. 1 lower panel) follow the air temperature variation in the beginning of the winter until enough snow has accumulated into the fracture isolating the crack air temperature from the atmosphere. From then, the air temperatures in the crack remain between 0 and –2°C. In end of summer 2010 a thermistor was installed in the deepest accessible part of the backscarp directly into the ice body identified there (Fig. 1 lower panel). Also this part of the fracture experienced significant early winter cooling before enough snow filled the crack preventing further cooling. A relatively stable winter temperature of around -2°C is then reached. In May, when snowmelting starts, the ice temperature increased up to around 0°C. This stable summer temperature continued until the early autumn, when most likely meltwater erosion have further increased the temperature and melted the ice right around the sensor. Field inspection in end of summer 2011 was not possible, as new ice had formed on top of the part where the sensor was located.

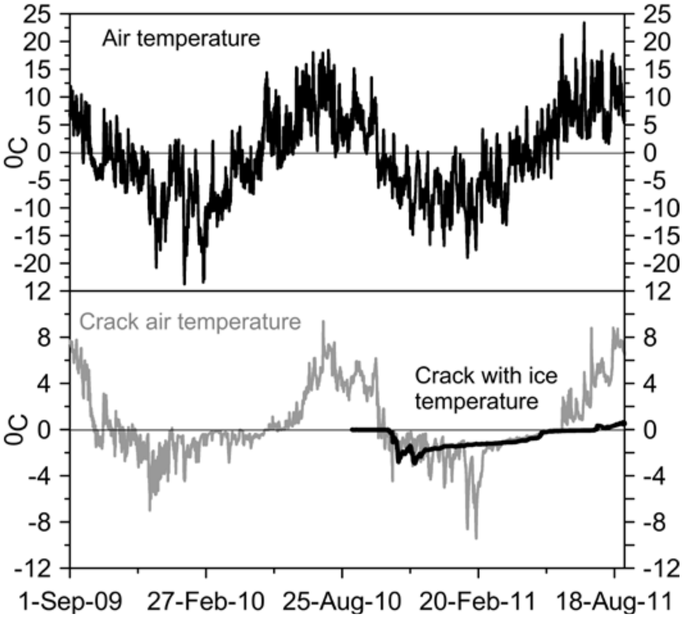

Figure 1.The air temperature (2m) from the Nordnesmeteoro-logical station (upper panel) (see location in fig. 4). Crack air temperature measured app. 10 m below the terrain surface and the temperature recorded in the ice in the lower part of the active backscarp (lower panel). Observe difference in scale on the y-axes.

Discussion and Conclusion

Permafrost has been found in the bottom of large open back fractures .The Jettan seasonal displacement pattern cannot only be caused by snowmelt. Moreover, the displacement shows no correlation with precipitation. The controlling process for this characteristic pattern is thus interpreted to be melting and refreezing of ice in deep fractures largely affected by cold air drainage.

The driving mechanisms for the Jettan rockslide seems thus to be controlled by processes linked to the occurrence and changing characteristics of snow and the frozen ground thermal regime in the unstable rocks. The shear strength of the detachment planes can be largely controlled by thermal conditions and characteristics of the ice in the permafrost due to several processes:

1. Increased ice temperatures during snowmelt in the spring as meltwater drains into the fractures and later refreezes in lower and still colder parts. This produce heat, which will increase the ice temperature from being several degrees below freezing up to close below the melting point. This temperature increase will drastically reduce the shear strength if ice occurs along the sliding planes.

2. Summer meltwater eroding its way downwards causes refreezing in the permafrost thermal regime of the lower parts of the back fracture forming ice in the deep fractures. This can lead to volume increase, and thus a pushing effect along the active back fracture.

3.Meltwater in the spring can lead to melting of ice in the sliding planes causing a possible reduced shear strength.

The shear strength of the sliding plane(s) will be largest with the occurrence of cold ice, and smallest with the occurrence of warm ice just below 0°C. Largest displacements should thus be experienced during stages were warm ice is present in these areas, which should be initiated during maximum snowmelt in late spring or early summer. More details on all aspects of the Jettan rockslide is presented in Blikra & Christiansen (in prep.).

Clearly, the processes linked to ice formation and erosion in marginal permafrost environments is most likely important driving mechanisms for rockslides. It seems that occurrence of ice in fractures and detachment zones is needed to reduce the shear strength and thus drive the rockslide movements. Efficient cooling is obtained primarily in early winter by cold air drainage into the open fractures of the rockslide. In conclusion, the increased understanding of the coupling between the permafrost thermal regime and the displacements of the Jettan rockslide in the arctic landscape in northern Norway, enables identification of a series of important questions related to the evaluation of hazard, and how society is going to cope.

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Determining the Dependences of Permafrost Physical Characteristics near Mys Kamenny Village

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Introduction

Today there is enough experimental and theoretical information that enable to find out regularities for the stressed-deformed state of permafrost. The porosity coefficient and the total moisture content were described as functions of permafrost density. The total moisture content was described as the function of the porosity coefficient.

Mys Kamenny is a village in Yamalsky District of Yamalo-Nenets Autonomous Region. It is the administrative centre of Mys Kamenskoye Rural Community. The village is located in the Yamal Peninsula, to the West of the Gulf of Ob, along the Kamennaya Spit. It was founded as the base of the Transpolar Geophysical Expedition.

Main Part

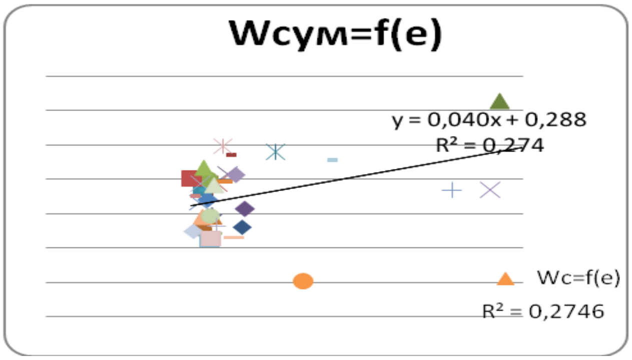
The physical properties of the grounds studied and the physical and mechanical properties of the samples delivered from the site were investigated at the same time.

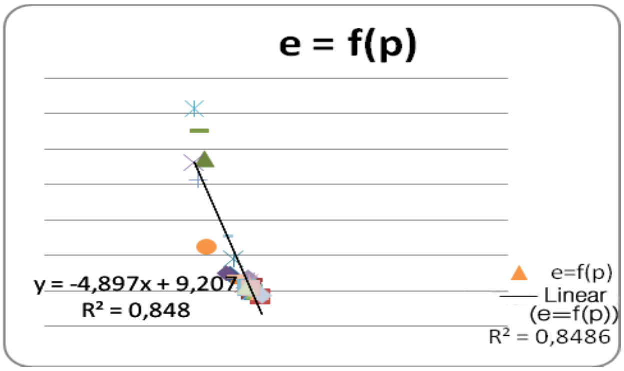
According to the existing identification methods for the durability and deformability characteristics, the abovementioned characteristics depend heavily on the content of ice, readily soluble salts and biogenic remnants. The ice content is characterized by the total ice content (i_{tot}) including the ice content due to the ice that cements ground particles (i_{ic}) and the ice content due to inclusions.

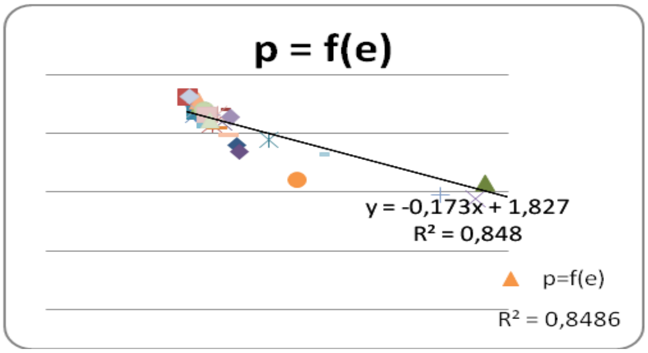
The structure of frozen and thawing grounds is a very important indicator for forecasting their durability and deformability characteristics. It is characterized by morphological peculiarities that depend on the orientation and location of structural elements in the ground. Massive, layered and reticulate structures are predominant in the area in question. Layered and reticulate cryogenic structure is typical of clayey silt grounds. Moisture content after monolith cutting, soil density (by the cutting ring method), density of soil particles and salinity were determined for each sample. In the sands, moisture content varies from 21 to 37%, density varies from 1.35 g/cm^3 to 1.80 g/cm^3. Massive cryostructure is typical of frozen sands. Moisture of the clayey silt grounds falls within the range of 26-38%. However, grounds with a high content of ice and the total moisture content of 70-128% are also present. Plasticity indices were determined in accordance with GOST 5180-84 and GOST 25100-95 in order to classify clayey grounds. Particle size distribution in the sands was determined in accordance with GOST 12536-79. A wide range of physical properties is typical of grounds. As to the particle size distribution, there are fine sands, silty sands, sandy silts, clayey silts, clays present. The total ice content in the grounds and the ice content due to ice inclusions were calculated in accordance with expressions A.10 and A.11 of GOST 25100-95.

Conclusions

The total moisture content and density were described as functions of permafrost porosity coefficient, the porosity coefficient was described as the function of permafrost density. Diagrams of many other dependences were made.







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High CO_2 and CH_4 Emissions from Alaskan Streams: Potential Sources and Processes

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Introduction

Small boreal streams may be globally important sources of carbon gases (CO_2 and CH_4) to the atmosphere [*see Teodoru et al., 2009; Humborg et al., 2010*]. We investigated the magnitude and potential processes responsible for CO_2 and CH_4 saturation and concurrent fluxes in a headwater catchment of the Yukon River Basin, Alaska. The results of this investigation are important for understanding both the aquatic carbon cycle in general, and the role of aquatic systems in carbon-rich permafrost regions. We hypothesized that stream CO_2 emissions would be a significant component of the ecosystem carbon balance and would be fueled mainly by soil CO_2.

Permafrost Setting

The study region in the zone of discontinuous permafrost is likely underlain by epigenetic permafrost (based on observations of exposed ice) which has partially thawed due to recent wildfire. Mean active layer thickness is ~0.5 meters. The shallow active layer likely constrains groundwater flow through CO_2 rich soils and may be further confined by the presence of hillslope stone stripes. There is also evidence of thermokarst formation in many locations within the study region.

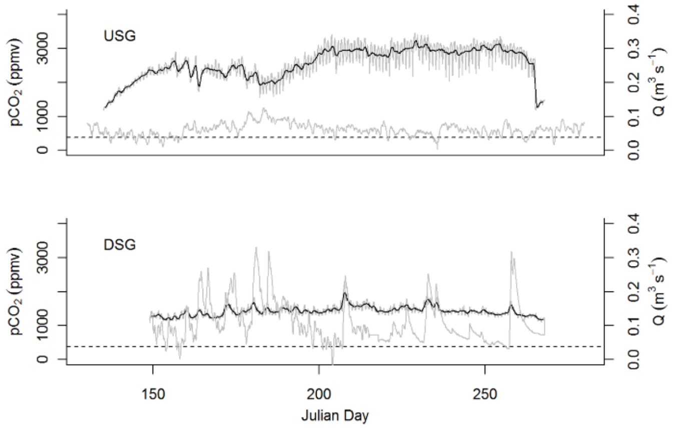

Figure 1. pCO_2 (black line is the moving average overlaid on observed data (gray line)) and discharge (Q) (bottom gray lines) time series from two locations on a single stream. Responses to elevated Q differ between the two sites (negative response at upstream gage USG, positive response at downstream gage DSG) despite being separated by less than 2km. Dashed line is atmospheric CO_2, which shows that these sites are consistently supersaturated and are constant sources to the atmosphere.

Results

Catchment Carbon Gas Emissions

Estimates of CO_2 and CH_4 emissions from streams are dependent on accurate measurements of stream evasion rates and surface area. We utilized chamber measurements and a model of stream geometry [*Leopold & Maddock 1953*] to scale emissions of both gases to the study catchment. Our results indicate that stream emissions have the potential to decrease net ecosystem production (NEP) by at least 5% (assuming NEP of approximately 40 g C m^2 $year^{-1}$ on land [*Bonan and Van Cleve, 1992*]). The magnitude of this ecosystem carbon loss is surprising given that streams cover < 0.2% of the landscape. Methane losses were not significant (<0.1% of NEP) for the overall catchment carbon balance, but the evasion rates (mean = 126 mgC m^2 day^{-1}) were higher than nearly all published values for similar environments. This suggests that northern streams may be a potentially important but unaccounted source of CH_4 to the atmosphere. We believe that recent permafrost degradation and the formation of thermokarst wetlands may be important sources of CH_4 to streams.

Processes and Controls

The partial pressure of stream CO_2 (pCO_2) remained relatively constant throughout the open-water season, with daily fluctuations likely controlled by in-stream processes. However, storm events altered stream pCO_2 and the response depended upon specific hydrologic flowpaths within the catchment. For example, Figure 1 shows the stream pCO_2 response to stream discharge (Q) at two locations on one stream. At the downstream gaging site (DSG), pCO_2 increased during storms. Alternatively, pCO_2 decreased slightly at the upstream gage (USG) during storms. Elevated pCO_2 during storm events suggests an enrichment of CO_2 from shallow groundwater flow through CO_2 rich soils, whereas a decline in pCO_2 occurs by simple dilution of stream water pCO_2. Fitted parameters from our process model (equation 1) of pCO_2 depend upon initial conditions. Results of this model suggest that the combined effects of gas evasion (Fluxatm), respiration (R) and photosynthesis (P) essentially offset one another (pCO_2 is similar at beginning and end of each day) and that there is a consistent background source of CO_2 to streams that is modified throughout the course of each 24 hour period.

$$pCO_2\,[t+1] = pCO_2[t] - P + R - Flux_{atm} \qquad (1)$$

Conclusion

Our results indicate that small streams may be an important component of the carbon balance in permafrost regions such as interior Alaska. However, this study only includes one type of permafrost and the magnitude of stream gas emissions in other permafrost environments may differ due to varying hydrologic patterns and carbon processing. Degassing of CO_2 and CH_4 in streams is rarely accounted for in most studies of ecosystem carbon dynamics and may alter our current interpretation of this important elemental cycle. More work is needed to elucidate the sources of CO_2 and CH_4 to streams due to the potential mobilization of previously frozen carbon stores in permafrost soils. Our future work plans include isotopic characterization of stream CO_2 and dissolved inorganic carbon, both of which will further our understanding of carbon cycling in permafrost regions.

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Study on the mechanical degradation of a frozen Alpine soil

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Degrading or thawing permafrost has been identified as being an issue of national importance with respect to its potential for causing severe damage or even loss of life in densely populated Alpine regions due to climate change [*Gruber 2004, 2007*]. On this basis, a joint study was initiated by Safe Mountain Foundation (Fondazione Montagna Sicura, Cormayeur, Italy) and University of Parma to investigate the variations of the geotechnical behavior of Alpine permafrost with temperature.

Permafrost may be found in Alpine regions at elevations higher than 2500 m above sea level, depending on the slope location and exposure. Its mechanical features are determined by the coupled contribution of the soil particles and of the ice. The water content can strongly influence the frozen soil resistance: if water content is low the ice will not able to include the soil particle, however, if it is too high the resistance will be mostly determined by the ice itself [*Andresland 1987*]. The temperature is another driving factor that influences the ice mechanical behavior [*Fish 1997*].

On this basis this work is dedicated to analyze the behavior of morainic deposits widespread in Alpine areas, subjected to different climatic conditions when temperature increases.

The work is, in particular, dedicated to the mechanical characterization of the thinner component of a two different morainic deposits present in Valle d'Aosta region: the first one situated close to Salati Pass in Gressoney Valley (Monte Rosa) and the second one close to Cime Bianche North Pass (Cervino). In particular the Salati Pass deposit is characterized by 40,5% of sand and 52% of gravel but its composition changes with depth, increasing the thin component.

Laboratory tests

Temperature, water content and deformation velocity influence on soil stress-strain behavior was investigated by means of uniaxial compressive tests by varying the temperature (between -4 and -22°C), the water content (about 10% and 23%), the strain rate ($9.06\ 10^{-5}$ and $2.52\ 10^{-4}\ s^{-1}$).

Vertical displacements and normal load were recorded during the test, and stress-strain curves computed. A thermo couple on the specimens was constantly recording the temperature.

The tests were carried out by using a MTS press equipped with a thermo controlled cell and by imposing an axial stress induced in strain rate control condition. Tests were performed on cylindrical specimens having diameter of 100 mm and height of about 200 mm and constituted by different soil-material: ice, saturated monogranular river sand and saturated morainic soil. The morainic soil was sieved with an upper cutoff of 50mm in such a way to respect the ratio of 1/20 between the specimen diameter and the maximum soil particle. All specimens have been frozen at the chosen temperature by keeping them in a thermal chamber.

Although some authors [*Arenson 2002*] have shown as these kind of deposits are not completely saturated and the circulation of air is one of the cause of the rapid permafrost degradation when temperature increases, only fully saturated specimens where tested. The reason of this choice being that a segregation of thinner soil component was observed with depth, which induces a reduction in permeability and consequently a slower air and water circulation. By consequence, a larger water/ice content can be assumed for these deposit strata.

Obtained results

The sample response during tests allowed interpretation on a small scale level. It seems that, depending on the volumetric, solid and ice content and the applied strain rate, the behavior changes from brittle to dilatant (or ductile). The shape of the specimens after failure showed this phenomena.

Compression of the sample resulting in a brittle response occurs at lower temperature and dilatant behavior is shown at higher temperature (Figure 2). This fact induces different failure mechanisms: at lower temperature a localized failure plane is evident whilst at higher temperature a global volumetric deformation is recorded.

The stress strain curve reported in Figure 1 clearly shows this phenomenon.

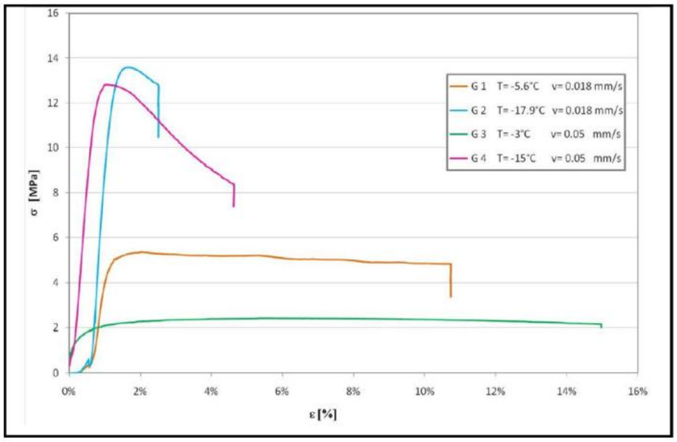

Figure 2 Stress strain curves of the saturated "Gressoney" samples obtained by varying temperature and strain rate.

The experimental results show as the frozen soil mechanical behavior is mainly affected by the sample temperature, whilst the water content and the strain rate don't substantially change neither the deformation nor the strength of analyzed material.

In particular both the deformability modulus E (computed at 50% of maximum strength) and the uniaxial compressive strength (Co) increase with a temperature decreasing as reported in Table 1.

Table1. Uniaxial compressive strength (Co) and deformability modulus obtained for tests carried out on frozen morainic samples (Cime Bianche).

Sample	***T***	***W***	***v***	***Co***	***E***
	[°C]	***[%]***	***[mm/s]***	***[MPa]***	***[MPa]***
1A-a	-3	12.21	0.007	0.84	40.00
1A-b	-3	12.21	0.014	1.37	64.00
1A-c	-5	12.21	0.021	2.40	224.00
1A-d	-1	9.76	0.021	0.25	19.00
1A-e	-5	9.76	0.021	0.61	73.00
1A-f	-11	12.33	0.014	1.32	73.00
1A-g	-6	12.33	0.014	1.50	140.00
1A-h	-2	12.33	0.014	0.83	81.00
1A-i	-11	12.33	0.021	1.58	40.00
1A-l	-12	12.33	0.007	1.00	36.50
1B-a	-10	9.1	0.014	1.31	150.00
1B-b	-12	11.19	0.014	1.61	107.10
1B-c	-5	11.19	0.014	1.34	213.30
1B-d	-3	11.19	0.014	1.88	107.80
1B-e	-10	11.19	0.021	1.90	183.30
1B-f	-12	11.19	0.007	1.58	84.80
2a	-9	10.36	0.007	2.30	300.00
2b	-10	10.36	0.021	3.10	616.00
2c	-2	11.31	0.021	0.48	82.20
2d	-4	11.31	0.014	1.11	105.60
2e	-4	11.31	0.021	1.00	51.10
2f	-12	10.61	0.014	2.77	319.00
2g	-3	10.61	0.014	1.04	0.00
2h	-1	10.61	0.014	0.35	24.00
2i	-8	10.61	0.021	2.00	151.30
2l	-13	10.61	0.007	2.04	355.60

One of the most important result regards the failure mechanism: a decreasing temperature shows not only the transition from a brittle to plastic behavior of frozen saturated soil but also an higher strain level at failure, increasing from 2% up to 15% at lower temperatures. This fact could have a strong influence on the slope pre-failure behavior to be taken into consideration in slope monitoring, for instance.

Concluding remarks

Climate changes can involve permafrost temperature variation, and thus induce a strong alteration in frozen soil mechanical behavior.

The tests performed showed that the most evident effects of a temperature increase are a strength reduction and a transition from brittle to ductile behavior.

This fact could have a direct drawback on Alpine slope stability since a strength reduction determines at first a reduction of slope safety factor.

Changing in mechanical behavior has also different consequences to be taken into account in Alpine slope monitoring purposes: in fact more ductile behavior involves larger deformation of the slopes to be correctly measured and interpreted. Not only, but when structures or buildings (e.g. ski-lift piles, mountain refuges) are constructed on frozen soil slope large deformation not compatible with structure serviceability states could occur.

Acknowledgments

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Active Layer Freeze-up Predictions to Support North-Slope Tundra Travel Management

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Introduction

Tundra travel on the North Slope, Alaska, is managed by the Alaska Department of Natural Resources (ADNR) to protect the tundra ecosystem from damage caused by transportation activities. In the past there have been various standards applied to determine tundra travel opening and closing dates. These methods included a slide-hammer test to estimate the strength of the frozen soil and a measurement of snow depth, which helps to shield the vegetation from vehicle impacts. The latest management approach is to use the 30 cm depth soil temperature of -5˚C as a criterion of opening tundra travel. The DNR maintains a network of manual observation sites to manage the four main tundra travel management zones on state-owned land on the North Slope. Individual projects may also collect data for specific needs as part of the regulatory permit process.

For this study, we used established research sites to simulate observed ground temperatures. A forecast tool was set up to run a 14-day ground-temperature prediction based on real-time measurements and weather predictions (air temperature).

Methods

Soil temperatures vary across the tundra and are affected by a variety of physical soil, snow and surface parameters. These parameters and variables include soil layering, heat capacity, soil moisture, thermal conductivity, soil-freezing characteristics, porosity, air temperature, snow density and geothermal heat flux. In order to understand and evaluate active layer dynamics we model soil temperatures throughout the year with a state-of-the-art model GIPL [*Daanen et al. 2011*, *Marchenko et al. 2008*, *Romanovsky et al. 2002*, *Sazonova and Romanovsky 2003*, *Sergueev et al. 2003*]. The model was developed to simulate freezing and thawing as well as long-term permafrost temperature simulations.

The model is prepared for a particular site using a multi-year dataset of temperature profiles to calibrate the model variables and parameters. The first step is the calibration of soil parameters using soil-surface temperature as input to the model. These parameters include soil layering and adjustment of soil thermal parameters to match the observed temperature data. The second part of the calibration process involves adjusting model parameters that simulate the impact of snow cover. This allows the model to accurately use air temperature as the controlling surface boundary condition. Snow has varying thermal properties from year to year, but the snow characteristics of a particular site are similar from year to year. An example of a calibrated model simulation is shown in Figure 1. The Deadhorse site is located near the end of the Dalton Highway.

After model calibrations are completed with historical data, we can use the parameters in the model to simulate new temperature predictions for the next 14 days, updated on a daily frequency. Using the GIPL model in this mode creates an effective soil-temperature forecast tool. The initial conditions for the forecast tool require real time data from the previous day of observations. If deep temperatures are not available we use preset numbers for the deeper portion of the temperature profile. These numbers are based on multiyear simulations with the model where we constructed a temperature profile based on an average temperature profile for each day of the year. Snow depth is collected from the research site and the density is set based on the calibration for the site. The air temperatures used to drive the model are collected from the National Weather Service (NWS) website for the Deadhorse airport on the North Slope.

We run the model automatically through scripts on a server at the University of Alaska Fairbanks. We run the model for 14 days based on the current conditions and the weather prediction for the next 7 days. Air temperatures for day 8 through 14 are set the same as the temperature on day 7. The results of the simulation are stored and forwarded to a server where they can be plotted and viewed.

Results

The model was setup to simulate a site on the North Slope of Alaska operated by the Geophysical Institute. An example of a calibration dataset is given in Figure 1. The prediction of ground temperatures is still largely depended on the driving air temperature, which is predicted by the NWS for the following 7 days. These data are automatically downloaded every day to drive the soil temperature forecast tool. The additional 7 days of constant temperature, the same as the last NWS predicted temperature (day 7), have similarity to a long term average temperature for the dates they are predicted for. The output data of the model are sent to a webserver where the data is plotted for an end user to observe. An on-line example of the forecast for the Deadhorse site is provided by the permafrost laboratory of the Geophysical Institute University of Alaska Fairbanks (www.permafrostwatch.org).

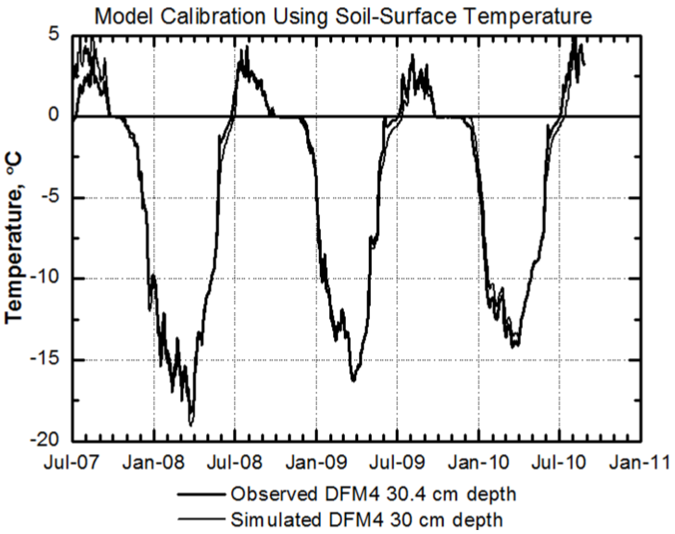

Figure 1 Model calibration for a permafrost site near Deadhorse Alaska.

Discussion

The multi-year calibration provides a good method for accurate daily predictions. The simulation results reflect the complexity of the freezing-soil physics solved in the model. Some physical soil parameters may vary from year to year and can be adjusted to improve the results for that year. One example is the surface wetness which can be adjusted each fall if those conditions are known. Snow is fairly consistent between years, but unusual heavy snowfall early during the winter may also require adjustments to the snow density.

The predictions of soil temperatures have been hampered by the stability of the telemetry connection with the permafrost observation site. The battery voltage limits the communication link with the remote station to conserve battery power. During extreme cold weather this voltage can drop to a level that would prevent establishing reliable data transmissions.

Accuracy of the prediction also depends on the availability of a good dataset for proper calibration of the model. New observation sites will need to have a few years of data in order to find the correct set of calibration parameters. In addition to shallow temperature measurements (30cm) this calibration also requires temperature time series from deeper depths in order to calibrate the lower soil profile fluxes.

In order to use a site in a production run for ground temperature predictions, an observation site will also require measurement of air temperature, snow depth, surface temperatures and soil moisture. These values are used as input variables in the forecast tool.

Conclusions

We have created a forecast tool to simulate soil temperatures based on real-time observations in the field and regional weather forecasts. The forecast tool is developed on an established permafrost observation point near Deadhorse, Alaska. The predictions are produced daily by the hosting server through automatically running scripts that have been developed to gather the required input data. The GIPL model is then run to make a ground-temperature prediction for the next 14 days based on the collected weather forecasts and site specific parameters.

Acknowledgements

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Changing Permafrost in the Arctic and its Global Effects in the 21st Century (PAGE21): A very large international and integrated project to measure the impact of permafrost degradation on the climate system

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The challenge

The northern permafrost region contains approximately 50% of the estimated global below-ground organic carbon pool and more than twice as much as is contained in the current atmospheric carbon pool. The sheer size of this carbon pool, together with the large amplitude of predicted arctic climate change implies that there is a high potential for global-scale feedbacks from arctic climate change if these carbon reservoirs are destabilized.

Nonetheless, significant gaps exist in our current state of knowledge that prevent us from producing accurate assessments of the vulnerability of the arctic permafrost to climate change, or of the implications of future climate change for global greenhouse gas (GHG) emissions. Specifically:

- Our understanding of the physical and biogeochemical processes at play in permafrost areas is still insufficient in some key aspects
- Size estimates for the high latitude continental carbon and nitrogen stocks vary widely between regions and research groups.
- The representation of permafrost-related processes in global climate models still tends to be rudimentary, and is one reason for the frequently poor performances of climate models at high latitudes.

Project Objectives

The key objectives of PAGE21 are:

a) to improve our understanding of the processes affecting the size of the arctic permafrost carbon and nitrogen pools through detailed field studies and monitoring, in order to quantify their size and their vulnerability to climate change,
b) to produce, assemble and assess high-quality datasets in order to develop and evaluate representations of permafrost and related processes in global models,
c) to improve these models accordingly,
d) to use these models to reduce the uncertainties in feedbacks from arctic permafrost to global change, thereby providing the means to assess the feasibility of stabilization scenarios, and
e) to ensure widespread dissemination of our results in order to provide direct input into the ongoing debate on climate-change mitigation.

Methodology

The concept of PAGE21 is to directly address these questions through a close interaction between monitoring activities, process studies and modeling on the pertinent temporal and spatial scales. Field sites have been selected to cover a wide range of environmental conditions for the validation of large scale models, the development of permafrost monitoring capabilities, the study of permafrost processes, and for overlap with existing monitoring programs. PAGE21 will contribute to upgrading the project sites with the objective of providing a measurement baseline, both for process studies and for modeling programs. PAGE21 is determined to break down the traditional barriers in permafrost sciences between observational and model-supported site studies and large-scale climate modeling. Our concept for the interaction between site-scale studies and large-scale modeling is to establish and maintain a direct link between these two areas for developing and evaluating, on all spatial scales, the land-surface modules of leading European global climate models taking part in the Coupled Model Intercomparison Project Phase 5 (CMIP5), designed to inform the IPCC process.

Expected Results

The timing of this call is such that the main scientific results from PAGE21, and in particular the model-based assessments will build entirely on new outputs and results from the CMIP5 Climate Model Intercomparison Project designed to inform the IPCC Fifth Assessment Report.

However, PAGE21 is designed to leave a legacy that will endure beyond the lifetime of the projections that it produces. This legacy will comprise

an improved understanding of the key processes and parameters that determine the vulnerability of arctic permafrost to climate change,

the production of a suite of major European coupled climate models including detailed and validated representations of permafrost-related processes, that will reduce uncertainties in future climate projections produced well beyond the lifetime of PAGE21, and

the training of a new generation of permafrost scientists who will bridge the long-standing gap between permafrost field science and global climate modeling, for the long-term benefit of science and society.

Analysis and Design of Low-Temperature Phonetic Geothermometer

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Abstract

Geothermometer is a special instrument to measure soil temperature, the core component of which is usually mercury glass thermometer. The general maximum measuring range of geothermometer is 300mm. In low temperature conditions of cold regions, the mercury thermometer has the limitations of inconvenient reading, shortage range and finite application for field test. Due to these limitations, the design scheme of the Low-Temperature Phonetic Geothermometer is put forward in the paper. In the practical circuit system, temperature sensor chip DS18B20 with stainless steel encapsulation is chosen as a temperature sensor, AT89S51 single-chip microcomputer is employed in temperature signal acquisition, data processing and voice play back controlling device, voice chip ISD1420 is adopted as voice recording and playback device. Soil auger is the measuring carrier of geothermometer and the design has achieved an integration of digital with voice broadcast as one of the low temperature and large range geothermometer. The design meets most of the requirements for the frozen soil conservation monitoring test in the aspects of temperature range and cold resistance. Along with all the improvements, the handiness and accuracy of frozen soil moisture monitoring tests will be greatly enhanced.

Changes in the Salinity Degree of Lakes Under the Influence of Anthropogenic Factors and Cryogenic Processes: Case of Krugloye Lake, Yakutsk

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Introduction

Low terraces of the middle course of the river Lena abound with oxbow shallow lakes of an erosion origin. These lakes, along with shallow rivers, were drains for surface and suprapermafrost waters. Currently, due to strong flow control, they are collectors of different polluting agents. The hardest anthropogenic stress affects the lakes located on the territory of the Yakutsk city.

Study Methods

The task of studying changes in chemical composition of the lakes affected by natural and anthropogenic factors has required conducting the analysis of the hydrochemical testing data of Krugloye Lake located on the second terrace above flood-plain of the the Lena River. The results of chemical analyses of water for years 1954, 1963 and 1994-2007 were taken from stock materials of the Permafrost Institute. Since 2008 water samples have been taken with the participation of the author. It should be noted that in 1994-2011, during the period of maximum freezing of the water reservoir, the water was taken from six holes (five along the perimeter and one in the center of the lake). The analyses results were averaged out for obtaining a general hydrochemical characteristic.

Discussion of Results

Krugloye is a shallow lake, it has a small water-collecting area, lake shore lines are poorly marked. The water reservoir in the 1950-s had dimensions 40x30 m and the maximum depth in summer did not exceed 1.5 m. The lake basin was covered by grassland vegetation. The water body was naturally fed by atmospheric precipitation and suprapermafrost waters of a seasonally thawed layer. In 1954 the water had sulphate-hydrocarbonate composition, with mixed cations and prevailing calcium. The salinity level was 0.4 g/l. In winter the water reservoir froze, except for the central part where the water layer had thickness of 0.5 m. Below the lake there was a closed talik, 13 m thick, which froze from the top to the depth of 2.3 m in a winter period. Water-bearing soils are quarternary silty and fine-grained sands. The total thickness of loose quaternary deposits is 25 m. The underlying soils are weathered Malm sandstones. The water composition in talik includes magnesium and sodium chlorides and hydrocarbonates, with salinity of 4.5 g/l.

In order to preserve the lake, from 1963 till the mid of the 1980-s it was intermittently fed from the neighboring bore hole with subpermafrost water, which was extracted at the depth of 310 m and had sodium chloride/hydrocarbonate composition and salinity of 1.29 g/l. In order to prevent surface- and over-permafrost flow of water from the lake to local mesodepressions, the water reservoir was dammed at the eastern side. A road was laid along the northern and western edges of the lake basin. The pumping of subpermafrost waters resulted in the 6-time increase of the lake area and the lake depth became 3.6 m.

According to testing data of 1963, the water salinity in the lake in summer was 0.941 mg/l, the anionic composition remained the same, the cationic composition changed: sodium became a prevailing cation and its content increased from 25 %/me* to 62 %/me*. During winter period the content of chemical elements in the lake water reached 2.1 g/l through increase of ions of sodium, magnesium, sulphates and chlorides. The increase of the water salinity caused changes in vegetation around the lake: its shores began to be overgrown with reed.

In 1985 a bore hole was drilled in the center of the lake. This bore hole detected significant increase of talik thickness – over the entire thickness of quaternary deposits. No hydrochemical testing of talik waters was conducted but the high migration capability of ions of sodium, sulphates and chlorides, which enriched the lake water, evidences, without any doubt, the considerable growth of salinity of water in the talik.

In spite of termination of pumping of subpermafrost waters to the lake from the mid of the 1980-s, no decrease of lake salinity is observed, which is connected with the anthropogenic disturbance of the over-permafrost flow. It can be deemed that since the end of the 80-s the chemical composition of the lake has been formed mostly under the influence of natural factors.

According to data of hydrochemical research conducted in 1994-2011, the water in the lake has the least salinity at the end of May - in June. But even at this time it exceeds 2.5 g/l. By the end of summer, intense water evaporation results in enrichment of water with chlorides, sulphates and sodium and water salinity increases to 3.0-3.5 g/l. During winter period, because of settling of calcium hydrocarbonate and cryogenic concentration of chlorides, sodium and magnesium, salinity of the water reservoir increases to 4.3-5.8 g/l reaching 8 g/l in individual cold years.

When studying the changes in chemical composition of the lake along its perimeter, it was noted, that site No. 3 annually features minor decrease of water salinity. Basing on the method proposed by Anisimova N. P, [*Anisimova, Makarova and others, 1989*], it follows that submerged discharge of suprapermafrost waters can exist on this site.

In order to confirm the fact of suprapermafrost waters flow into the lake, 2 bore holes were drilled in 2011 (boreholes 4/11 and 5/11). According to drilling data, thawed water-bearing grounds in the bore hole located at the distance of 30 m from the lake underlie at the depth interval of 2-5 m; thawed grounds in bore hole 5/11 located at the distance of 35 m from the lake are registered at depths of 2.1 and 3.7 m. According to hydrochemical testing data, suprapermafrost waters have similar chemical composition as lake waters but their salinity is significantly lower - 0.7 g/l. Bore holes are fitted with equipment for monitoring observations over the level and chemical content of suprapermafrost waters.

Conclusions

The growth of water salinity is caused by cryogenic concentration of salts in colder years with low thickness of snow cover and increased thickness of ice, and the decrease of lake salinity is a consequence of dilution of lake water with atmospheric precipitation.

Notwithstanding the fact that fresh suprapermafrost waters feed the lake, its salinity is not reduced due to minor volume of suprapermafrost waters flowing from water-collecting area.

Table 1. Average chemical composition of Krugloye Lake, me

Date	**Ca^{2+}**	**Mg^{2+}**	**Na**	**Na+K**	**HCO$_3^-$**	**SO$_4^{2-}$**	**Cl$^-$**	**Total hardness**	**Salinity, mg/l**	**pH**
March 1, 1966	4.0	7.0		21.1	6.2	16.4	7.9		1963.12	-
February 2, 2000	1.4	24.1		64.2	21.2	22.3	40.7	25.5	5771.15	8.95
March 2, 2006	7.2	20.0		46.8	19.4	17.7	37.1	27.3	4217.72	-
March 26, 2007	5.1	21.6	39.8		23.0	14.7	27.1	26.6	4369.31	9.02
March 14, 20088	3.8	13.2	26.2		18.3	7.5	14.0	17.0	2833.05	7.38
March 3, 2009	4.5	19.0	26.7		26.9	8.1	22.9	23.5	3793.74	7.58
March 30, 2010	9.1	37.3	69.9		53.2	18.9	47.0	46.4	8076.74	7.94
March 1, 2011	5.6	22.7	44.8		30.1	14.9	27.3	28.3	4091.01	8.27

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Linkage Between Frozen Ground Change and Streamflow Regime Over Northern Watersheds

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Abstract

Climatic condition and its change significantly affect the thermal regime of active layer and permafrost. Climate warming in the northern regions results in higher active layer/permafrost temperatures, northward movement of the permafrost boundary, and a deeper active layer. Many studies show that permafrost temperature in the northern regions has warmed more than 2-3°C and active layer thickness has increased by up to 20-40 cm over the past several decades. It has been predicted that, under a moderate climatic warming scenario, changes in permafrost temperature and active layer thickness will become more significant in the next few decades over the Arctic/subarctic regions. Changes in the active layer thickness impact surface runoff processes, directly affecting groundwater storage and river discharge. Recent analyses reveal that low flows during the fall-winter season have increased over the northern regions, i.e. in Yukon River and Siberia watersheds. This may indicate hydrologic response to climate and permafrost changes.

The linkage between streamflow processes and permafrost changes is not well understood due to limited data and field observations. Recently, we carried out investigations on ground temperature, active layer depth, and streamflow changes over the northern regions/watersheds. We examined long-term climatic/hydrologic (discharge) and permafrost data to explore/define the relationship between discharge characteristics and basin permafrost coverage/soil temperatures over selected watersheds. We have focused our efforts on the regions/basins with significant climate/permafrost/hydrology changes, such as the Yukon River in Canada/USA, and the Aldan basin in the upper Lena river, where ground temperatures and low (base) flows have increased in the last decades. We have produced new and interesting results; these results are useful to quantify and assess the impact of permafrost changes on streamflow variations in the northern basins, and they improve our understanding of climate change, permafrost dynamics, and basin hydrology over the high latitudes.

Temperature Regime of Permafrost Affected Soils in Northern Yakutia

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Introduction

Monitoring of soil temperatures in Northern Yakutia using automated data loggers has been run mainly as part of the CALM international program (Circumpolar Active Layer Monitoring), since 1998 in the Kolyma Lowland and since 2008 in areas west of it (Allaiha rIver, R31) and Bykovskiy Cape, R29A). Altogether, measurements have covered 19 soil profiles (Fig. 1).

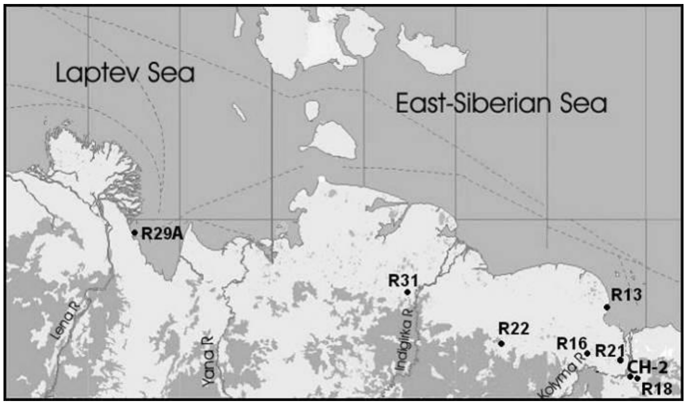

Fig. 1. Location map of key temperature monitoring sites in Northern Yakutia. R13 – Malyi Chukochiy Cape; R16 – Segodnya Pingo; R18 – Rodinka Mountain; R21 – Akhmelo Lake; R22 – Alazeya River; R29A – Bykovskiy Cape; R31 – Allaiha River; CH-2 – Malinovy Yar.

Results and Discussion

The temperature regime of zonal loamy tundra soils (Cryozem soils, Haplic Cryosols) on drained watersheds under vegetation consisting of low shrub-grass-green moss or grass-green moss-dryad plant communities depend on latitude. In the Arctic tundra (site R29A, 71°47’ N), the mean summer temperature (June-August) at 20 cm below the soil surface is negative (-0.3°C) (the temperatures are reported hereafter as the mean multi-year values) because of low June temperature while the monthly mean of August, the warmest month, is 0.45°C; mean summer temperatures in typical tundra (R13, 70°05’ N and R31, 70°33’ N) are 1.9-2.0° and the August means are 3.0-3.4°C; the respective values for southern tundra at the northern forest line (R22, 69°19’ N) are 3.9° and 5.4°C (Fig. 2). The annual sums of positive daily means at 20 cm below the surface are 53°C in Arctic tundra, 227-262°C in typical tundra, and 429°C in southern tundra; the percentages of ecologically sufficient temperatures (above 5°C) relative to those values are 0%, 34-36%, and 58%, respectively.

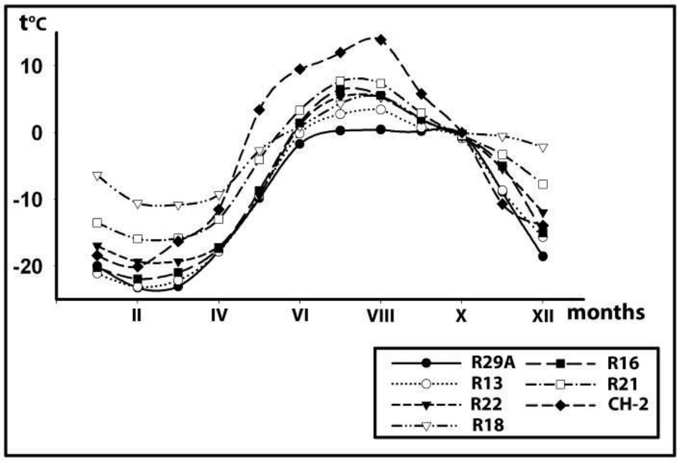

Fig. 2. Annual dynamics in soil temperatures at key monitoring sites (monthly means, measured 20 cm below the soil surface).

The distribution of temperatures according to small-scale elements of frost moundy microrelief in tundra (R22) is worth special consideration. The mean summer and the mean August monthly soil temperatures are 3.2-3.3°C lower in overwetting and peaty soil of intermound depression relative to those of frost mound, at the same depth (20 cm), while the respective differences in annual amplitudes and in sums of positive temperatures are 5.7°C and almost 300°. The temperatures never reached the ecologically sufficient values over the observation period, even in the abnormally warm year of 2007.

Zonal soils in northern taiga have more diverse temperature regime than those of tundra. They differ as a function of timber stand thickness, succession stage of plant communities, soil cover features, as well as direction and slope angles and exposure. The mean summer temperature of Pale soil (Cambic Cryosol) is 3.6° (mean August temperature is 5.4°C) at a plain site of green moss – lichen – low shrub larch light forest (R18, 68°45’ N) at 20 cm depth (Fig. 2) while in a flat southern slope these temperatures are, respectively, 4.9°C and 5.8°C. The predominance of moss decreases the summer and August means to 1.3°C and 2.6°C, respectively. The sum of positive daily temperatures is in the range 165-515°, with 54-66% of values above 5°C, but soils never warm up to 5° in the presence of moss parcels. Generally, they are winter rather than summer temperature means that are warmer in northern taiga relative to those in southern tundra. For instance, the means of February, the coldest month, measured at the 20 cm depth, are -23.3°C in Arctic tundra, -23.1°C in typical tundra, and -19.4°C in southern tundra but are as high as -7.6 to -10.8°C in taiga (Fig. 2). The sum of negative temperatures at 20 cm below the surface is markedly lower in northern taiga (R18) than in southern tundra (R22): -1280° against -3045. Winter temperatures of taiga soils are warmer due to vegetation and snow covers, the snow being less dense, thicker, and more stable than in tundra. In open taiga areas where no thick snow cover can accumulate, winter soil temperatures are closer to those in tundra rather than to the taiga values. The mean annual values of soil temperatures (20 cm deep) are 4-5°C higher in taiga than in tundra (mainly at the account of winter temperatures): from -2.3 to -2.9°C against -7.2, respectively; the annual amplitude of monthly means is 8.5-11.0°C lower.

The soil texture controls the temperature regime of soils, along with latitude and climatic zone location. Sandy Podbur soils (Spodic Cryosols) in tundra (sites R16 and R21) have more contrasting temperatures than loamy Cryozem soils, with higher summer means and colder winter temperatures. The winter temperatures being lower, the annual amplitudes are 3.2-4.4°C larger in sandy than in loamy soils. Furthermore, sandy soils are more thermal conductive than loamy ones and can warm up to greater depths. The temperature of Loamy Cryozem soils below 30 cm, both in tundra and in taiga, are never above 5°C while sandy Podbur soils have temperature sums of 23-195°C at 50 cm below the surface, which is 12-49% of the total sum of positive values. In some years, Podbur soils at the depth 20 cm had active (above 10°C) daily means, which has never occurred in any loamy zonal soil. Mean multi-year sums of active temperatures make 15-16% of the total sum of positive temperatures. Podbur soil in drained tundra (R21) is the warmest of all considered zonal soils: its summer mean (at 20 cm below the surface) is 6.1°C, the mean temperature of the warmest month is 7.7°C (Fig. 2), and the annual sum of positive temperatures is 653°.

Among azonal soils, those in small steppe areas are the warmest in the region. The mean summer temperature of one such soil profile (at 20 cm depth) on a southern coastal slope (CH-2) is 11.8 and its August mean is 13.9°C (Fig. 2), which is about 6oC higher than the respective temperatures of Podbur soils in drained tundra (R21), the warmest zonal soil. The sum of positive temperatures at 20 cm below the surface is 1370°, out of which 93% are above 5°C and 66% above 10°C. Active daily means in these profiles penetrate as deep as 40 cm. Steppe soils with low water contents are subject to high temperature contrasts, annual amplitude reaching 34°C (20 cm deep).

Heat availability (amount of heat available for warming the soil from zero to maximum temperature) estimated according to enveloping temperature curves increases in the series: tundra Cryozem soils (3600-3700 kcal/m^2 per year) – taiga Pale soil (5200 kcal/m^2 per year) – tundra Podbur soils (6000-6200 kcal/m^2 per year) (Fig. 3). Thus, formation of genetically different soils depends on the amount of heat they receive.

Conclusions

1. Temperatures of loamy soils in the Kolyma Lowland increase in the series from north to south. The same trend is for percentages of ecologically sufficient temperatures (from 5 to 10°C) per sum of positive values. The soil temperature difference between tundra and northern taiga is due more to winter rather than summer temperatures because of warming effects of forest vegetation and snow cover.

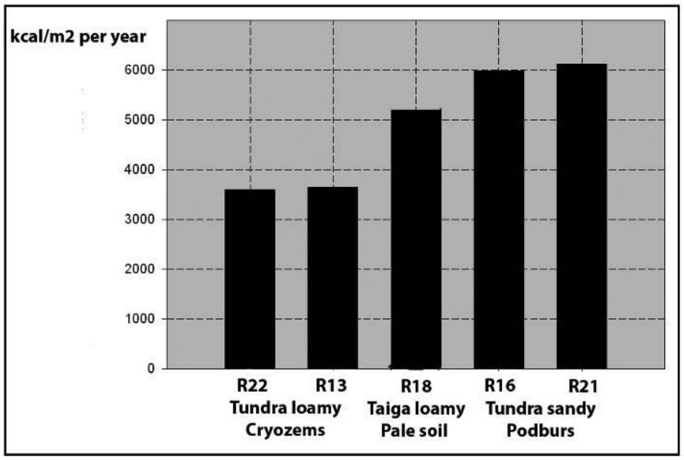

Fig. 3. Heat availability of main zonal soils of Northern Yakutia..

2. The frost moundy microrelief and the related soil cover complexity in tundra cause diverse temperature regime in the active layer. Intermound depressions are always cold (below 5°C) and have much lower annual temperature amplitudes than frost mounds.

3. Sandy Podbur soils have higher summer temperatures and greater depths (to 50 cm) of the 5°C isotherm than the loamy soils of tundra and taiga. In some years, Podbur soil profiles (20 cm below the surface) reach mean daily temperatures above 10°C, which never occurs in other zonal soils.

4. Xeromorphic loamy soils of extrazonal steppe communities are the warmest over the study area. They have the highest summer temperatures and maximum annual amplitudes.

5. The zonal soils of Northern Yakutia make up a heat availability series growing as ‘tundra loamy Cryozem soils < taiga loamy Pale soil < tundra sandy Podbur soils’.

Model Experiment Study on Pile Skin Friction during Frozen Soil Thawing Process

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Introduction

With the economic development of Western China, engineering construction has just been unfolding in cold regions. But as the global warming and construction disturbance, the mean annual ground temperature is increasing and the permafrost is degenerating. Some engineering diseases such as frost-heave and thaw-settlement become common phenomena. In order to ensure the stability and normal working of structure on frozen ground, some engineering and technical measures must be taken to guarantee the engineering foundation stability. Considering pile foundation has preferable load-carrying properties relative to the other foundation, it is widely used in the cold regions building [*Orlando B. Andersland and Branko Landanyi, 1994*]. However, due to the ground warming effect caused by atmospheric temperature increase and human disturbance will change the relationship of pile-soil interaction, which will further bring about the pile-soil interface adfreezing force decline, and at last, lead to the pile foundation settlement. In turn, this interfacial shear sinking process exacerbated the interface temperature increasing, which will bring about the pile skin friction distributed unevenly along pile skin, and produce an excessive downdrag to pile. This downdrag force is named negative skin friction produced by subsoil thawing settlement. With regard to negative skin friction in civil engineering, there has progressively gained attentions from the engineering profession after many foundation failures due to excessive downdrag. They suggest that there are six probable, but not limited to, reasons of existence of negative skin friction, namely, self-weight of unconsolidated recent fill, surcharge-induced consolidation settlement, consolidation settlement after dissipation of excess pore pressure induced by pile driving, lowering of groundwater level, collapse settlements due to wetting of unsaturated fill, and crushing of crushable subsoil under sustained loading, causing subsoil settlement [*Shi Peidong 2008*]. However, the settlement induced by subsoil thawing will not be motioned. But in cold region, the influence of the freeze-thaw transfer has to be considered as it will produce froze-heave or thaw settlement of soil around pile. This will change the way of pile-soil interaction and lead the structure damage. This paper investigate the influence of frozen soil temperature, pile section shape, load on soil layer, and cryostructure on pile skin friction by a series of model experiments. Meanwhile, by making use of the indoor model test (Fig. 1), this paper has also discussed that, the relationship between pile skin resistance and soil temperature, the relationship between pile axial stress and soil temperature, and the relationship between pile skin resistance and pile-soil relative displacement during the thawing process of frozen soil. At last, contrasted theoretical pile axial stress with pile axial stress measured by experiment in the pile, it is found that, the theoretical pile axial stress basically agreed with the measured pile axial stress. The following main conclusions have been obtained according to research.

Figure 1. Model pile test assembly picture

1. Although frozen soil temperature is different, distribution curve of the pile skin resistance caused by the thawing soil settlement along the pile presents on the shape of "S". The maximum pile side resistance reduces with the frozen soil temperature increasing. The position where the maximum pile side resistance appears falls with the frozen soil temperature increasing. The neutral plane falls with the frozen soil temperature increasing.
2. The surface load on the soil layer has great influence on the pile side resistance caused by the thawing soil settlement. The maximum pile skin resistance increases with increasing of load. The position where the maximum pile skin resistance appears rises with increasing of load. The neutral plane falls with increasing of load.
3. The different section shapes of piles have great influences on the maximum pile skin resistance and the neutral plane position. During the thawing process of frozen soil, the maximum pile skin resistance of the circular pile is greater than that of the foursquare pile. The neutral plane of the circular pile is lower than that of the foursquare pile.
4. The different thickness ice layers are located in the soil in order to produce different cryostructures. The different cryostructures have great influences on the maximum pile skin

resistance. The three different tests have been carried out, which are no ice layer test, single ice layer test and double ice layer test. Among three different tests, the maximum pile skin resistance of the no ice layer test is the greatest, and the maximum pile side resistance of the double ice layer test is least. Meanwhile, the position where the maximum pile side resistance appears is the highest in the no ice layer test, and the position where the maximum pile side resistance appears is the lowest in the single ice layer test.

5. During thawing process of frozen soil, the pile skin resistance τ and the pile-soil relative displacement δ present on the function. The pile axial stress formula is obtained by making use of the load function relation. Contrasted the theoretical pile axial stress with the pile axial stress, it is found that, the distribution curve of theoretical pile axial stress basically agreed with that of the measured pile axial stress. It shows that the pile shaft stress formula is reasonable.

Acknowledgments

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Problems of Ensuring Geotechnical Safety of Small Populated Areas in the Arctic Regions of Russia (the Case of Igarka Town)

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Abstract

Northern populated places located in Russia recently received a new impetus for further development. It is primarily associated with the development of large deposits of fossil fuels as well as with the attention that the government pays to the Arctic region. Based on the case of Igarka town, this paper discusses the problems connected with the development and operation of the infrastructure of northern populated places that are associated with the presence of permafrost. Another goal of this work is to trace the climatic trends of the 20th century and the response of permafrost serving as foundation ground to these trends. The anthropogenic factor is taken into account.

Keywords: anthropogenic impact; geotechnical state; permafrost response; Yenisey North.

Due to the increasing intensity of the economic development in the Yenisey North associated with the development of fossil fuel deposits, the problem of ensuring geotechnical safety of the region is rather urgent. The town of Igarka has a long and glorious history connected with a permafrost research station established here as early as 1930s. One of the first studies of the mechanics, rheological characteristics, strength, thermal regime and other parameters of frozen grounds were conducted in this laboratory. Over the past decades, the town experienced hard times, which took its toll on its geotechnical situation.

Igarka is located in close proximity to the southern border of permafrost distribution. The existence of islands in this area is determined primarily by ground characteristics (particle size distribution, moisture content, peat content) and landscape conditions. This area is characterized by a great thermal impact of various covers on the temperature of ground masses, as shown in earlier works of the employees of the Igarka Permafrost Research Station [*Pavlov et al. 1976; Pavlov & Sergeev 1989*]. The town is located on the surface of the Karginskaya terrace of the Yenisey River. Predominant deposits are cover clayey silts underlain by fluvioglacial sands and varved clays; bedrocks are represented by tuff-breccia. Most of the population currently lives in two residential districts built during the period from late 60s to early 90s, in buildings with cold reheat systems, which indicates the intention to preserve the foundation grounds in the frozen state. The foundations of buildings are mostly point bearing piles resting on a shallow (5-15 m) rock bed.

The analysis of surface temperatures demonstrated that the mean annual air temperature during the period from 1930s to 2000s increased on average by 0.0062° C for a year, largely due to summer heating. In this regard, we can speak about a very important role that the snow cover plays in the formation of grounds thermal regime. Although the snow cover is not very thick in this area (on average, 50-60 cm), its distribution largely depends on natural conditions (prevailing wind direction etc.) and its redistribution by people.

During the operation of the buildings located in a residential district, building 27 was partially demolished due to subsidences that made its further operation impossible. The efforts to save the building beside it were not successful, and as a result, its residents were moved out. Apparently, the reason for this was a break in utility pipes, which caused thawing of newly formed permafrost. New formation of permafrost occurs due to the presence of the cold reheat systems in buildings and compaction of snow in the areas adjacent to the buildings (trackways etc.).

Figure 1. Activities aimed at preventing deformations of a residential building in the 1st district. The central part of the building is dragging the side parts along. (Photo by S.V. Poznarkova, July 2010).

Also, large fill layer that freely filters waters, persistent snowbanks and permafrost under trackways and spaces free of snow aggravate the hydrogeological situation in the town. Another example is the recently constructed somatic department of the children's hospital that was not commissioned on time and was left empty for several years. Cracks caused by uneven heaving deformations due to aggradation of permafrost under the building are visible on the building's grillage.

We should also note the state of buildings that are located on spatial shell foundations. The monitoring of thermal regime under the building is being conducted. Inclinometers are installed in the largest cracks. Another building constructed on the same foundation type, but which is located in a frozen area was demolished in 2010.

Conclusions

The main geotechnical issues in the town of Igarka are:

1) violations of rules of buildings operation;

2) design errors;

3) absence of monitoring of the state of structures and foundation grounds.

It is also important to note that global climate processes do not have a significant impact on the thermal regime of grounds in Igarka.

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Remote Sensing for Permafrost Monitoring

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Aerial and satellite monitoring of permafrost within lease areas and linear engineering structures (pipelines) in oil and gas fields under development is part of general monitoring of the subsurface.

Monitoring of the subsurface is a system of regular observations, acquisition, accumulation, processing, and analysis of data used to estimate the state of the subsurface and to predict its possible changes in response to natural and anthropogenic impacts associated with petroleum exploration and production, pipelining inside and outside oil fields, and other activities.

The obtained permafrost monitoring data are used in mine-surveying geodetic, geotechnical, productional, environmental, engineering-geological, and other kinds of monitoring.

Remote sensing (aerial and satellite imagery), the quickest and a relatively cheap geoinformation technology, integrated in a system together with other ways of monitoring the subsurface state and changes, furnishes basic permafrost-relevant information.

Geocryological aerial and satellite monitoring performed while developing oil and gas fields in permafrost is a subsystem (at the level of objects) of subsurface monitoring concerning surface and shallow geological processes. It is compulsory in reservoir studies and in petroleum production, and is regulated by special guideline documents.

This kind of monitoring is necessary to minimize the risks of hazardous permafrost-related processes associated with petroleum exploration and development.

Remote sensing data have implications for:

- current state of permafrost-related processes in oil and gas fields, including the zones of their substantial influence;
- current, short-term, and long-term dynamics of hazardous permafrost-related processes, both within the fields and in their influence zones;
- damage costs, including the costs of preventive and mitigation measures against permafrost hazard and its negative effects on the environment during development;
- measures and respective techniques for providing sustainable production, preventing emergency, and mitigating impacts upon shallow geological processes and groundwater circulation;
- efficiency of production improvement measures that provide complete recovery at minimum possible inexpedient losses;
- changes to the subsurface which, in turn, result from changes in permafrost conditions associated with petroleum exploration and development, as well as other related economic activities;
- development planning, especially the recommended position of well clusters and ways of their transfer to the optimum permafrost conditions.

Interpretation of deciphered aerial and satellite images in terms of permafrost allows detecting and mapping hazardous processes and phenomena that have to be taken into account in planning and development works within the permafrost zone.

The major permafrost-related hazard is from thermokarst, thermal erosion, ice-wedge polygons, frost heaves, icing, solifluction, and landsliding.

The goal of the aerial and satellite monitoring of permafrost is to provide information for nature management in terms of control, assessment, and prediction of natural and man-caused permafrost hazard.

Particular monitoring objectives depend on the conditions of subsurface use licenses and on performance specifications.

The acquired information is used in management decision making for preventing emergency, reducing negative environment impacts of development, and supervising the adherence to license conditions.

Changes in permafrost conditions (reactivation of hazardous processes) show up as changes in permafrost temperature within well clusters, in the subsurface around them, and in other infrastructure objects (quarries, pipelines, engineering sites).

Changes in permafrost conditions may have natural causes (climate warming) or be triggered by production activities. Hazardous permafrost changes are linked with changes in geological, hydrogeological, and engineering-geological conditions, and this linkage has to be taken into account when setting up and performing the monitoring work.

Temperature changes in frozen ground give rise to thermokarst, ice-wedge polygons, and heaves and induce erosion, icing, solifluction flow, and landsliding.

Monitoring can be successful provided that there is a single information space created on the basis of advanced GIS technologies. The latter imply data integration and thus can be a powerful tool for collecting, storing, systematizing, and presenting information. The characteristics of geoinformation systems make this technology the basic one to be used for the purposes of processing and control of monitoring data.

Inasmuch as remote sensing databases store record of all environment parameters (geological, cryological, geographic, agricultural, ecological), it is reasonable to interpret them jointly and to analyze the deciphering results (including integration with geophysical and exploration data) within the limits of geoinformation systems, with controlled visualization of specific maps and their objects. This approach can yield consistent sets of maps, instead of complicated and often overburdened ones, i.e., provides well organized presentation of data to be used efficiently for different purposes, including deciphering other remote sensing images.

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Active Layer Monitoring in Limnopolar Lake CALM Site in Byers Peninsula, Livingston Island, Antarctica

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Introduction

South Shetland Archipelago, Antarctica, is located near the 0°C isotherm of Mean Average Air Temperature -MAAT- what involves the Antarctic continent. It means that frozen soils (permafrost) could be degraded under the warm climatic conditions of the summer. Thaw period could derive on permafrost melting and increase on its Active Layer Thickness -ALT-, what could be reflected on the landscape (periglacial features). ALT evolution is a tool to understand the landscape geomorphology, but also check the effect of the climate on the permafrost. Then, in order to monitor ALT in the South Shetland Archipelago area, we established a 100 m x100 m grid to measure it deep by mechanical probing, in February 2009,, following the Circumpolar Active Layer Monitoring (CALM) protocol [*e.g., Brown et al. 2000*]. Moreover, we monitor ATL thermal state by sensors on the surface and inside of it by mean of two shallow boreholes, we also monitor air temperature data in the area. This CALM site increases our monitoring sites established in different locations of Deception and Livingston islands since 1989, although continuously since 2000 [*e.g., Ramos et al. 2007*] in order to study the effect of the climate evolution in Maritime Antarctic permafrost. Measurements have been done during the thaw season in February 2009, 2010, 2011 and 2012, thanks to the logistics of the Spanish Antarctic Campaigns. In this paper we present the Limnopolar Lake CALM site, its instrumentation and a brief summary of the most important results for 2009-2011 period.

The study area

Limnopolar Lake CALM site (62°38’59.1’’S, 61°06’16.9’’W) was established in the Limnopolar Lake basin, Byers Peninsula, Livingston Island, South Shetland Archipelago, Antarctica (Figure 1). This site is a glacier-free area with an open character without orographic barriers upwind, without thermal anomalies (such as occurs on Deception island) and with detritical material (and not rocky and coarse materials such as occurs on Livingston island). Then, those characteristics should make it an excellent location for detecting regional changes in climate.

Byers Peninsula is the largest non-glaciated area in the South Shetlands, although snow covers it during 7-8 months per year. Precipitation is well in excess 200 mm [*e.g., Toro et al. 2007*]. Mean summer air temperatures are about 1°C to 3°C, with daily extremes values of 10°C and -10°C. In winter, daily air temperature ranges between 0°C and -35°C [*e.g., Toro et al. 2007*]. These conditions convert this region on the climatic limit of permafrost existence.

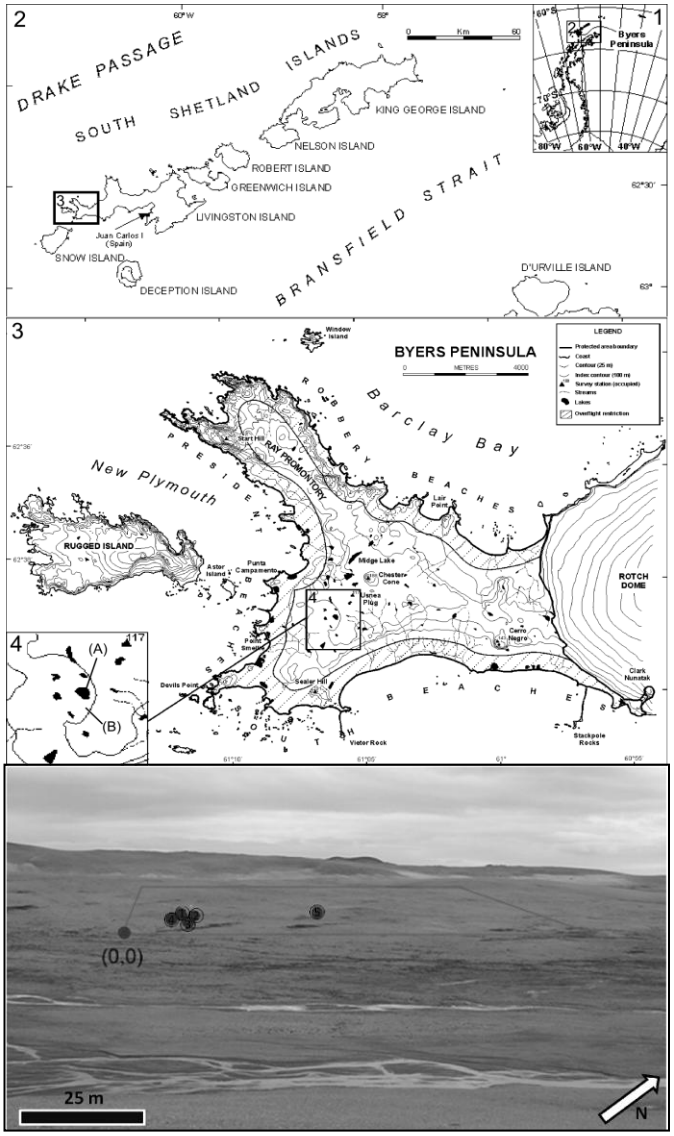

Figure 1. (Above) Location of the Limnopolar Lake CALM site; Antarctica (1), South Shetland Archipelago (2). study area in Byers Peninsula (3), (Below) View of the CALM site (grey box) and instrumentation (Black dots).

Byers Peninsula is dominated by a smooth undulated plateau at about 105 m a.s.l. forming small drainage basins. The geology is mainly characterized by Upper Jurassic – Lower Cretaceous volcanic, volcanoclastic and sedimentary materials (both detritical and carbonates), as well as different intrusive igneous bodies, and Quaternary sediments [*López-Martínez et al. 1996*]. Periglacial, glacial, fluvial, and weathering processes affected the bedrock after the deglaciation of the peninsula generated a mantle of gravels, sands, and debris, locally forming stone circles, polygonal terrains, patterned ground, and other landforms [*López-Martínez et al. 1996*]. These features show the important role of periglacial dynamics and many of them are indicators of permafrost [*López-Martínez et al. 1996*].

The CALM site, instrument and methods

The CALM site is a square grid 100 m x100 m, with 10 m spaced nodes, limited by orange-painted wood stacks in the grid edges. The site extends from the highest to the lowest part of the flank of a small hill (Figure 2) at the southwestern shore of the Limnopolar Lake, with a gentle slope (<3%). The site samples a wide variety of characteristics, such as slope, altitude, grain-size, water table levels and geomorphologic features. ALT is measured at each node of the grid by mechanical probing close to the end of the thaw season (generally February, depending on field logistics operations). Complementarily we also measure soil strength with a pocket soil penetrometer (ST207) and temperature at 5 cm depth with "K" thermocouple (Fluke).

In order to compliment ALT and better understand climate forcing controls and the ground thermal regime, the CALM site includes complimentary instrumentation to monitor air, ground surface and terrain temperatures (at two shallow boreholes), as well as temperature sensors to monitor snow thickness (Table 1). These instruments were installed in February 2009, and data are recovered annually. Outside the CALM site, an automatic digital camera takes pictures once per day (midday) all year around. Temperatures are measuring every 3 hours by iButton sensors (DS1922L model, manufactured by Maxim company) with an accuracy of ±0,5ºC, except for the air temperatures that are measured hourly with an accuracy of ±0.2°C (TinyTag sensor, from Gemini company, with external sensor). [*e.g. Nelson et al. 2004, 2009*]. In February 2012, 36 temperature sensors have been regularly distributed in the grid to measure surface temperature in order to correlate them later to the ALT spatial distribution.

Table 1. Instruments installed in the CALM site.

Instrument	Sensor	Accurate, °C	#	Frequency
Air temperature	Tinytag	0.05	1	1 hour
Snow thickness	iButton	0. 5	7	3 hours
Surface temperature	iButton	0. 5	1	3 hours
Ground temperature 1	iButton	0. 5	7	3 hours
Ground temperature 2	iButton	0. 5	8	3 hours
Grid temperature	iButton	0. 5	36	3 hours
Picture	C640	–	1	1 day

We used the ALT measurements and data provided by the different sensors to derive statistics (maximum, minimum, mean and deviation) and thermal behavior of the weather, snow thickness and ground properties, freezing degree-days for near-surface ground (FDDs) and air (FDDa), as well as n-Factor. We also plotted maps of ALT, surface resistance, and thermal diagram of temperature ground gradient at both boreholes, as well as other plots representing evolution of near-surface ground and air temperatures. We also calculated the apparent thermal diffusivity.

Results

The data from our sensors and measurements in the 2009-2011 period allow us to observed that MAAT increased from -2.9ºC to -1.6ºC between 2009 and 2011, meanwhile the temperature amplitude reduces from 26ºC to 24ºC. Although snow season generally starts in May, the permanent snow coverage starts in early July and finish in early November. Calculated snow thickness shows a reduction of snow layer between 2009 and 2010: about 80 cm in 2009 and 40 cm in 2010. These data also reveals that melting of snow coverage was longer in 2010 with a gradual reduction of snow thickness (in about one month), meanwhile in 2009, although the snow layer was thicker (in few days). This annual variability is also reflected on ALT (Table 2). Mean average ALT in the CALM site were 47 cm, 43 cm, and 41 cm in 2009, 2010 and 2011, respectively, with a dispersion of 97 cm, 92 cm, and 79 cm respectively. These measurements are consistent with thermal evolution of ground measured in two shallow boreholes, what reveals that the ground was frozen during a longer period of time in 2009 than in 2010 (about 250 and 200 days in 2009 and 2010, respectively). In summary, ALT reduced in this period (colder conditions) meanwhile the frozen days decreased (warmer conditions).

Table 2. ALT (cm) and statistics in Limnopolar Lake CALM.

Year	Max.	Mean	Min.	St. Dev.	Amplitude
209	105	47	8	29	97
2010	99	43	7	19	92
2011	85	41	6	20	79
Mean values	96	43	7	22.6	89

Then, the tendency that we could observe in the period 2009-2011 is to an increase on both air temperature and Active Layer Thickness.

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Ice-Ground Grout Curtain of Earth Dams in Severe Natural and Climate Conditions

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Creation of ice-ground grout curtains by means of deep freezing with the use of vertical heat stabilizers (thermo-syphons) can be an effective option for earth dams in severe natural and climate conditions. We can name the cases of the Irelyakh and Pevek dams, since their long-term operation has provided the experience of engineering, construction and operation of such dams. In order to create the ice-ground grout curtain at the Irelyakh dam, they used the freezing columns ventilated by cold outdoor air, liquid and vapor-liquid heat stabilizers. Heat stabilizers were to be replaced due to the breach in the design thermal regime of the dam's foundation and body grounds, as well as the possibility to use more efficient technical solutions. The similar situation currently exists at the Pevek dam, where the frozen core thawing on separate sites has led to seepage from the water basin.

Therefore, the prediction of the thermal regime of the dam's foundation and body grounds during the operation and elaboration of technical solutions aimed to ensure reliability and long service of such structures are urgent problems of our time.

In this particular case, the creation of the ice-ground grout curtain by means of effective seasonal cooling units is a technical solution that allows to eliminate infiltration not only through the dam's body, but under its foundation ground as well.

Let us consider the case of the earth dam at the Maysk mining and processing complex in Chukotka that was designed and constructed in 2010-2011. The dam's ice-ground earth curtain was frozen by means of modern vapor-liquid heat stabilizers installed deep into the underlying natural soils in order to prevent water infiltration from the water basin under the dam.

The dam's body was filled during the summer season. Debris and rubble grounds were used to build the dam's body, and its core and toe wall were made of clayey silt.

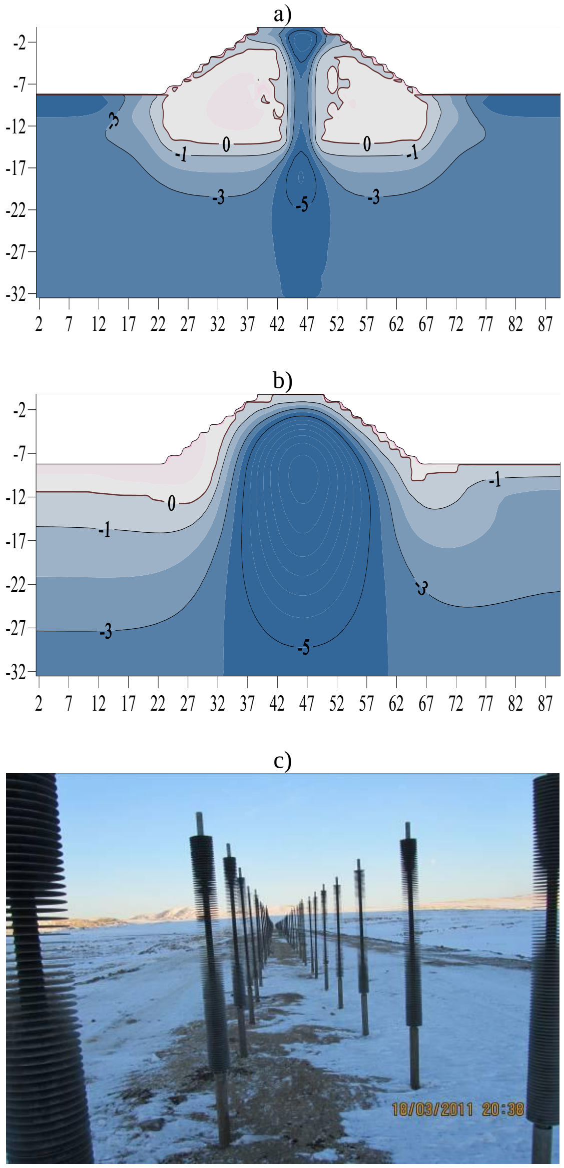
Thermotechnical estimates used as the ice-ground grout curtain's design basis were performed given the following initial conditions: temperatures of the unfrozen banked earth in the dam's body are equal to 10°C; temperatures of water after filling of the water basin are from 3.0°C to 10.0°C in summer and 1.0°C in winter; foundation ground is formed by confluent permafrost soils represented by interlayers of clayey silts, debris and rubble grounds, sandstones, and siltstones; average annual soil temperature at zero amplitude level varies from -4.0°C to -6.5°C.

Thermotechnical estimates were carried out using the PROGNOZ software designed for thermotechnical estimates of temperature regimes of permafrost soil by means of numerical methods. The PROGNOZ software meets the requirements of normative documents RSN 67-68 and SNiP 2.02.04-88. The Certificate of Conformity № ROSS RU.SP15.H00165 was issued by the certification body for software products for construction ROSS RU.0001.11SP15 on July 05, 2008.

Thermotechnical estimates helped to determine the number, dimension types and effective layout of vapor-liquid heat stabilizers, so that creation of grout curtain takes only one cold season, given the empty water basin. The minimal design width of frozen ground that remains unthawed to the end of summer period (September) after the first winter cycle is not less than 3.0 m, and under the dam's toe wall the frozen ice-ground curtain joins with the underlying naturally formed permafrost soils. These conditions prevent water infiltration from the water basin.

As a result of thermotechnical estimates, the temperature field for the full soil mass volume can be obtained for the purpose of analysis at any estimated time point for the given direction of the section formed by the vertical and horizontal planes. Formation of the ice-ground grout curtain is represented on Figure 1 by temperature fields after one year (Fig. 1a) and five years (Fig. 1b) of operation of heat stabilizers.

The results of temperature measurements carried out in thermometric wells included in the geotechnical monitoring project after the first month of operation of heat stabilizers demonstrated practically complete coincidence of the estimated and actual temperature values. These data confirmed the correct choice of the grout curtain's parameters, as well as the fact that the ice-ground grout curtain is really preserved in warm periods (during the passive operational cycle of heat stabilizers). According to the thermotechnical estimates, the temperature of frozen grounds is decreasing during further operation while the width of the ice-ground grout curtain is growing, thus ensuring reliability and long-term operation of the dam.



d)

Depth, m	Date			
	13.03.2011	20.03.2011	26.03.2011	30.03.2011
1	-6.37	-10.74	-9.43	-12.68
2	-10.78	-12.47	-12.78	-13.9
3	-10.27	-11.27	-11.34	-12.21
4	-8.62	-9.31	-9.31	-9.87
5	-6.71	-7.09	-7.27	-7.52
6	-4.68	-4.99	-5.31	-5.49
7	-2.52	-3.02	-3.34	-3.65
8	-0.15	-0.34	-0.46	-0.65
9	-0.09	-0.15	-0.28	-0.28
10	-0.34	-0.53	-0.72	-0.84
11	-1.78	-2.41	-2.59	-2.72
12	-3.53	-3.65	-3.78	-3.96
13	-4.27	-4.21	-4.34	-4.46
14	-4.55	-4.49	-4.55	-4.62

Figure 1. Formation of ice-ground grout curtain at the dam of the Maysk mining and processing complex

a, b – temperature fields after one year and five years of operation of heat stabilizers;

c – picture of the dam’s crest with the installed heat stabilizers;

d – table of lowering temperatures in ice-ground grout curtain

Development of Proposals on Constructive Solutions to Hot Oil Pipeline Laying on Permafrost

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The studies were conducted under the contracts with Giprotruboprovod OJSC.

The oil pipeline route passes along the left bank of the Pur River, its terraces and the adjoining lake-fluvial plain. The general pattern of the area is represented by a flat-hilly plain with the elevation up to 40-50 m and the general incline to the east towards the Pur River. The dissection and the drainage conditions of the surface are low and are most clearly expressed in the near-edge parts of terraces. The route crosses the valleys of the Pur River's left tributaries the most significant of which include: Purpe (the width is 56 m, the depth is 5.2 m), Tydeotta (the width is 60.5 m, the depth is 2.1 m), Yageneta (the width is 36.6 m, the depth is 2.2 m), the Khylmigyakha River (the width is 17.9 m, the depth is 0.97 m). The meandering river valleys are rich in oxbow lakes and minor channels in addition to the main bed.

The lithological composition of deposits in the upper part of the section varies much along the whole depth of the study in the process of geotechnical research (till 10-15 m). This is typical of the deposits of fluvial and lake-fluvial genesis. Clayey silt, sandy silt and sand massifs, lenses and interbeds form a pattern of complex variability of the section both in plan and in depth. The pattern is also complicated by wide development of peat accumulations covering mineral grounds.

The oil pipeline is designed for oil transportation with the temperature below 60 degrees.

Surface oil pipeline construction makes it possible to avoid multiple unfavorable situations occurring (as was mentioned above) due to underground laying. Technogenic transformations of natural landscapes and alteration of ground settings can also occur in the process of installation of supports under the surface oil pipeline. But these transformations will be local. While choosing the points of support installation, one shall avoid zones of slope bending, especially near bogged and lake areas of the catchment basin so that they did not form the situation when the transformation of a natural landscape (and primarily microrelief transformation) can form conditions for the formation of a concentrated surface runoff and erosion. Surface laying shall be accompanied by ground freezing around piles because their bearing capacity increases with freezing of the ground with low bearing capacity (that is widely developed along the route). In this case it shall be taken into account that ground freezing around supports in the conditions of high water content in massifs will be accompanied by frozen ground block bulging.

The thermophysical calculations were conducted with the purpose of evaluation of the oil pipeline underground and surface laying possibilities, including laying with the use of technical means for foundation ground thermal stabilization.

The calculations were completed with help of the method of mathematic (numerical) modeling. The finite difference method was used. The detail data on the goal setting, method particularities and the calculation algorithm are given in the Report.

In all calculations the oil pipeline diameter is assumed equal to 1.0 m (with heat insulation of 1.2 m), the depth of the upper generatrix – 1.0 m, the lower generatrix – 2.2 m, the thickness of heat insulation – 100 mm, and the heat conductivity coefficient of its material – 0.033 W/(m•K).

The calculations were executed for two conventional homogeneous geotechnical sections composed of grounds that are most widely developed along the oil pipeline route. One of them is represented by sands with the density in a dry state ρd = 1600 kg/m3 and the total moisture content Wtot = 0.22, while the other is represented by clayey silts (ρd = 1300 kg/m3, Wtot = 0.35). The thermophysical characteristics of grounds were assumed on the basis of SNiP 2.02.04-88 "Bases and foundations on permafrost soils".

Low-temperature and high-temperature permafrost was calculated independently. The first one is characterized by the temperature at the zero annual heat exchange depth $T_o = -3$°C and confinedness to the initial (northern) site of the oil pipeline, and the second one ($T_o = -1$°C and –0.5°C) is developed on the middle and the southern sites. The climatic parameters for the low-temperature (northern) site are assumed on the basis of the Yamburg weather station, and for the high-temperature sites - on the basis of the Tarko-Sale weather station (SNiP 23-01-99 "Construction climatology"). The oil temperature at the low-temperature (initial) site is assumed equal to +60°C, and at the high-temperature sites it is assumed equal to +45 and +30°C.

The problem of permafrost thawing around the oil pipeline was solved in the 2-dimensional setting; the vertical section was considered perpendicular to its axis. The problems of ground chilling and freezing with a heat stabilizer were solved in the 3-dimensional axis-symmetric setting. In this case the temperature fields were presented in the vertical plain passing across the axis (heat stabilizer). The thermophysical parameters of the TMD-5 and DOU-1 heat stabilizers constructed and produced by the Inter Hit Pipe CJSC were assumed in the calculations as the most effective ones of the known seasonally operating chilling devices.

The underground oil pipeline laying can be used in permafrost areas in exceptional cases only, when the surface option of laying is eliminated due to inevitable objective causes. Every site of this kind requires accurate calculations and analysis for the preparation of technical concepts preventing the development of adverse geocryological processes hazardous for oil pipeline stability.

Stake-by-stake recommendations on the structural solutions for oil pipeline laying were given as a result of work.

A large work scope was dedicated to the analysis of pile applicability in different conditions along the route. The optimal structures of pile foundations were developed and the recommendations for their use along the route were given/

The Cryolithozone of the Arctic Shelf of Eastern Siberia

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Introduction

Topic relevance

Submarine cryolithozone on the shelves of the Northern Hemisphere occupies the area of about 5 mln km^2. Its structure includes horizons of permafrost cooled down to the temperature below 0°C. Permafrost is mainly relic. The development of such relic permafrost, unlike subaerial permafrost, is characterized with pronounced cyclicity. At the stage of shelf drainage it is formed (aggrades) and at the stage of flooding it degrades. Its modern spread, occurrence depth and thickness more critically depend on the genesis of natural environment, than the parameters of subaerial permafrost.

The future of fuel and energy sector of Russia is linked with development of oil and gas resources of arctic shelves. That is why the regional geocryology faces the evolvement of a new scientific trend connected with the submarine cryolithozone studies focusing on the genesis of natural environment and the role of natural environment in formation of the modern state of cryolithozone. Such state is understood as data on cryolithozone material composition, vertical structure, spread and thickness, depth, horizon thickness and temperature of permafrost at the modern stage of the cryolithozone development.

It is also necessary to know the modern state of cryolithozone for making forecasts on global warming. Currently, only emission of greenhouse gases released during the destruction of arctic sea coasts composed of permafrost is evaluated. Meanwhile, in the process of bottom abrasion the sea is also supplied with organic carbon preserved in permafrost. And its largest holding reservoir is a gas hydrate stability zone lying within the permafrost layer and below it. This is why the evaluation of evolution of permafrost and gas hydrate stability zone gains great practical importance.

One of the least studied zones is a shelf of Eastern Siberia (of the Laptev Sea and of the western part of the East Siberian Sea). The spread and the thickness of permafrost layer of this shelf were first evaluated during the 60-80s of the 20th century on the basis of coastal studies and mathematical modeling. The obtained results – including diametrically opposite ones – were preconditioned by extreme insufficiency of basic data, different concepts about variations in climate and sea level and low development of computing facilities.

Scientific novelty

1. For the first time scientists developed concepts about the geocryological cyclicity of the Eastern Siberia shelf. The indicated cyclicity derives from the cyclicity of global fluctuations of climate and sea level and is manifested by cyclic changes in development trends of cryolithozone and cryogenic morpholithogenesis. Concepts about cyclicity of cryogenic morpholithogenesis and differences in its manifestation in positive and negative neotectonic structures made it possible for the first time to remodel the progress of the Late Pleistocene-Holocene marine transgression with due consideration of changes in shelf relief.

2. Fundamentally new concepts about the modern state of relic cryolithozone of the Eastern Siberia shelf were obtained. This is a cryolithozone with continuous permafrost spread within the interval of modern sea depths from 0 to 50-60 m. Within the depth interval from 50-60 to 80-100 m (shelf edge) permafrost has discontinuous and island distribution.

3. Arctic shelves were classified by their geographical location, which made it possible to distinguish them from each other on the basis of cryolithozone formation conditions and its modern state. It is established that the cryolithozone peculiarities of the Eastern Siberia shelf are defined by cryogenic processes resulting from the impact of Asiatic continent. The formation of the cryolithozone of other shelves in the Middle Pleistocene - Holocene was noticeably influenced by climatic and hydrological factors of the Atlantic and Pacific oceans.

Practical importance

The results of this study can be used for development of managerial solutions when planning exploration and survey of mineral resources on the shelf, for making forecast scenarios of the changes in the Arctic and Earth climates and for scientific research.

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On the Question of Conducting Hydraulic Fracturing in Gas Wells in the Case of Permafrost Presence in the Section

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Abstract

The work substantiates the necessity to use special liquids with regulated rheological properties for conducting works connected with preparation for hydraulic fracturing and drilling as well as for development of wells after hydraulic fracturing for the conditions of the Far North, in the case of permafrost presence in the well section. The works also substantiates the necessity to give special properties to proppants and proppant-bearing process liquids for hydraulic fracturing. The ways of study of these areas for improvement of hydraulic fracturing process parameters are described, taking into account the specifics of work in the Far North conditions.

Keywords: chemicals; hydraulic fracturing; liquids; permafrost; proppant; rheological properties.

Permafrost in well sections is rich in organic residuals and is characterized by high moisture content (28-30%) and ice content values that reduce down the section, and serves as a reservoir for significant gas and gas hydrate accumulations. Gas emissions from permafrost significantly complicate drilling and operation of gas-producing wells located in the cryolithozone area. They lead to various accidents, which requires improvement of the well drilling and operation technology [*Geykhman et al. 2009*].

The use of gas inflow intensification methods is often reasonable for putting such wells into operation. As the hydrocarbon field development experience shows, hydraulic fracturing is one of the most efficient intensification methods. It allows not only to intensify the development of the well drainage area by means of reservoir energy loss reduction in the bottom zone, but also significantly widen this area by means of connection of primarily poorly drained interlayers in thin-stratified clayed layers with a fracture system [*Kustyshev et al. 2005*].

Order No. 5 of the Russian Federation Ministry of Energy dated June 24, 2004 On approval of "Recommendations for Determination of the Types of Repair Works in Wells Operated by Organizations of the Oil-Producing, Oil-Processing, Gas and Oil-Chemical Industries" [*Order… 2004*]. Hydraulic fracturing includes a set of works on KP7-2 (preparation for hydraulic fracturing), KP7-3 (hydraulic fracturing) and then development after hydraulic fracturing. The control and regulation of the process itself are important for high-quality fulfillment of the whole work scope. In this case gas wells have their own specifics. The known methods of hydraulic fracturing of a gas well, including well killing, hydraulic fracturing execution, wellhead re-connection and well development, have a number of disadvantages.

This is primarily high labor intensity of preparatory works before hydraulic fracturing and of finishing works after it, high probability of repeated well killing for removal of a tubing string with a high-pressure packer from the well in case of early gas inflow, and inevitable contamination of the bottom zone of the reservoir worsening the effect received from hydraulic fracturing [*Zinchenko et al. 2007*].

The regulation of this process is achieved by means of correct choice of the material (proppant) and process liquids. Liquid properties are defined by their nature, ability to dissolve chemicals, carrying capacity (rheological properties) and the choice of chemicals for regulation of these properties depending significantly on the ambient temperature both at the surface and near the well bore.

This all makes it necessary to use such special nonfreezing liquids as proppant-bearing ones, with regulated rheological properties. They are primarily required in wells where the presence of permafrost influences both hydraulic fracturing and the possibility of formation of gas hydrate plugs that can be formed down to the depth of approximately 700 m. Therefore, the efficient regulation of technological properties of the proppant-bearing liquid is required for high-quality hydraulic fracturing in the conditions of permafrost presence, especially in the conditions of severe climate in the north of Western Siberia. Such regulation eliminates the freezing of the proppant-bearing liquid at the surface and provides the required transportation (rheological) properties in the well bore that significantly depend on the efficiency of entered chemicals. The effect of the entered chemicals primarily depends on the temperature and other well factors (pressure, brine water inflow, its mineralization degree, interaction with hydrocarbons, formation of gas/liquid mixtures, etc.). These problems are usually solved by means of use of special salt solutions with regulated parameters (such as concentration, temperature, viscosity, shear strength, filtration parameter, sedimentation stability, and density). These properties must ensure the destruction and the washing-out of gas hydrate plugs and elimination of their repeated occurrence, especially in anomalously low reservoir pressure conditions. This all will allow to reduce the duration of work connected with well development after hydraulic fracturing and to improve the hydraulic fracturing quality in general. The proppant-bearing liquid "compatibility" with reservoir fluids must be taken into account in the process of hydraulic fracturing and after it. This can significantly complicate the hydraulic fracturing process and worsen the productive stratum permeability and porosity.

In order to solve these problems, we conduct studies for giving special properties to proppants used for regulation of phase permeability in terms of oil, gas and water in the "screen" formed as a result of hydraulic fracturing. We also study the influence of various chemicals on the hydraulic fracturing process for regulation of rheological and other properties of the proppant-bearing liquid, especially in the case of permafrost presence in well sections.

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Spatial Distribution of Marine Chemical Tracers in Waters of Pechora Delta

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Abstract

Hydrological sampling in the Pechora Delta shows that, besides the "river-sea" trend, river water in different water bodies differs notably in contents of typically marine elements (Na and Cl) and in salinity (TDS). The Na and Cl concentrations are the highest in open water and the lowest in small inner streams that have no direct connection with the sea. Stagnant water in the vicinity of a past gas well accident in the Maly Gusinets channel is highly polluted with petroleum. Surge events increase seawater influence on the delta waters.

Study area and methods

The hydrological studies have been run by the Institute of Earth's Cryosphere in the Pechora Delta. River deltas in the Arctic basin are particular transitional ecosystems that exist in the zone of sea-river water interaction. They differ considerably from typical zonal landscapes and belong to azonal hydromorphic ecosystems, along with peatland. The Arctic deltas are remarkable for strong chemical barriers that result from the contact of marine and river water (a marginal filter), rapid accumulation of suspended matter on delta islands, and periglacial processes in the sides and floors of river valleys [*Korotaev et al. 2006; Nikanorov et al. 2007; Polonsky 1984*].

The reported study focuses on the spatial distribution of typically marine elements (Cl and Na) that are seawater chemical tracers in streams of the Pechora Delta, while accumulation of river-borne sediment and periglacial processes are beyond this consideration.

In 2011, different delta waters were sampled, from the surface, in the Pechora lower reaches from Nar'yan-Mar city to the Pechora and Korovinskaya bays.

The ion and chemical compositions of the natural water samples were analyzed by the standard chemical method at the Dokuchaev Institute of Soils (analyst R. Grishina) and by atomic absorption spectroscopy (AAS) at Esenin Ryazan State University (analyst S. Torbatov).

Main results

Delta landscapes develop in zones of marine influence which decreases away from the sea. The influence of seawater is recorded in typical marine elements of sodium and chlorine which enter main landscape components (water, soil, and plants) and thus act as chemical tracers. Floodplain and terrace landscapes are subject to sea influence all over the Pechora Delta area from Bolshaya Sopka Village to Pechora and Korovinskaya bays (Polonsky 1984). The Cl and Na contents are the highest within the river mouth and decrease notably upstream [*Dombrovskaya & Ukraintseva 2011*].

In addition to the "river-sea" trend, river waters sampled at different sites in the delta show a notable difference in Na and Cl concentrations and in salinity (total dissolved solids, TDS). Several groups of waters have been sampled: (1) large channels (Bolshaya Pechora, Tundrovy Shar, Srednii Shar); (2) shoal areas of the seaward delta edge; (3) poorly flowing and stagnant small channels inside islands; (4) offshore areas.

The seawater influence is the strongest in open-water offshore areas (Pechora Bay and seaward margin of Korovinskaya Bay) and is much weaker in the delta edge shoal (Fig. 1). Chlorine is the best marine proxy out of three chemical tracers (Fig. 1) being markedly different in different waters. Its concentration in the Bolshaya Pechora which opens into the saline Pechora Bay is higher than in the Tundrovy Shar channel flowing into the freshest interior part of the Korovinskaya Bay. Chlorine is the lowest in the Srednii Shar channel and in small channels that have no direct connection with the sea.

Salinity (TDS) and sodium ions remain almost invariable within the delta but increase offshore (Fig. 1).

In shoal areas of the seaward delta margin, Cl, Na, and salinity grow notably from west to east, from the landward margin of the Korovinskaya bay (site 32-11) to its seaward margin and the Pechora Bay (sites 44-11 and 30-11, Fig. 2).

The environment of the Pechora Delta and its channels experience major anthropogenic loads from gas-condensate production and drilling. There was a strong accidental gas blowout in the early 1980s, and two dams were built around the well, which bar the Maly Gusinets channel and make a mechanic and chemical barrier to the runoff.

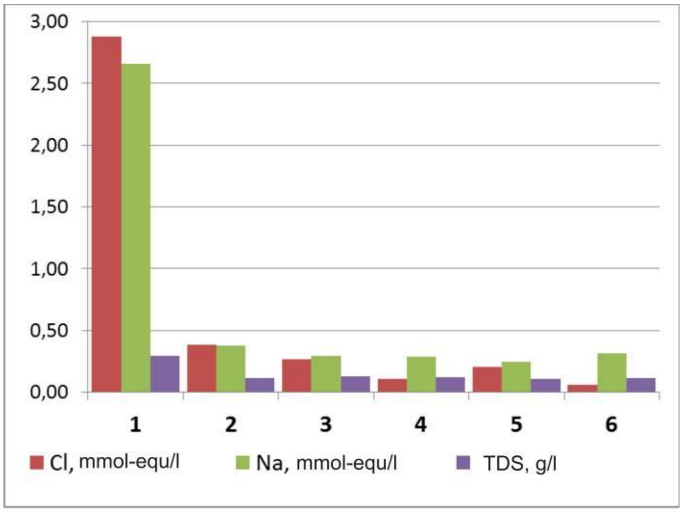

Fig. 1. Tracers of seawater influence in waters of Pechora Delta
1 – offshore areas of Pechora and Korovinskaya bays; 2 – shoals of seaward delta margin; 3 – Bolshaya Pechora; 4 – Srednii Shar channel; 5 – Tundrovy Shar channel; 6 – small channels (with stagnant water).

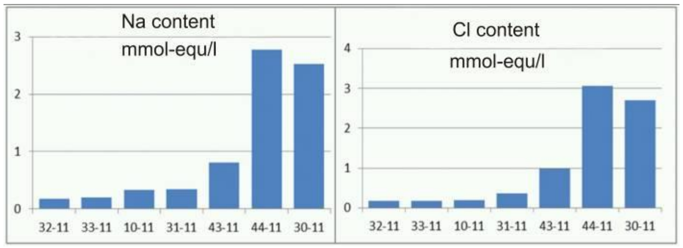

Fig. 2. Na and Cl contents in shoal areas of seaward delta margin, from left (west) to right (east) toward open sea. 32-11, 33-11… are sampling sites.

Chemical analysis of water samples showed 4-5 times higher contents of petroleum products in stagnant backwater between the dams than in river water 200-300 m away (Fig. 3).

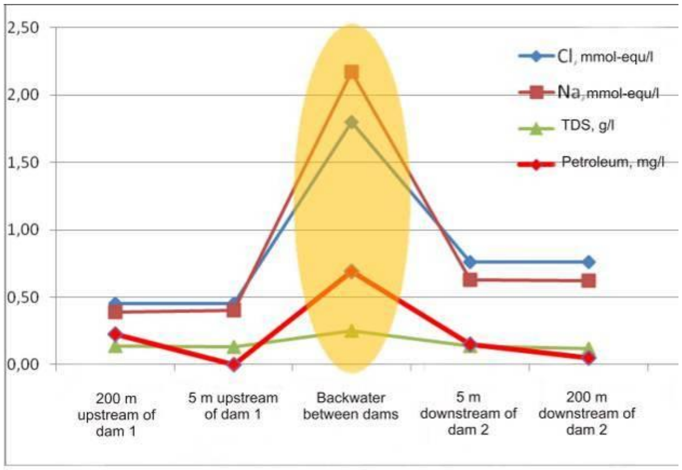

Fig. 3. Cl, Na, TDS, and petroleum in backwater between dams and outside it in Maly Gusinets channel.

In addition to petroleum contents, the salinity of backwater between the dams is likewise much higher (up to 200 mg/l TDS against the 60-80 mg/l background in main channels), as well as typically marine ions of Cl and Na. The higher concentrations of Cl and Na indicate stronger seawater influence. The upper dam blocks completely the river outflow. Low-salinity seawater of the Korovinskaya Bay flows over the dam during surge events.

Conclusions

Thus, the results allow the following inferences.

1. The contents of Na and Cl, typical marine elements, are the highest in the Bolshaya Pechora mouth and decrease considerably upstream.
2. The contents of Na and Cl are the highest in open sea but are lower in shoal areas of the seaward delta margin and in large channels. Chlorine is the lowest in the Srednii Shar channel and in small inner channels that have no direct connection with the sea.
3. Chlorine is the best marine proxy out of three chemical tracers.
4. Surge events increase the seawater influence in the delta and can damage or even destroy engineering structures built to prevent oil pollution.

Acknowledgments

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SOC Pools and Stocks in Permafrost-affected Soils on the Tibetan Plateau

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Introduction

A particularly sensitive area with regard to effects of global climate change is the Tibetan Plateau. Approximately two thirds of the total area is affected by permafrost. Specific soil hydrological properties in permafrost regions have a major impact on soil moisture and hence on the accumulation of organic matter.

Prevailing low temperatures and permanently low turn-over rates result in large SOC (soil organic carbon) stocks, which show great emission potential for greenhouse gases such as CO_2 and CH_4. Even small changes in SOC pools may produce significant variations in atmospheric CO_2 concentrations. Thus, an estimate of carbon stocks in their extent and distribution is important to forecast the feedback of SOC on global climate change.

Major objectives of this study are (1) to investigate soil organic carbon (SOC) stocks and their affiliation to pools by density fractionation and CN analyses and (2) to examine the influence of soil hydrological and topographical parameters on SOC stocks.

Materials and Methods

Study sites

The study sites are located on the northeastern Tibetan Plateau, Qinghai Province, China and were investigated in May/June 2009 and 2010 (Fig. 1). Site HUA is situated in the Yellow River catchment area, 4300 m a.s.l., which is affected by the East Asian Monsoon and characterized by discontinuous permafrost. MAP is 326 mm and MAAT is -4.1 °C.

Site WUD, situated at 4805 m a.s.l., has less precipitation (255 mm) and a slightly lower MAAT (-5.6 °C; continuous permafrost).

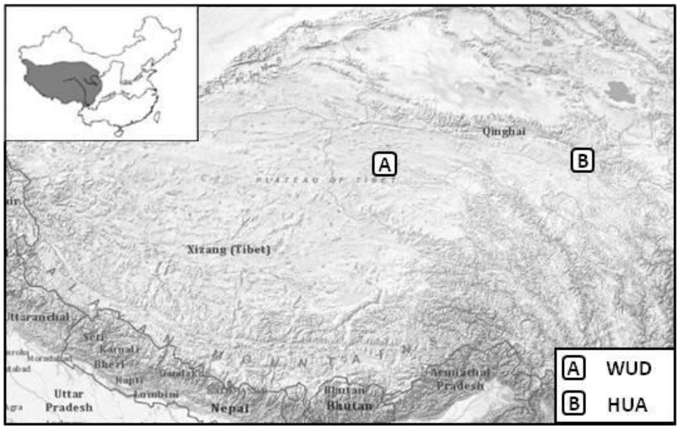

Figure 1. Location of the study sites on the Tibetan Plateau.

Soils at site HUA are classified as gleyic Fluvisols, haplic Regosols and mollic Cryosols, whereas cambic Cryosols are common in WUD. All subsites are affected by permafrost with an active layer depth less than 100 cm.

Alpine meadow is the dominating vegetation type with several main species, particularly *Kobresia stellera chamaejasme, K. pygmaea* and *K. humilis*. Plant composition is similar at both sites, differing along the altitudinal gradient according to water supply.

Field methods

The soil pits were arranged along an elevation gradient at both sites. Soil sampling was split into two parts: schematic sampling conducted by drilling at four depth-increments (0-5, 5-10, 10-20 and 20-30 cm) for C analysis and volumetric sampling at the same depths for bulk density and gravimetric water content determination. Soil moisture was additionally measured with TDR (Delta-T Devices Ltd. Cambridge, UK).

Laboratory analysis

All soil samples were air-dried and sieved to < 2 mm. $CaCO_3$ was analyzed volumetrically on ground subsamples (Calcimeter, Eijkelkamp). Total C and N of bulk soil samples and of density fractions were determined on ground subsamples by heat combustion (1150°C) with a CNS analyzer (Vario EL III, Elementar GmbH, Hanau, Germany). SOC is calculated as the difference between total carbon and inorganic carbon values. Water content was determined gravimetrically, corrected by the skeleton content (> 2 mm). Bulk density and gravimetric water content were determined at Peking University.

Density fractionation was carried out according to Grünewald et al. [*2006*]. Three fractions were isolated: the light fractions free particulate organic matter (FPOM) and occluded particulate organic matter (OPOM) with a density < 1.6 g cm^{-3}, plus a heavy fraction of mineral associated organic matter (MOM) with a density of > 1.6 g cm^{-3}.

SOC stocks for bulk soils and individual fractions were calculated down to a depth of 30 cm, according to Ohtsuka et al. [*2008*]:

$$SOC\ [kg\ m^{-2}] = 0{,}001 \cdot M \cdot \rho_B \cdot SOC \cdot (100 - S) \qquad (1)$$

where M is the soil layer thickness in m, ρ_B is the bulk density (g cm^{-3}) of the soil, SOC is the soil organic carbon concentration in Mass% (bulk soil or fraction) and S is the skeleton content (Mass%).

Results

The mean recovery of SOC after density fractionation was 95 %. FPOM has an average SOC content of 25.2 %. Higher values were found in the intermediate OPOM (32.0 %). MOM has the lowest SOC content with 2.9 %. Due to the lower mass the easily decomposable fractions FPOM and OPOM contribute 27 % to the total stocks in HUA (WUD: 22 %). POM values of 36 % occurred only in wet profiles.

SOC stocks in HUA range from 1.9 kg m^{-2} to 19.3 kg m^{-2} with a mean of 10.4 kg m^{-2} (Tab. 1). Significantly lower stocks were found in WUD ranging from 2.5 kg m^{-2} to 5.0 kg m^{-2} (mean: 3.4 kg m^{-2}). SOC stocks decreased with depth, particularly in WUD. SOC contents up to 1.5 % were found in frozen soil horizons below the active layer, depending on its depth.

Table 1. Max, Min, Mean values and variations of total and fraction SOC stocks at HUA (n=24) and WUD (n= 20).

Site	OM-Fraction	Max [kg m^{-2}]	Min [kg m^{-2}]	Mean [kg m^{-2}]	Standard deviation
HUA	FPOM	5.0	0.2	1.9	2.1
	OPOM	2.4	0.1	0.9	0.9
	MOM	12.9	1.5	7.6	4.5
	Σ OM	19.3	1.9	10.4	7.1
WUD	FPOM	0.7	0.2	0.5	0.2
	OPOM	0.4	0.2	0.3	0.1
	MOM	3.9	2.2	2.7	0.6
	Σ OM	5.0	2.5	3.4	0.8

A significant correlation between soil moisture and SOC stocks can be confirmed for both study sites. The correlation between the depth of the active layer and SOC stocks in the soils is positive for site HUA with $R^2 = 0.78$, in WUD $R^2=0.01$.

Discussion

Yang et al. [*2008*] found comparable contents of SOC stocks ranging from 0.93 to 18.6 kg m^{-2} (mean: 6.17 kg m^{-2}) in the depth increment 0-30 cm of alpine meadow soils on the Tibetan Plateau. Whereas Wang et al. [*2008*] found SOC stocks of only 9.33 kg m^{-2} in the 0-30 cm depth increment [*Wang et al. 2008*].

Due to the less litterfall in WUD, the lower fraction masses and SOC concentrations lead to lower portions of POM fractions of total stocks. This shows that an accumulation of predominantly easily degradable organic matter takes place under wet and humid conditions.

The mean active layer thickness is similar at both sites, but the depth variations are significantly higher at HUA compared to WUD. This may be caused by the higher variability in substrates at HUA and a higher MAP.

Soil moisture affects significantly amount and distribution of carbon stocks on the Tibetan Plateau [*Yang et al. 2008, Baumann et al. 2009*]. At site HUA soil moisture, active layer thickness and SOC stocks are significantly correlated. Because of the moister soil hydrological conditions and the higher amount of aboveground biomass, more organic matter is accumulated at HUA than at WUD. Here, a shorter growing season and drier soil conditions produce less litterfall by simultaneously faster mineralization processes.

Conclusions

The main influencing parameters of spatial distribution and fractions of SOC were investigated in permafrost-affected soils at two sites in continuous (WUD) and discontinuous (HUA) permafrost areas on the Tibetan Plateau. We found that soil moisture affects the spatial distribution of SOC significantly. Highest SOC stocks were found in moist to water saturated soils indicating seasonally poor turnover conditions (HUA). Further, moist sites have higher contents of easily decomposable POM fractions.

Our findings imply also that such sites are particularly vulnerable to climate change. Our results should not be upscaled so far, since they are based only on two sites with 11 soil pits. Since 2011we investigate eight other sites on the Tibetan Plateau.

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Effects of a Changing Permafrost Regime on Hydrology and Ecosystems in Interior Alaska

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Background

Large areas of permafrost in Interior Alaska have shown signs of degradation [*Jorgenson et al., 2001*]. These changes in permafrost distribution have affected ecosystems in Interior Alaska through widespread drying in some regions and wetland expansion in others [*Osterkamp & Jorgenson 2006*].

Climate warming is expected to have pronounced effects on high latitude ecosystems, especially in locations underlain by warm, discontinuous, permafrost such as the Interior of Alaska [*Arctic Climate Impact Assessment 2005*]. Future climate scenarios predict a roughly 5°C increase in mean annual air temperatures for the Alaskan Interior over the next 80 years [*Chapman and Walsh 2007*]. This is expected to initiate permafrost degradation which could lead to widespread thermokarst and talik development and potentially a thicker seasonally thawed (active) layer. These surface processes could dramatically affect ground surface topography, vegetation, and hydrology.

Forecasting ecological responses to climate warming is complicated by many factors including variations in soil type, precipitation, surface and ground water hydrology, vegetation, slope, aspect, fire prevalence, and the thermal state of permafrost.

Technical Approach

We are making field measurements and time series repeat imagery at upland and lowland landscapes in Interior Alaska to determine where and what ecosystem processes may be most susceptible for rapid or unpredictable changes with climate warming or changing land use activities. By integrating existing cryospheric (permafrost and snow), hydrologic, and vegetation succession modeling capabilities we hope to enhance our ability to predict how climate change and other stressors may affect ecosystem dynamics and fire susceptibility

We are coupling the physically-based and spatially-distributed Gridded Surface Subsurface Hydrologic Analysis (GSSHA) model of the U.S. Army Corps of Engineers and the spatially-distributed soil thermal regime model from the Geophysical Institute Permafrost Lab (GIPL). Input data requirements for GSSHA and GIPL include a digital elevation model, vegetation and soil maps, precipitation, air temperature, wind speed, air vapor pressure and incoming shortwave radiation.

GSSHA is a spatially explicit hydrologic model that simulates 2-D overland flow, 2-D groundwater flow, and 1-D flow in stream networks and includes evapotranspiration, infiltration, snow accumulation and snow melt. Additional simulation capabilities include artificial drainage and irrigation networks, wetlands hydraulics, and urban drainage hydrology. The GIPL model simulates soil temperature dynamics and the depth of seasonal freezing and thawing by numerically solving a 1D nonlinear heat equation with phase change. In this model the process of soil freezing/thawing occurs in accordance with the unfrozen water content curve and soil thermal properties, which are specific for each soil layer and for each geographical location. The finite difference numerical scheme implemented in GIPL makes it possible to use coarse vertical resolution without loss of latent-heat effects in the phase transition zone, even under rapid or abrupt changes in the temperature fields.

The GIPL model captures physical processes essential for robust and appropriate modeling of permafrost dynamics in Alaska. Specifically, soil thermal properties are parameterized according to soil texture and organic matter. Additionally, GIPL includes thermal insulation of the snow cover and geothermal heating at the appropriately-selected depth. The GIPL model also incorporates an efficient algorithm to estimate soil thermal properties using in-situ temperature measurements in the active layer and in permafrost. This simplifies model calibration for specific sites in Alaska.

The combined GIPL-GSSHA model system will allow us to predict how soil warming due to climate change and its associated impacts on the soil thermal state will affect surface hydrology. Project sites for our modeling application include upland ecosystems of the Caribou-Poker Creek Research Watersheds (CPCRW) north of Fairbanks and the upland hills east of Fort Wainwright as well as the lowland ecosystems of the Tanana Flats south of Fairbanks.

Currently, we have linked the GIPL and GSSHA models and have been generating a series of model outputs for watersheds in the CPCRW. There is a large body of soil thermal, surface water discharge, and permafrost mapping information for the CPCRW so it is a logical location to couple our models and verify outputs with measurements representing a variety of permafrost regimes and spatial scales. In addition, the digital elevation model, soils database information, and vegetation-ecosystem information are well mapped for the CPCRW.

Results

Our initial model outputs were applied to two watersheds in the CPCRW that represent high (53%) and low (4%) permafrost coverage [*Petrone et al., 2007*]. Fig. 1 includes the results from a GSSHA model output representing flow in these two watersheds. The output represents flows prior to and during a hypothetical wet precipitation event. To represent permafrost an impermeable layer was placed in the 2-dimentsional surface soil domain with a hydraulic conductivity of 10^{-8} meters per second. The results compare favorably to actual discharge measurements measured following precipitation events in these two watersheds [*Petrone et al., 2007*].

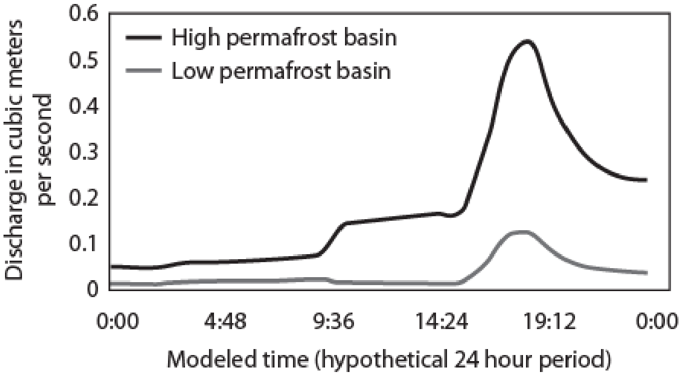

Figure 1. GSSHA model outputs for a hypothetical flow event at Caribou-Poker Creek produce runoff differences in high- and low-permafrost basins.

It is apparent that the increased coverage of permafrost in the High permafrost basin leads to less soil pore water storage and a flashier response to the precipitation event. Loss of permafrost in Interior Alaska will likely lead to enhanced connectivity between the surface and ground water storage regimes. This, in turn, could lead to longer water-rock and water-soil interaction times. The effects of this on watershed nutrient availability and fluxes is not well known.

Future Directions

We plan to further calibrate and validate the GIPL and GSSHA models using permafrost temperatures, active layer thickness, evapotranspiration, runoff, and groundwater table measurements from numerous study sites in the Alaskan Interior. This will allow the development of the first hydrological modeling framework that includes an integrated, physical description of permafrost and soil moisture dynamics.

We will project future permafrost and hydrologic conditions using the newly developed modeling tool in a set of climate projection scenarios with varying degrees of non-climate related anthropogenic stressors out to the year 2100.

Future simulations will be forced with the Scenarios Network for Alaska Planning (SNAP) data set (daily time step). Future projections from SNAP are derived from a composition of the five best ranked General Circulation Models (MPI ECHAM5, GFDL CM2.1, MIROC3.2 MEDRES, UKMO HADCM3, and CCCMA CGCM3.1) out of the 15 used by the IPCC models for Alaska. The SNAP dataset includes years 1980-2099 and are downscaled to 2 km grid cells. Results from three emission scenarios (A2, A1B and B2) are available from the web site (http://www.snap.uaf.edu/home). The mid-range CO_2 emission scenario is projected to result in a 3°C increase in July mean air temperatures and a 7°C increase in mean January air temperatures from a historical timeframe (1961-1990) to the end-of 21st century.

We anticipate that the results from our projected soil thermal and hydrologic regimes can be used to identify important hydrologic and thermal thresholds that may lead to ecological regime shifts in Interior Alaska.

Acknowledgments

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The Influence of Ice-Pressure on P-Wave Velocity in Alpine Low-Porosity Rocks: A Modified Time-Average Model

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Theoretically, refraction seismics are incapable of differing between frozen and unfrozen low-porosity rocks, which constitute most Alpine rock walls, since pore infill determines the changes in p-wave velocity [*McGinnis et al. 1973*]. The very opposite may be true. Here, we show the significance of the ice-pressure-induced matrix velocity increase in low-porosity rocks while velocity increase of the pore infill is negligible. Hence, the applicability of refraction seismics in low-porosity rock walls is confirmed. We present (1) the data of p-wave measurements of 22 different alpine rocks, (2) determine the increase of matrix velocity and (3) the decrease of anisotropy due to ice pressure and (4) modify Timur's [*1968*] time-average equation for alpine rocks by implementing (lithological referenced) matrix velocity changes.

Permafrost affects most high-latitude and many high-altitude regions. Permafrost distribution and dynamics have been investigated with geophysical methods since the early 1970s; the use of seismic field and laboratory measurements is a standard approach. Several laboratory studies have focused on Arctic high-porosity rocks and soils and various seismic models have been derived from the results while only Timur's [*1968*] models can be applied to rocks. In Timur's 2-phase time-average equation the increase of p-wave velocity due to freezing is based on the velocity increase of the pore infill (v_i) while matrix velocity (v_m) remains constant:

$$\frac{1}{v} = \frac{\Phi}{v_i} + \frac{1-\Phi}{v_m} \qquad (1)$$

where Φ is porosity. All tested rocks possess high porosities; however, alpine rockwalls consist of low-porosity rocks. McGinnis et al. *[1973]* implemented Timur's results in

$$\Delta v_p = \frac{\Phi - 0.0363}{0.0044} \qquad (2)$$

where Δv_p is p-wave velocity increase. Equation 2 denies applicability of seismic approaches to low-porosity rocks. Pore shape, cracks and fractures determine seismic anisotropy ("induced anisotropy") and correspond to stress, while anisotropic minerals and textural-structural characteristics cause "intrinsic anisotropy" and are stress-independent. Anisotropy is defined according to Johnston and Christensen [*1995*]

$$A = \frac{v_{\max} - v_{\min}}{v_{\max}} \qquad (3)$$

where v is the p-wave velocity parallel and perpendicular to cleavage or bedding.

Methods

We sampled 22 decimeter-large rock specimens with a natural texture of more than 100 micro-fissures and effective porosities lower than 6 % from alpine rock walls, rock glaciers and talus slopes from Switzerland, Germany, Austria, France and Svalbard. Rock samples include 14 metamorphic rocks (mostly schists and gneiss), 4 magmatic rocks (plutonites and volcanites) and 4 sedimentary rocks (e.g. sandstones and carbonates).

All samples were saturated, effective porosity and degree of saturation were determined (see Draebing & Krautblatter (subm.) for details). P-wave velocities were measured parallel and perpendicular to cleavage or bedding in a temperature range from 25°C to -15°C in a WEISS WK 180/40 high-accuracy climate chamber. 2-3 calibrated thermocouples were used to monitor continuously rock temperature; p-waves were generated with a Geotron ultrasonic transducer and measured with a Fluke Scopemeter. Matrix velocity V_m is calculated for frozen and unfrozen status according to

$$V_m = \frac{(1-\Phi)}{\left(\frac{1}{v} - \frac{\Phi}{v_i}\right)} \qquad (4)$$

and change of matrix velocity ΔV_m is assessed according to

$$\Delta V_m = \frac{(V_{mf} - V_{ms})}{V_{ms}} \qquad (5)$$

where V_{mf} is matrix velocity in the frozen status and V_{ms} is matrix velocity in the saturated status. The change of anisotropy ΔA due to freezing is calculated according to

$$\Delta A = A_s - A_f \qquad (6)$$

where A_s is the anisotropy after 48 h saturation and A_f is the anisotropy when frozen.

Results

Effective porosities of all samples are lower than 6 %; only the Tuffeau Limestone derived from non-alpine location possesses effective porosities of 45 % (Table 1). After 48 h saturation the degree of saturation of all samples is higher than 91% and pre-conditions for cryostatic pressure build-up upon volumetric expansion is achieved. Due to freezing, p-wave velocities increases by 7-78 % parallel to cleavage or bedding and 11-166 % in perpendicular direction. We plotted p-wave velocities increase due to freezing against the mean effective porosity to assume the dependence of p-wave velocity increase from porosity. For detailed results of the measurements parallel to cleavage or bedding see Draebing & Krautblatter (subm.).

Results for perpendicular measurements are shown in Fig. 1. The black line is the linear regression by McGinnis et al. [*1973*] based on measurements by Timur [*1968*] which is incaple of explaining p-wave velocity increase. Due to solution weathering and vugular pores, carbonate rocks are not plotted against porosity.

Here, p-wave velocity is dominated by matrix velocity increase (Table 1) as shown in Eq. 4 and Eq. 5. Pore ice pressure due to freezing reduces induced anisotropy from the saturated to the frozen status. Anisotropy decrease is calculated according to Eq. 6. In 15 of 22 samples anisotropy is reduced due to the developing ice pressure.

Table 1. Effective porosity, matrix velocity increase parallel and perpendicular to cleavage or bedding and anisotropy of gneiss (G), other metamorphic rocks (O), schists (S), plutonic (P) and volcanic (V) rocks, clastic (Cl) and carbonate (Ca) rocks; error values indicate mean deviation.

Rock	Porosity	parallel	perpendicular	Anisotropy
	Φ [%]	ΔV_m [%]	ΔV_m [%]	ΔA [%]
G	0.97± 0.04	5.08± 4.08	9.24± 2.23	2.92
O	1.14± 0.13	13.50± 4.46	8.95± 4.51	-3.31
S	1.48± 0.50	13.65± 7.76	61.52±45.18	15.24
P	1.43± 0.55	14.44± 1.24	14.56± 0.44	-0.35
V	3.24± 0.21	26.38± 6.33	11.81± 4.80	0.72
Cl	5.62± 0.41	23.90±20.96	17.49±13.07	-0.25
Ca	23.54±21.63	59.44± 9.93	168.53±62.00	26.96

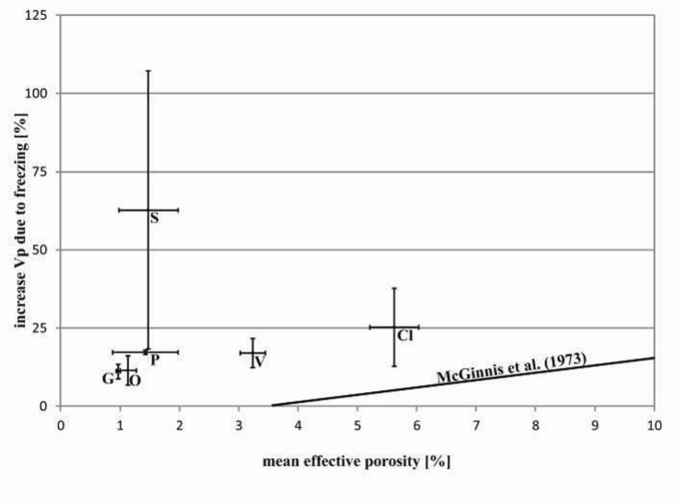

Figure 1. Percentage p-wave velocity increase due to freezing plotted against mean effective porosity for gneiss (G), other metamorphic rocks (O), schists (S), plutonic (P) and volcanic (V) rocks and clastic rocks (Cl) perpendicular to cleavage, the black line indicates the linear regression based on McGinnis et al. (1973); error bars indicate the mean deviation.

Discussion and Conclusion

P-wave velocity increase is affected by porosity but also by pore form, the degree of fissuring and ice pressure development. Pore form determines pressure susceptibility and ice effects as well as pore linkage which affects the saturation. The development of pores, fissures and fractures which provide the space and control the effects of confined ice growth is determined by the weathering history. Volumetric expansion and/or ice segregation cause ice growth which is restricted by the rigid matrix of low-porosity rocks and causes development of high levels of stress [*Matsuoka 1990*]. The combined effect of increasing matrix velocity and decreasing anisotropy result from intrinsic stress generation originated from ice pressure building. Our laboratory set up of a quasi-closed system and saturated samples are analogous to natural conditions but favor volumetric expansion more than ice segregation due to cooling rates of 6°C/h [*Matsuoka 1990*].

(1) P-wave velocity increases from 7.3 ±3.7 % for gneiss to 78.7 ±7.0 % for carbonate rocks parallel to cleavage or bedding and from 11.1 ±2.4 % for gneiss to 166.0 ±56.9 % for carbonate rocks in perpendicular direction. These increases are too high to be explained by Eq. 2. Porosity is not the relevant determinant of low-porosity bedrock.

(2) Parallel to cleavage or bedding, matrix velocity increase reaches from 5.1 ±4.1 % for gneiss to 59.4 ±10.0 % for carbonate rocks; perpendicular measurements show matrix velocity increasing from 9.0 ±4.5 % for other metamorphic rocks to 168.5 ±62.0 % for carbonate rocks.

(3) Anisotropy decreases up to 45 %, resulting from crack closure due to ice pressure in 15 of 22 rock samples.

(4) Based on our results we modify Eq. 2 with a pressure-induced variable m. We use lithology as a proxy for pore form and assume an elevated level of stress due to cryostatic pressure:

$$\frac{1}{v} = \frac{\Phi}{v_i} + \frac{1-\Phi}{v_m} * \frac{1}{m} \qquad (7)$$

where

$$m = 1 + \Delta V_m \qquad (8)$$

The proposed values of m can be derived from Table 1 for the specific lithology group.

Acknowledgements

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Simulation of Heat and Moisture Transfer in Grounds Using the Thermal and Hydraulic Resistance Method with Regard to Ventilation of the Structures' Crawl Spaces

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This paper discusses a comprehensive software new in its essence. It is designed for numerical simulation of thermal-hydraulic processes in the foundation grounds with regard to “water-to-ice” and “water-to-vapor” phase transitions, ventilated layer aerodynamics, radiation produced by on-surface structures, heat sources of arbitrary shapes, and intensity in the grounds. Its modules can work autonomously or installed jointly. This software is based on the thermal and hydraulic resistance method that allows to ensure process convergence and stability.

The computed model allows to take into consideration the presence of a structure of “active” structural elements in the foundation ground (pipelines, heating or cooling units of various designation, including heat stabilizers and heating cables), as well as “passive” ones that do not introduce additional heat flows into the foundation grounds (bases, piles, heat insulation layers, etc.). The abovementioned elements, as well as surfaces and limits of the calculated areas, may have arbitrary configurations and different heat-transfer conditions.

Boundary conditions may be represented by the actual relief and configuration of the underground parts of the structures, as well as by the parameters of the heat sources and sinks, and other features of foundation grounds. Moreover, the estimates take into consideration the whole set of climate conditions (dynamics of temperatures, directions and velocities of the ambient air, snow accumulation, etc).

Results of the estimates presented in the tabular and graphic style in any points of the computed area include the following information:

- dynamics of the thermal and moisture conditions of foundation grounds and the bearing capacity of pile foundations during their operation;
- values of heat, hydraulic, and aerodynamic resistances;
- seepage flow rates and velocities;
- air exchange and heat regime in ventilated crawl spaces, ducts, etc.

Simulation of heat and moisture transfer using thermal and hydraulic resistances is one of the methods of numerical solution of the equations defining these processes. It allows to solve tasks in the stable (stationary) as well as in the transitional regimes.

In the latter case, conditional breakdown of the elementary ground volume into two constituents (the skeleton and the pore liquid) eliminates the need to use the enthalpy method in heat estimates, including those with phase transitions (e.g. with regard to the displacement of salts from pore moisture for saline soils).

The thermal-hydraulic resistance method allows not only to solve, in three-dimensional definition, the adjoint problem of heat and moisture transfer in thawing and freezing grounds, including those regarding vaporization processes, but also to input, at any stage of computations, the heat sources and sinks of various configuration and nature without the degradation in accuracy and speed of computations. All this allows to simulate real physical processes, which, as the final result, eliminates divergence of iterative calculations.

This method of computations allows to simulate the interaction between the cavities with the moving outdoor air (ventilated crawl spaces, ducts, pipes, etc) with the foundation grounds and to estimate, for example, the dimensions of edge vents in the ground floor of ventilated crawl spaces, or of cross-sections of ventilated pipes and ducts that maintain the required thermal regime of foundation grounds of the buildings and the required air movement velocity. The option of computing the effect of the heated bodies’ emission processes on the heat conditions of the foundation grounds included into the software allows to take into consideration the temperature of air or any other matter inside the structures (buildings, tanks…). For intense emissions, e.g. those generated by flares at gas and condensate fields, the “ice-into-water” and “water-into-vapor” transitions are considered depending on the formed temperatures of the grounds.

As it is demonstrated by the operation of such objects as earth dams, motor roads and railroads, flare units in the permafrost areas, the seepage, vaporization and radiation processes contribute a lot to the thermal regime of foundation grounds, facilitating their thawing and subsidence.

Estimates of seepage processes in the suprapermafrost layer should be taken into consideration during spread embankments design, laying of “warm” underground pipelines, construction of drains under the roads and other linear structures, as well as in view of ground thawing during designed pre-construction or operation of the facility.

The developed software package enhances operational reliability of complex structures, such as structures with large in-plane dimensions, including those with ventilated crawl spaces, on-surface and underground pipelines, producing wells, infrastructural facilities of airports and railroad stations, and oil and gas production facilities.

The above-mentioned factors enhance topicality of the developed software. Its use ensures reliable prediction of the foundation ground’s operational behaviour. Also, this software helps to elaborate the activities on thermal stabilization of the grounds and engineering protection of the territories that will ensure the design bearing capacity, long operating life of the bases and structures, and environmental safety of the areas under construction.

Area of the software’s application: estimates of the foundation grounds of buildings and structures during their design engineering, construction and operation in severe natural climate conditions (permafrost, deep seasonal freezing).

Validation of Current Ground Thermal Conditions, Alaska Highway Corridor, Yukon Canada

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Introduction

Permafrost presents significant challenges to northern development. Information on permafrost distribution and ground thermal conditions is required for engineering design of northern infrastructure to ensure its long-term integrity and to minimize environmental impacts.

There is potential for construction and operation of a natural gas pipeline in the Alaska Highway Corridor (Figure 1). Much of the available information on ground thermal conditions in the corridor was collected 30 years ago. Analysis of air temperature records from Environment Canada stations in the corridor indicate that mean annual air temperatures have increased 0.4 to 0.5°C per decade since the 1970s. Recent studies in the corridor [*James 2010*] and from other regions [*Smith et al. 2010*] indicate that permafrost has warmed over the last 30 years and in some places it may have completely degraded. There is a need therefore, to validate current ground thermal conditions within the region to improve the regional characterization of permafrost conditions. In summer 2011, a suite of instrumented field sites were established to provide new information on ground temperatures for the region and to characterize the changes in the ground thermal regime that have occurred over the last three decades.

Field Investigations

In the late 1970s and early 1980s, ground temperatures were measured in 17 boreholes throughout the corridor by the Geological Survey of Canada [*Burgess et al. 1982*]. Most of these boreholes were 6 to 10 m deep. Field investigations in summer 2011 focused on locating these boreholes and installation of temperature cables. The goal was to acquire information that could be used to characterize current ground thermal conditions and also to compare with the earlier measurements to determine how conditions have changed.

Fifteen of the boreholes were found in summer 2011. All of these were located between Whitehorse and the Alaska border. In most cases the boreholes were found to blocked by ice and had to be opened through steaming. Where this process was successful, a new PVC casing (25 mm diameter) was installed to preserve the borehole for installation of a multi-thermistor cable.

Eight boreholes were successfully opened to depths of at least 5 m and cased (Figure 1) and instrumented. The temperature cables were connected to eight-channel data loggers manufactured by RBR Ltd. to provide a continuous record of ground temperatures. A manual reading was also taken from each cable shortly after installation to provide preliminary information on the ground temperatures. Frost probing was also conducted during the site visit. Site visits are planned in summer 2012 to acquire data from the loggers.

It was not possible to unblock some boreholes beyond a depth of 3 or 4 m and it was therefore not practical to install multi-sensor cables. However, instantaneous manual temperature measurements were made at some sites (M2 to M5 in Figure 1). Additional instrumentation, including four-channel HOBO data loggers will be installed at some of these sites in summer 2012 to acquire additional information on the shallow ground thermal regime.

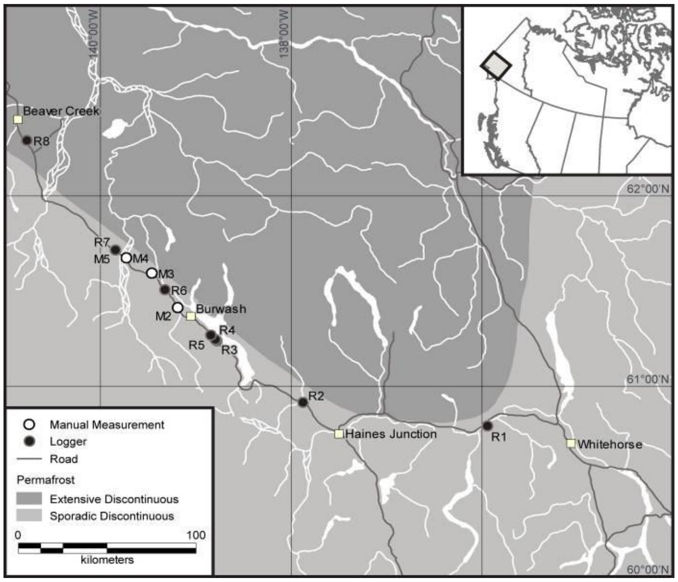

Figure 1. Location of boreholes for ground temperature measurement in the Alaska Highway Corridor. The solid circles represent boreholes where cables and loggers were installed.

Preliminary Results

Measurements made between 1978 and 1981 in boreholes between Whitehorse and the Alaska border indicated that ground temperatures at depths of 6 to 10 m were generally above -2°C with exception of three boreholes (located between Burwash and the Alaska border) where the temperature was between -2 and -3°C [*Burgess et al. 1982*]. The earlier measurements also indicate that frozen conditions existed at 13 of the 17 boreholes. Manual measurements were made in August 2011 at 7 of the 8 boreholes instrumented with cables and loggers. Conditions however, may not have completely stabilized following the disturbance associated with unblocking the boreholes. These preliminary measurements do indicate that permafrost exists at 5 boreholes (R3 to R7) where frozen conditions were also found three decades earlier. Frost probing at R8 indicates that permafrost still persists at this borehole. Unfrozen conditions were found at the other two boreholes (R1 and R2) which was also the case in the late 1970s.

Although permafrost has continued to persist at these sites over the last 3 decades, it is likely to have warmed in response to increasing air temperatures. Ground temperatures for warm permafrost in the Mackenzie Valley Northwest Territories for example have increased by about 0.2°C per decade since the mid 1980s [*Smith et al. 2010*]. Sufficient data is not yet available for the Alaska Highway Corridor boreholes to adequately describe the current conditions and to compare to earlier measurements to determine the magnitude of change that may have occurred.

Summary

Fifteen boreholes, in which ground temperatures were measured between 1978 and 1981 were found in the Alaska Highway Corridor between Whitehorse and the Alaska border. Eight of these were successfully instrumented with temperature cables and loggers. The preliminary ground temperature measurements indicate that at sites where frozen conditions existed 30 years ago, permafrost generally continues to persist. Data collection for at least one year will be required to characterize the current ground thermal regime and to gain insights into how conditions are changing. Continued data collection will ensure an adequate baseline is available for the identification of environmental effects that may be associated with development within the corridor.

Acknowledgements

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Dynamics of Permafrost-Induced Landslides in Central Yamal: Evidence from Repeated Topographic Surveys

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Keywords: dynamics; permafrost-induced landslides; topographic survey.

Introduction

Repeated topographic surveys were performed in Central Yamal, within coastal plain III, on a hill slope at the permafrost monitoring station Vas'kiny Dachi of the Earth Cryosphere Institute SB RAS (Tyumen), in September 2011, using a TopCon GTS-235 tachymeter, to an accuracy 5''. The previous surveys were in 1990 by an optical theodolite and made basis for a 1:500 topographic plan.

The objective of the repeated measurements was to assess the activity of landsliding by comparing the contours of landslide bodies and relative elevations of their fragments, using the mapping method and advanced GIS tools for estimating the amount of displacement and erosion rates.

By processing the field data and comparing the hypsometric plans of different years, the general terrain pattern was found out to remain the same throughout the slope area.

Notable changes consist in a 1 +\- 0.5 m advance of a thermal-erosion gully in the central part of the sliding surface in a landslide of 1989, as a result of erosion progress over 22 years. Table 1 lists some relative elevations of rill thalwegs in the gully from 1999 through 2011.

Table 1. Thalweg elevations in a thermal-erosion gully in 1990 and 2011

	Lower reaches	Middle reaches	Upper reaches
1990	21.81	21.94	28.34
2011	21.63	21.78	28.22

The elevation changes are within 10-20 cm, hence, this kind of erosion is less active than lateral erosion. Note that the rill has locally produced a terraced profile (Fig. 1).

The width of the sliding surface likewise has changed markedly. The contour line pattern (Fig. 1) highlights terraces, possibly of solifluction origin, formed by zones adjacent to the primary sliding surface. This may be evidence that the slope is prone to still more intense sliding under respective climate or other conditions.

There are also some other changes: in the landslide wall position and locally in the edge where new small landslides have appeared. Main possible future directions of landsliding are shown in Fig. 1.

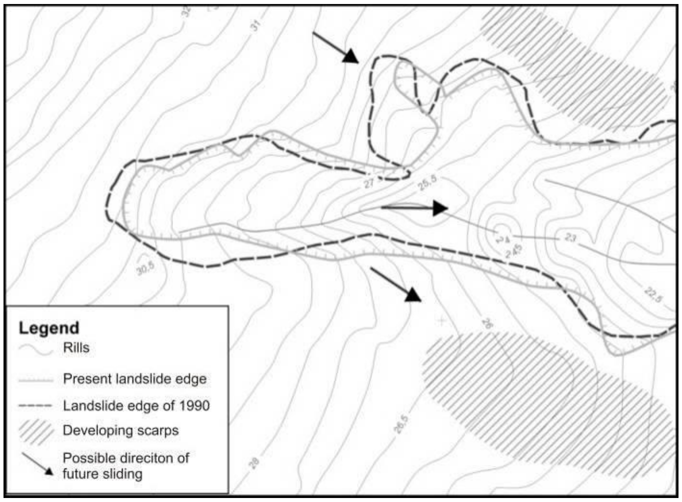

Fig. 1. Landsliding dynamics for 22 years from 1990 through 2011. Vas'kiny Dachi site, permafrost monitoring station.

The results of repeated tachymetry are consistent with evidence from ultrahigh-resolution satellite imagery (geoeye-1).

Thus, the applied method of repeated topographic surveys allows estimating parameters of hazardous permafrost-induced processes and is applicable to study the dynamics of landsliding. However, the method has some drawbacks, such as expensive instruments, weather and climate sensitivity in the Extreme North conditions, and problems with positioning (both coordinates and elevations).

Rockglacier movement detection by D-InSAR in French Alps using ERS archive data and TerraSAR-X data

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Interferometric Synthetic Aperture Radar (InSAR) is a method of measurement based on the phase difference between two radar images, which represent the same area but at different time intervals. The technique generates interferograms, maps of surface deformation in two-dimensions allowing for the detection and quantification (in centimeters) of variations in distance between the target and the radar between two different data acquisitions. Recent research has shown that the InSAR technique can be used to quantify rockglacier deformation (under the assumption that certain conditions are respected with regard to generating and interpreting the interferograms) [*Strozzi et al., 2004 ; Delaloye et al., 2005*].

ERS radar images (dating from 1991 to 1995) were obtained in courtesy of ESA with the aim of generating interferograms. An initial study was carried out which focused on the Queyras Natural Regional Park [*Echelard 2010*] to validate data and detection methodology. In this study, we are interested by the detection of rockglacier movements in all the French Alps. We selected all ERS archive data and chose the more relevant of them. Finally more than 20 interferograms were generated. To analyse this amount of data two methods were employed :

- an empirical analysis of interferograms with orthophotography and topographic data in a GIS. Two geomorphologist separately analyzed the data in order to compare and improve the inventory of movement detection.
- A comparison between interferograms and existing rockglaciers shape inventory [*Monnier 2006 ; Bodin 2007 and Echelard 2010*] was completed to provide a range of potentially creeping formations.

At the end of the analysis a map of the French Alps with all detected movements was edited. A brief overview of this kind of map is presented on figure 1.

Measurements of the movement on rockglaciers were carried out in the field (DGPS). Using the results of this validation, statistical analyses were carried out to allow greater understanding of the limits of the InSAR method. The ultimate objective of the study is to allow for the inventory of creeping landforms over vast areas (100 km width for ERS-1-2 by 100 km length making 10,000 km^2) and to keep a record of their evolution.

Another part of the present study uses TerraSAR-X data on a local scale and tries to compare different kind of method to detect and quantify rockglacier movements. Analyses focused on one rockglacier : “Le Dérochoir” rockglacier, Mont-Blanc massif, France (45°51’57’’N ; 6°48’31’’E). We used and compared differential interferometry, texture tracking and permanent scatterer with summer data from 2007 to 2011. We will present in this communication the first results of this ongoing TSX study.

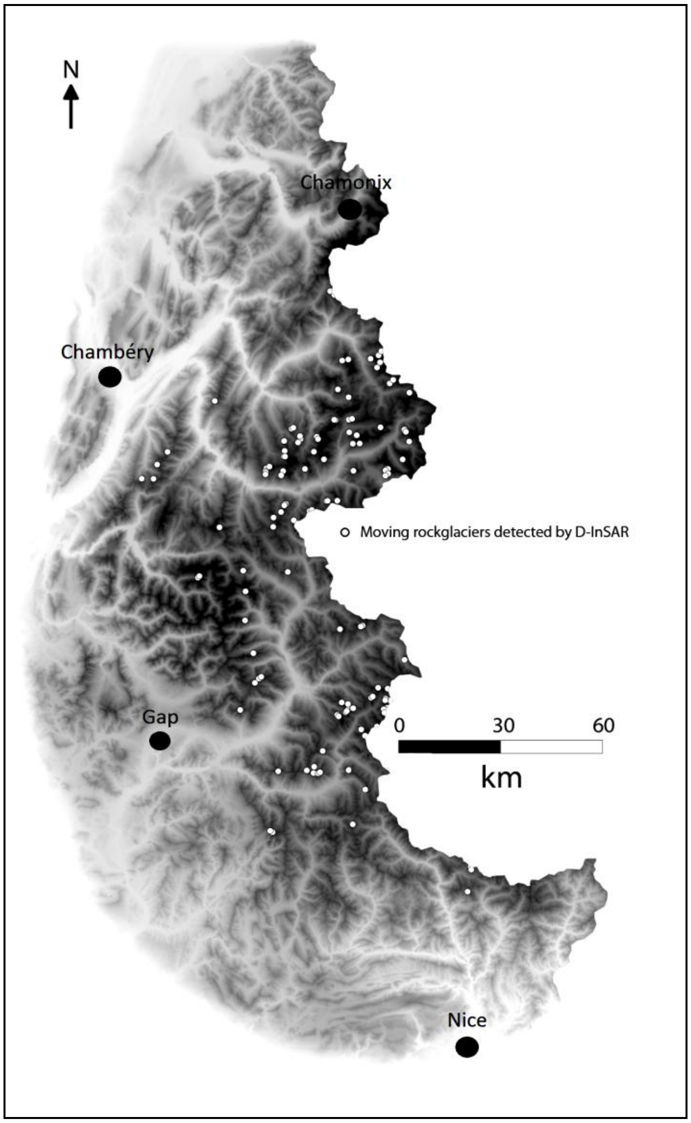

Figure 1 : Map of moving rockglaciers detected by D-InSAR in the French Alps (data : ERS 1 & 2 ; 1991 to 1995).

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The Geomorphological Effect Of Cornices On Gruvefjellet, Central Svalbard

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Introduction

Theory and High Arctic perspective

Rockwall retreat rates are important indicators of geomorphological denudation and accumulation work. Quantitative data has been provided by a number of field studies [*Krautblatter & Dikau 2007*]. Rockfall has been ascribed as the most significant agent of rockwall retreat. However, the role of snow avalanches should not be underestimated, as they are an efficient transport agent from high to lower relief on steep slopes. Still, quantification of their particular importance is rare and often limited to extreme events.

Rockwall retreat rates from the High Arctic are sparse and the geomorphological effect of snow avalanches is only ascribed to full-depth, slush and dirty spring avalanches. However, recently Eckerstorfer et al. (submitted)identified cornices, situated on the leeward edges of the extensive plateau mountains in central Svalbard, as agents of erosional significance. Highly weathered sedimentary sandstone is incorporated into cornices during their onset and plucked out when the cornices deform downslope. The sediment is then transported downslope by cornice fall avalanches, when cornices collapses. A study by Siewert et al. (submitted) from central Svalbard showed that Holocene rockwall retreat rates on slopes with cornices on top where 100 % higher than on slopes without.

Scope of the study

Cornice fall avalanches are the dominant type of snow avalanche in central Svalbard [*Vogel et al., accepted*]. We thus hypothesize that rock slope denudation by cornice fall activity is, in comparison to other slope processes, presently the most active one in central Svalbard. Here we present an up to seven-year long record of debris transport by cornice fall avalanches from two sites in the Longyeardalen valley, central Svalbard.

Study area and sites

The periglacial climate in Svalbard has a mean annual air temperature of -4.1°C, and mean annual precipitation of 187 mm water equivalent (w.e.) at sea level in 2010 in Longyearbyen.

Both study slope sites, Nybyen and Larsbreen, are situated within the same bedrock formation; with near horizontal sedimentary layers of sandstones and shales of the Van Mijenfjorden Group, lower Tertiary. The slope systems consist of large v-shaped gullies, insisted by fluvial erosion processes and small gullies or ravines, caused by a combination of gravitational processes. In the lower part the slope systems are dominated by talus, consisting of depositional avalanchefans or talus cones.

Methods

Rockwall retreat rates

Recent rockwall retreat rates are calculated for each catchment on an annual basis, and averaged over the two slope systems at Nybyen and Larsbreen. We use a direct method of calculating rockwall retreat rates, based on the volume of the snow avalanche deposits, the bulk density of the bedrock, the area of the rockwall and the time of deposition [*Hoffmann & Schrott 2002*].

Snow avalanche monitoring and rock sediment collection

Snow avalanche observations were carried out frequently on site and with automatic time-lapse cameras. Only snow avalanches that reached the talus cones were included, as only there, rock sediment was collected. These point measurements are upscaled to the total area of the snow avalanche deposit and multiplied by a mean rock density of ~2.25 g/cm^3 [*Siewert et al. submitted*].

Results

Table 1. Rockwall retreat rates (mm/a) for Nybyen (N) and Larsbreen (L).

Period	Larsbreen	Nybyen
2003/2004	0.16	
2005/2005	0.43	
2006/2007	0.24	
2007/2008	1.74	0.09
2008/2009	4.25	0.10
2009/2010	8.02	0.65
2010/2011	4.49	1.06
Median per catchment	**1.74**	**0.37**

In general, annual rockwall retreat rates, as well as the median per catchment, were higher at the Larsbreen site (Table 1). At Nybyen rock sediment was collected and weighted in 32 snow avalanche deposits. Rock sediment was visible in 97 % of the investigated snow avalanches. At Larsbreen, 120 snow avalanche deposits were analyzed, with rock sediment visible in 91 % of all releases. This underlines that not only dirty spring avalanches contributed to the talus accumulation. Hence, rock sediment, plucked from the backwall by cornices, is transported downslope during the entire snow avalanche season.

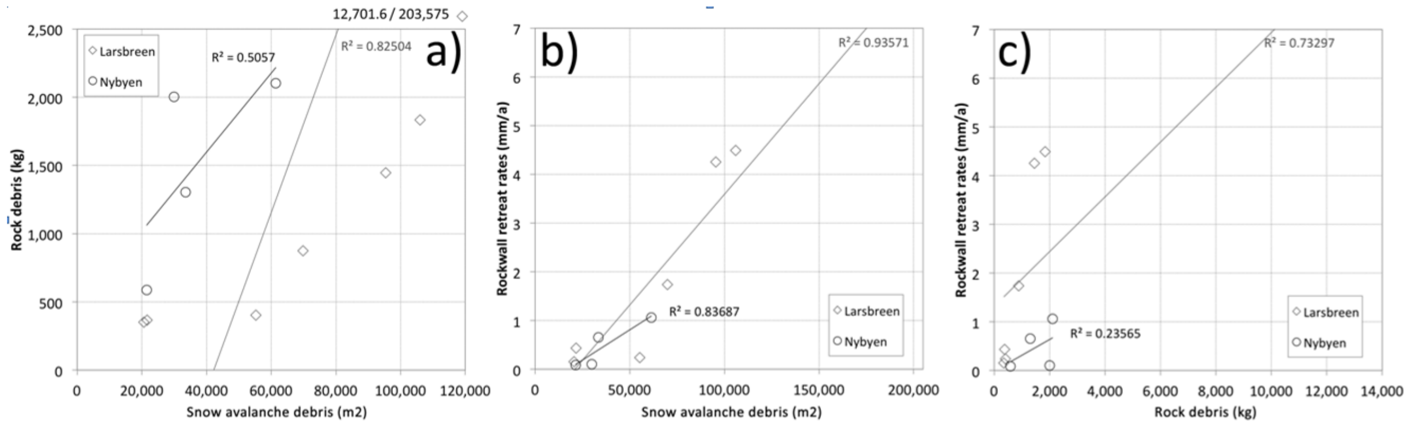

Figure 3: a) Relationship between rock debris and snow avalanche debris. b) Relationship between rockwall retreat rates and snow avalanche debris volumes. c) Relationship between rockwall retreat rates and rock debris amounts. Squares represent data from Larsbreen, circles from Nybyen. Rock debris and snow avalanche debris are annual sums; rockwall retreat rates annual averages

Strong correlations between snow avalanche debris size, rock debris weight and rockwall retreat rates are found, analyzing annual averages (Fig. 1). This method accounts for the differences in observation periods (4 years at Nybyen, 7 years at Larsbreen) for different catchments at both sites (Table 1). The larger the snow avalanche deposits, the more rock debris was collected, being a highly correlated relationship at Larsbreen (Fig. 1a). This relationship accounts also for the comparison of the volume of snow avalanche debris and rockwall retreat rates. Clearly in years with large snow avalanches at both sites, rockwall retreat rates were also high (Fig. 1b). Also, the more rock debris collected, the higher rockwall retreat rates were found, especially at Larsbreen (Fig. 1c).

Both sites have the same aspect, with the Larsbreen site being at slightly higher elevation. They are, however, in different morphological stages. Both sites were ice-free for the last 10 ka BP. The Little Ice Age (LIA) advance of the glacier Larsbreen pushed the snow avalanche derived rock glacier, situated at the foot of the Larsbreen slope system, downslope, but did not reach the Nybyen site. This indicates a later deglaciation of the Larsbreen site (after last Weichselian glacial maxima).The Nybyen site is more developed, with deeper incised gullies and couloirs and more low-angle areas above and behind vertical protruding bedrock noses. These sections act as sediment repositories or intermediate storages, making the Nybyen slope system more complex than the Larsbreen one. The Larsbreen slope system consists only of one source and one deposition area, connected by a straight transport zone. Rock sediment from the plateau rim are thus more efficiently transported downslope and deposited on the talus cones. At the Nybyen site on the other hand, some rock debris is first stored intermediately and further transported by consequent cornice fall avalanches. Another important difference between both sites is the slope system geometry. The Larsbreen site, producing higher rockwall retreat rates, is shorter vertically, and has an almost vertical, well-defined plateau rim. Thus, cornices are more likely to collapse, as they have less support then at the Nybyen site, where the plateau rim has a gentler angle. Annual average rockwall retreat rates for both Larsbreen and Nybyen sitesare among the highest rates measured in periglacial environments in the high Arctic. The cornices promote backweathering by inducing favorable conditions for frost weathering at the plateau edge [*Eckerstorfer et al. submitted*]. Moreover, the cornices trigger rockwall retreat by plucking the bedrock available in the backwall and transport it, in most cases by cornice fall avalanches, all the way down building the avalanche cones. We have shown that at both sites, these processes causes during winter “dirty snow avalanches”.

Due to the geomorphological significance of cornices, producing high rockwall retreat rates primarily on the west facing lee sides of the plateau mountains in Longyeardalen, an asymmetric valley development takes place.

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Numerical Modelling of Hydrothermal Processes in an Alpine Rock Glacier

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Introduction

Alpine Permafrost and Climate Change

Permafrost degradation deserves particular attention as a result of the impact of climate change. About six percent of the land surface of Switzerland is currently lying under alpine permafrost. The thawed active layer on a natural slope is potentially unstable. An increase in active layer depth can result in natural hazards such as rock fall or debris flows.

Goals of the project

Talik formation and occurrences of liquid water within rock glaciers leading to permafrost degradation have recently been observed in Alpine rock glaciers [*Zenklusen Mutter & Phillips 2012*]. The influence of water and of different types of heat transfer such as conduction, convection and latent heat transfer on the thermal regime of a rock glacier are investigated. Basic parametric studies are carried out on the Ritigraben rock glacier, which contains a talik and was chosen to test and calibrate the multiphysics program COMSOL. The latter has successfully been applied to model advective heat transport in rock clefts [*Hasler et al. 2011*].

Database

The Ritigraben rock glacier is located in the Western Swiss Alps in canton Valais and covers approximately 1.4 km^2. Measurements of borehole temperatures over depths up to 27.5 m have been available since 2005. A meteorological station is situated at the site. The stratigraphy can be estimated from six borehole profiles (not shown). The measurement campaign is still ongoing.

The Ritigraben rock glacier resembles a layered permafrost body. The active layer reaches a depth of 4 – 5 m. It consists of large boulders and voids in the upper half, followed by finer grained soils with ice lenses [*Zenklusen Mutter & Phillips 2012*]. Thermistor measurements showed frozen ground between depths of 5 and 27.5 m. There are no measurements at greater depths, but the temperature profile is just above 0°C at 27.5 m, so the permafrost base is assumed to be at this depth. Liquid water is encountered in summer between 11 and 13 m below the surface. This talik is reformed every summer between June and October [*Zenklusen Mutter & Phillips 2012*]. The rock glacier is ice-rich and consists of rocky debris, fines and ice. Liquid water can be found in summer within the talik.

Numerical Model

Modelling software

COMSOL Multiphysics® is a software program that is able to couple different physical phenomena and their corresponding interdependencies to simulate boundary value problems. Partial differential equations can be specified and linked by the user and material properties can be defined and parameterized freely. Pre- as well as post-processing can be carried out within the software and the results can be exported. COMSOL Multiphysics® 4.2a was used and the results were edited in Matlab.

Governing equations

COMSOL Multiphysics® offers several physics interfaces, of which two – the heat transfer and subsurface flow – were used in two dimensions. The heat transfer implemented included conduction and convection. Radiation is of minor importance and can be neglected. The heat transfer is expressed in the form

$$(\rho \cdot C)_{eq} \cdot \frac{\partial T}{\partial t} + \rho \cdot C \cdot \vec{u} \cdot \nabla T = \nabla \cdot \left(k_{eq} \cdot \nabla T\right) + q \qquad (1)$$

where ρ is the density, C is the heat capacity, T is the temperature, t is the time, k is the heat conduction coefficient, q is a source term and u is the velocity of the groundwater flow.

The subsurface flow uses Darcy's equation (eq. 2) combined with the continuity equation (eq. 3). This leads to the following formulae

$$\vec{u} = -\frac{\kappa}{\eta} \cdot (\nabla p + \rho \cdot g \cdot \nabla z) \qquad (2)$$

and

$$\frac{\partial(\rho \cdot e)}{\partial t} + \nabla \cdot (\rho \cdot \vec{u}) = Q_m \qquad (3)$$

where u is the velocity of the groundwater flow, e is the porosity, ρ is the density, Q_m is a source term, κ is the permeability, g is the gravitational acceleration, η is the dynamic viscosity, p is the pressure and z is the reference depth.

Material parameters

All material parameters are assumed to be constant over the simulated range of temperature, except for water, which has a phase change at 0°C where physical properties change significantly. The transitions are modelled with a Heaviside step-function that can be differentiated twice. The latent heat was implemented with the Gaussian integral: the area under the curve equals to the latent heat of 333 kJ/kg, the width of interval (corresponding to the standard deviation) is set to 2°C. Table 1 lists the calibrated parameters.

The depth z corresponds to the depth below the surface and includes the strata from the borehole profiles. The heat conduction coefficient k depends on the type of rock and varies generally between 2.2 for sand and 8.8 W/(m·K) for quartz. The heat capacity C is about 900 J/(kg·K) (sand) but can have higher or lower values for different parent rocks. The density ρ_s is defined as that for the solid rock without voids. The values for the unfrozen hydraulic conductivity were estimated from the porosity, because no measurements were available.

Table 1. Calibrated material parameters

	active layer	perma-frost	talik	air
z [m]	0–5	5–11, 13–55	11–13	-
k [W/(m·K)]	6	6	6	0.025
C [J/(kg·K)]	1’300	1’300	800	1’000
ρ_s [kg/m^3]	2’700	2’700	2’700	1.3
$k_{f,f}$ [m/s]	1e-8	1e-8	1e-7	-
$k_{f,u}$ [m/s]	1e-3	1e-6	1e-2	-
e [-]	0.4	0.5	0.7	-

Boundary conditions

The temperatures measured at a depth of 0.2 m were implemented as the upper boundary condition at the surface in the numerical model, which has a width of 50 m and a total height of 55 m. These data are undisturbed by boundary effects and allow a realistic 2D computation to be made. A geothermal heat flux of 0.06 W/m2 was set at the lower boundary of the numerical model at a depth of 55 m. The sides are thermally isolated. The hydraulic gradient is 1/50 and the phreatic line lies 0.5 m under the ground surface.

Numerical Analysis

Calibration

Figure 1 shows the temperature profile in a section in the centreline of the calibrated model. The active layer reaches a depth of 5 m, which is exactly the value derived from the thermistor measurements. The temperatures are above freezing point at a depth of 28 m, which is also in accordance with the measurements. Mesh-independence could be proven.

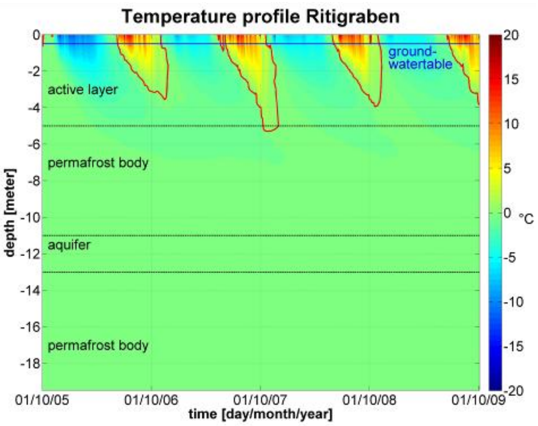

Figure 1. Calibrated modelled temperature profile of the Ritigraben rock glacier: only the upper part of the numerical model down to a depth of 19 m is shown. The thick line indicates the 0°-isotherm.

Validation and parametric studies

There was no possibility to run a long-term simulation to achieve an accurate validation due to a lack of long-term measurements. A series of parametric studies was carried out to show the influence of the material parameters. The most important factor is the depth of the groundwater table, as it corresponds directly with energy-intense phase change effects. The surface temperature plays a significant role in the long-term behaviour of the rock glacier: even small changes affect the depth of the active layer considerably. The permafrost base is strongly influenced by the heat conduction coefficient. The porosity and the heat capacity are of lesser importance.

Conclusion

The parametric studies showed that the temperature profile of a permafrost body cannot be computed accurately by accounting for heat transfer through conduction. Convection should be included whenever a groundwater flux is present. Significant amounts of energy are necessary for the phase change of water, which is referred to in the literature as the “zero curtain-effect”.

Alpine rock glaciers are often within a temperature range of a few degrees from the freezing point. Even small changes in the surface temperature have a significant influence on the ground thermal regime. Climate change with a temperature rise of 1°C or more may not only increase the thickness of the active layer but may result in the instability or the collapse of an Alpine rock glacier.

Coupling between hydrological and thermal processes play an important role in permafrost. The interactions between the equations and parameters require numerical modelling as analytical solutions are not suitable for the relevant conditions.

Further investigations

Many material parameters, such as heat conduction coefficients or heat capacity, need to be examined in much more detail to determine key characteristics such as the thermal diffusivity and to ensure a solid base for further calibration and validation tasks. So far, groundwater flow has not been measured systematically in Alpine rock glacier: neither the temperature of the groundwater nor its mean velocities are known in detail.

The numerical model could be set up to be more complex, including the derivation of the surface temperature from meteorological data and infiltration processes. The expansion to a 3D-model would be even more challenging and would allow the simulation of thermal disturbances such as water fluxes.

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Mechanistic Modeling Of The Vertical Soil Organic Matter Transport At A Global Scale

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Climate forcing exerted by the soil carbon dioxide and methane emissions is a critical component where global models cannot come to an agreement. Moreover, models are lacking the high latitude specific processes and there is high uncertainty of the total carbon stocks within those regions. These are driving the global model simulations to even a poorer confidence in estimating greenhouse gas emissions from high latitude permafrost soils. Indisputably, the permafrost carbon stocks and the amount of carbon that can be released in the event of thawing are wielding a great importance for the future climate. Following this, we have been extending the JSBACH terrestrial ecosystem model to better suit the physical forcing of soil organic matter dynamics in permafrost regions. Including the phase change process with concurrent coupling of hydrology and heat transfer to simulate the vertical soil temperature profile, has improved the seasonal temperature calculations to a great extent. Furthermore, allowing a multi layer snow scheme and an organic layer cover has provided the necessary insulation that is evident all over the Arctic region. Apart from that, in order to observe the outcome of the potential permafrost carbon release, soil organic matter with depth information is needed. For this reason, several sub soil carbon pools are added to the model. The litter distribution to these pools and the organic matter transport among the pools are modeled in accordance to Braakhekke at al., 2011. Additionally, a permafrost specific soil carbon transport process, cryoturbation, has also been implemented in our model. With this, organic matter transport caused by ice formation and melting, allows a churning of the soil matter in a much longer timescale. Consequently, by calculating the seasonal thaw depth and representing the vertical distribution of soil organic carbon stocks within the active layer, we are now able to assess the carbon emissions from permafrost soils in a more accurate way. We have tested the improved model version in several Arctic sites plus compared the results of our pan-Arctic simulations to data from circum Arctic observation networks. Our simulations has shown that improving the JSBACH model with the aforementioned processes leads to a better agreement in model simulations with the observed values and enhances the confidence of future climate simulations. In particular, adding the phase change process and above soil insulation, have provided the simulations to better match the observations for the freezing and thawing periods, which in turn helped us to better simulate the thaw depths. Having the vertically distributed soil carbon pools lets us assess the amount of organic carbon to be released within the physically calculated active layer. On the whole, all the physical process developments and the multi layered several pool representation of soil carbon, provides a valuable tool to investigate the permafrost carbon dynamics in a changing climate.

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Climate and grazing influences on dynamics of arctic tundra vegetation and implications for permafrost

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Numerous observations of the arctic tundra over time, using both field and remotely sensed methodologies, have indicated that the aboveground component of tundra vegetation has been increasing since at least the middle of the twentieth century. At the circumpolar scale, the greening of the northern high latitudes and the arctic tundra specifically has been observed with remotely sensed data for some time [*e.g. Myneni et al. 1997*], and more recent studies have noted the continuation of this trend [*Bunn et al. 2007, Bhatt et al. 2010*]. Bhatt et al. [*2010*] examined the link between sea-ice decline and tundra vegetation increases. They found a nearly ubiquitous greening of the near-coastal tundra, in both the maximum NDVI and the seasonally-integrated NDVI, with some decline in the Bering and West Chukchi regions. Interestingly, the tundra vegetation of North America appears to be greening to a greater extent than that of Eurasia [*Bhatt et al. 2010*]. Bhatt et al. [*2010*] found a 9 % increase in the maximum NDVI for North American tundra from 1982-2008, but only a 2 % increase for Eurasian tundra.One gap in our understanding of tundra phytomass dynamics is that a comprehensive spatial analysis of vegetation change within the arctic tundra biome has not been conducted. Both Bhatt et al. [*2010*] and Jia et al. [*2009*] have made advances in this regard, with Bhatt et al [*2010*] analyzing heterogeneity across Arctic oceanic sub-regions, and Jia et al. [*2009*] analyzing NDVI changes across arctic tundra subzones, but only for Canada. In the present study, we use a newly developed and highly robust relationship between satellite NDVI and field-sampled aboveground tundra biomass, constructed from points along North American and Eurasian arctic transects, encompassing the full latitudinal extent of arctic tundra [*Raynolds et al. 2012*]. We then examine the biomass dynamics throughout the circumpolar arctic tundra with respect to geographic regions, tundra bioclimatic subzones, floristic provinces, and vegetation types. However, we also recognize that the observed aboveground biomass changes are occurring in the presence of wild and managed grazers. The effects of these grazers may oppose, and thereby mask, vegetation responses to a dynamic climate, as observed from remotely sensed platforms. Aboveground biomass data were collected along two transects that spanned the full climate range of the Arctic. The North America Arctic Transect was sampled from 2002-2006, and included eight field locations [*Walker et al. 2012*]. The Eurasia Arctic Transect was sampled from 2007-2010, and included five field locations [*Walker et al. 2012*]. The field locations were chosen to represent the zonal vegetation of each of the five arctic bioclimate subzones as displayed on the Circumpolar Arctic Vegetation Map (CAVM) [*Walker et al. 2005*] — from subzone A in the north where shrubs are absent, mosses and lichens are dominant, and bare ground is common, to subzone E in the south, which is characterized by complete ground cover and abundant erect dwarf shrubs. At each of the 13 field locations (8 in North America and 5 in Eurasia), several 20 cm x 50 cm quadrats were harvested for aboveground biomass estimates. When sampling, the 20 cm x 50 cm sections of tundra were removed from the field intact. Vegetation above the dead moss layer (or above the mineral soil layer, when there was no dead moss present) was removed, dried, and weighed for estimates of aboveground biomass [*see Raynolds et al. 2012*]. The NDVI for the sampling date and location were extracted from a maximum annual NDVI dataset based on AVHRR 12.5 km pixel data extending from 1982 to 2010. This Global Inventory Modeling and Mapping Studies 3rd generation (GIMMS3g) dataset was developed specifically for polar areas, with a polar projection and revised calibration optimized for the Arctic. The new dataset addresses several issues in the previous GIMMS dataset for polar areas. We used the single AVHRR GIMMS3g pixel that encompassed each of our field locations for developing the relationship between NDVI and aboveground phytomass. The relationship between aboveground biomass and NDVI was calculated using logarithmic regression (NDVI = 0.383 ln(biomass) + 0.994, $r^2 = 0.94$, $p < 0.001$, where biomass is in kg m^{-2}). This relationship was applied to the GIMMS3g maximum annual NDVI data (1982-2010) to estimate biomass. Trends in biomass were calculated by applying a linear regression to the time series for each pixel. The significance of the trends was calculated, and only pixels with significant trends ($p < 0.05$) are displayed on the trend map (Fig. 1). The ArcVeg tundra vegetation dynamics model [*Epstein et al. 2000, Yu et al. 2011*] was used to assess the circumpolar grazing effects on tundra vegetation, with circumpolar inputs based on geographic climate subzones, soil organic nitrogen quantities, spatial patterns of caribou and reindeer grazing, and climate change scenarios. We used the model output to assess how much of the vegetation changes from remote sensing could have been affected by caribou and reindeer grazing. The aboveground phytomass of circumpolar arctic tundra increased from 2.02 Pg (10^{15} g) in 1982 to 2.41 Pg in 2010 for a total increase of 0.40 Pg, a change of ~19.8 % over a 29-year time period (0.7 % y^{-1}). A relatively ubiquitous increase in tundra phytomass over time is observed circumpolarly, with isolated areas of phytomass decline in Beringian Alaska and the Kanin–Pechora region of western Eurasia (Fig. 1). With respect to the different tundra bioclimatic subzones, the three southernmost subzones (C, D, and E) exhibited extensive increases in aboveground phytomass (20.9 %, 25.6 %, and 20.6 % respectively), whereas the two northernmost subzones (A and B) showed substantially smaller increases (2.1 % and 6.4 % respectively). In addition, subzones C, D, and E comprise 87.5 % of the tundra landmass and 95.5 % of the initial tundra biomass in 1982; therefore the dynamics of the three southern subzones dominate the circumpolar tundra phytomass change. Whereas subzone D showed the greatest relative phytomass increase of 25.6 %, subzone E exhibited the greatest average absolute biomass increase of 96.1 g m^{-2} (3.4 g m^{-2} y^{-1}). North America (Alaska and Canada) represents approximately 43.2 % of the tundra landmass and 45.4 % of the tundra aboveground biomass in 1982. Eurasian tundra is approximately 27.1 % of the tundra landmass, and 44.0 % of the tundra aboveground biomass. However, increases in tundra phytomass in North America over the past 29 years were generally greater than those in Eurasia. Alaskan tundra phytomass increased 7.8 %, and Canadian tundra phytomass increased 36.5 %, whereas tundra biomass in Russia increased 15.7 % (9.4 % in Western Siberia and 23.4 % in Eastern Siberia). The aboveground tundra phytomass is almost equally distributed between North America and Eurasia (0.91 Pg in North America and 0.89 Pg in Eurasia in 1982 compared to 1.07 Pg and 1.02 Pg respectively in 2010). Based on the ArcVeg modeling analysis, caribou and reindeer grazing have the capacity to reduce the tundra biomass response to climate change by greater than 50%. If the estimated vegetation change using remote sensing is the combined effects of climate dynamics and grazing, then the isolated vegetation response to climate changes could be double those observed. There was a high degree of spatial variability of change, particularly across subzones. Most of the biomass changes were seen in the three southernmost subzones (C–20.9 %, D–25.6 %, and E–20.6%), with very little change in subzones A (2.1 %) and B (6.4 %). The greatest relative changes occurred in subzone D, which is consistent with a remote sensing analysis of Alaska from 1981-2001 [*Jia et al. 2003*], whereas a remote sensing analysis of Canadian tundra showed subzone C peak-NDVI increasing by 0.79 % y^{-1} and subzone D peak-NDVI increasing by 0.67 % y^{-1} from 1982-2003 [*Jia et al. 2009*]. Phytomass increases in North America were greater than in Eurasia. These results are consistent with substantially greater summer warming for the North American arctic tundra compared to the Eurasian arctic tundra, and also for Eastern Siberia compared to Western Siberia [*Bhatt et al. 2010*]. Potential aboveground phytomass increases in response to warming could be constrained to a substantial degree by grazing, particularly by managed reindeer herds in regions throughout Western Siberia [*Forbes et al. 2009, Yu et al. 2011*]. The large difference in percentage increase between Alaska and Canada is due to spatial heterogeneity of change; whereas Canada exhibited relatively consistent greening, strong increases in aboveground vegetation on the North Slope of Alaska are countered by declines in green vegetation in the Bering region of the Seward Peninsula and the Yukon River delta. A 19.8% average increase in aboveground biomass has major implications for the structure and functioning of arctic tundra ecosystems. From the perspective of permafrost, the increasing vegetation could lead to decreases in albedo, which would increase the net radiation at the land surface and promote regional warming. On the other hand, the thermal insulation properties of increasing vegetation will cool ground temperatures in the summer (possibly protecting permafrost) and warm them in the winter. Trapping of snow by increasing taller shrubs will also affect the ground surface thermal regime. Finally, the resultant changes in soil temperatures will alter soil nutrient cycling rates, which feed back to influence vegetation. The ultimate effect of vegetation change on active layer depth and permafrost stability is therefore a complex combination of multiple interacting responses.

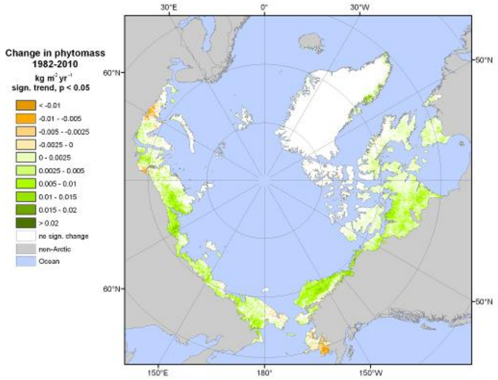

Figure 1 - Significant changes ($p < 0.05$) in aboveground tundra phytomass from 1982 and 2010.

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Microbial Community Traits: Evidence that Permafrost and Active Layer Microbial Traits have Different Abiotic Drivers

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Carbon in permafrost soils may be vulnerable to decomposition under climate warming. The ensuing release of carbon dioxide and methane into the atmosphere would result in a positive climate feedback. However, the accuracy of our carbon efflux predictions is constrained by our inadequate understanding of controls on decomposition in thawed permafrost [*Davidson & Janssens 2006*]. Decomposition in thawed permafrost will be a function of both soil organic matter (SOM) chemistry and the ability of microbial communities to degrade newly available substrates. Little is currently known about SOM chemistry, microbial community traits or functional diversity in permafrost soils [*Waldrop et al. 2010, Graham et al. 2011*]. Growth rate, carbon mineralization and catabolic diversity have been shown to correlate with SOM chemistry in temperate systems [*Degens et al. 2000*]. Understanding whether SOM chemistry also correlates with microbial traits in permafrost and active layer soils, or whether some other factor such as temperature is more important, will be critical in future predictions of the decomposition rate and carbon efflux from thawed permafrost.

Permafrost cores and active-layer soils were collected from Sagwon Hills, Alaska in August of 2009. Permafrost cores and the overlying active-layer organic and mineral soils were further separated into 5 cm increments and homogenized while frozen. Soils were analyzed with Fourier-transformed Mid-infrared spectroscopy (FT-IR) to quantify the relative abundance of chemical constituents of the SOM in each layer. The ability of the microbial communities to degrade a variety of substrates, which correspond to different components of the SOM, was analyzed using Ecolog plates (Biolog Inc) incubated at 10°C. Microbial community traits, including substrate utilization, growth rate and maximum substrate use, were determined by fitting a logistic growth model to the Ecolog incubation data (Eq. 1) [*Lindstrom et al. 1998*].

$$y = OD_{595} = \frac{K}{(1 + e^{-r(t-s)})} \qquad (1)$$

where OD_{595} is the microbial activity as measured by the optical density at 595 nm, K is an asymptotic maximum of OD_{595}, r is the growth rate, t is the time, and s is the time to half of K. Microbial community traits (growth rate, r; maximum substrate use, K) were then correlated to SOM chemistry using linear regression.

In the Ecolog experiment, the permafrost community grew on half as many substrates as the active-layer community ($p=0.0005$). The growth rate on nitrogen-rich substrates (amines, amides, and amino acids) of the active- layer community was more than twice that of the permafrost community, while the growth on carbon-rich compounds was not significantly different between the two microbial communities (Fig. 1).

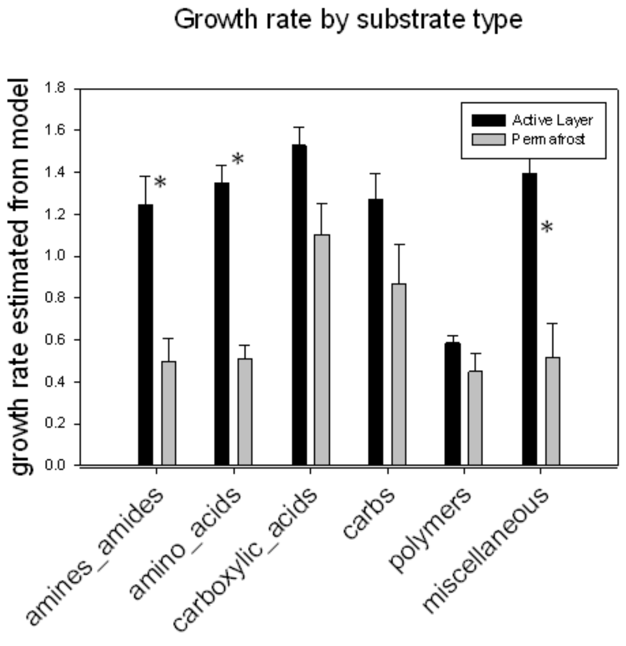

Figure 1. The growth rate on different substrates varied by microbial community.

Analysis by FT-IR indicates that the both the active-layer and the permafrost are characterized by undecomposed organic materials; however, they are more abundant in the active layer. Also, both the permafrost and the active layer have features attributable to decomposed material. Because the organic material has been decomposed in both soils, we expected that the traits of both microbial communities would be correlated to the SOM chemistry [*Degens et al. 2000*]. Correlations between the growth rates on specific substrates in the active layer and permafrost communities with SOM chemistry are preliminary. However, they indicate that the active layer growth correlates with SOM chemistry, whereas the microbial growth rates in the permafrost do not. This is intriguing because it seems that something other than SOM chemistry has organized microbial community traits in permafrost. Further investigations into the role of temperature in shaping the microbial community are underway, and will aid in our understanding of how the decomposers in permafrost will degrade the large reservoir of permafrost carbon as temperature rises.

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Permafrost Evolution in the North-Atlantic region (Svalbard, Norway and Iceland) during the last 150 years

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Introduction

Since 2003 numerous shallow boreholes were equipped to monitor ground temperatures in Norway, Svalbard and Iceland [*Christiansen et al. 2010*]. The total number of monitored boreholes is 42, of which 4 are located in Iceland, 10 in southern Norway, 16 in northern Norway and 12 in Svalbard. The monitoring stations are setup to characterize the ground thermal regime in different periglacial landforms and environmental settings, and to validate spatially distributed, equilibrium and transient permafrost models. Altogether 29 of these boreholes have been used to calibrate a transient heat flow model. Here we evaluate the variations in the ground thermal regime during the period of meteorological observations since the end of the Little Ice Age c. 1870, for Svalbard only since 1912, until today on monthly and daily basis. This forms an important background for assessing the response to future climate change.

Methods

Meteorological data

Mean annual surface air temperatures (SAT) were derived for selected sites in the study areas. In Iceland the instrumental data record from Akureyri starting in 1886 was used, and a linear regression between this record and SAT records at the various field sites were established (R2>0.7). For Svalbard a similar approach was used based on the SAT record from Svalbard Lufthavn. For Norway, long-term temperature records starting in the 1860s exists for six temperature regions each characterized by similar long-term air temperature variability. Those were related to the various field sites using observed temperature lapse rates. For all sites also seasonal SAT changes in relation to the last normal period 1961-1990 were calculated.

Modeling approach

The numerical modeling was applied to estimate ground thermal regime and the active layer thickness development during the modeling period. Hence, the SAT records were used to force a 1D heat flow model. Soil temperatures can be modeled using Fourier's law of heat conduction in one dimension

$$c(\text{eff}\ )\ \partial T/\partial t - \ \partial/\partial z\ (K\ \partial T/\partial z) = 0$$

where ceff denotes the effective heat capacity and K the thermal conductivity, both depending on the soil properties and are thus variable in time and space. The thermal effect of snow was parameterized using simple linear transfer functions between air and ground surface [*e.g. Etzelmuller et al., 2011; Westermann et al., 2011*]. The active layer thickness (ALT) was defined as the lowest depth of the modeled 0°C isotherm.

Results

Surface air temperature (SAT) variation

The air temperature record from Svalbard shows the largest variability and SAT increase, while Iceland shows the smallest increase during the instrumental period. At all sites besides Iceland, the highest SAT was reached after 2000. In Iceland, the 1930ies were warmer than today. The seasonal SAT deviations from the normal period 1961-1990 show largest observed deviations during winter, while the summer deviations are smallest. All sites show a marked increase since the 1990ies. Considering the whole period, spring temperatures show the most constant and largest increase since the end of the LIA in all regions, and particularly in Svalbard.

Ground temperature development

The model results indicate that the ground temperature (GT) increase at 20 m depth varied between +0.2°C and +2.2°C per 100 years for Iceland and Svalbard, respectively, following the SAT forcing. The GT development in the north Atlantic region is thus variable, and GT differences between comparable sites are decreasing over the region. All sites except the Icelandic ones show higher GT at present than during the warming in the 1930ies according to this modelling exercise.

Active layer thickness (ALT) development

Following the GT development, in all borehole sites in Norway and Svalbard, the thickest ALT is modelled under present climate conditions, with an accelerated increase of ALT since 2000. However, cold winters during the last years have counteracted somewhat this development. In Iceland, ALT is similar or less than during the 1930ies warming spell. The ALT increase in Svalbard is less pronounced than in the other sites as the GTs are lower there, and the major SAT increase has happened during spring and winter, and less during summer. The ALT development is also largely controlled by ground conditions such as the water/ice content and associated soil properties

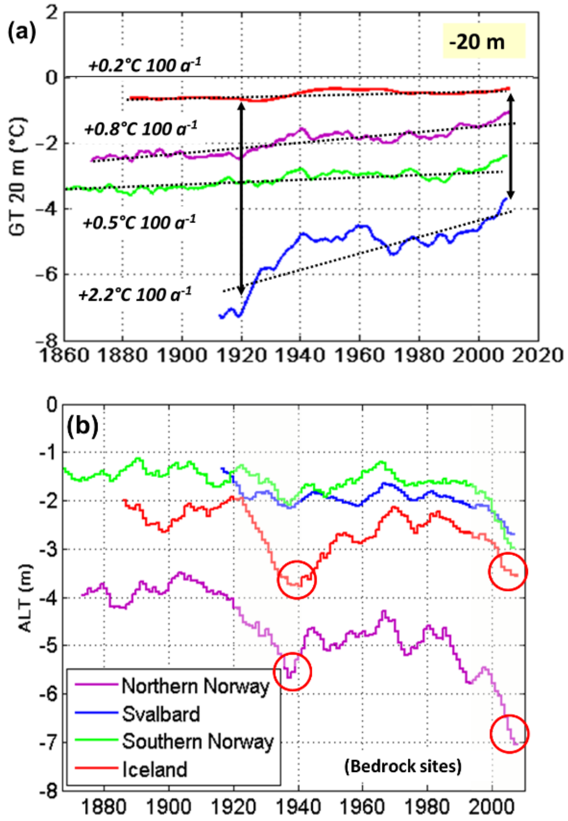

Figure 1. (a) Modeled ground temperature in 20 m depth for four selected sites (b): ALT development in bedrock-. In both graphs the curves are smoothed with a 7-yr Gauss filter.

Discussion and Conclusions

The modelling exercise displays clear regional differences in relation to SAT, GT and ALT development. Much of the SAT increase is driven by warming during the spring (MAM) months, while the winter temperature is highly variable, and there is no statistical significant increase. All areas have a summer warming since the 1990ies except Svalbard. A further warming would further warm (Svalbard) and partly degrade permafrost in many of the sites within the next decades. In Svalbard, the low laying coastal areas which are dry and dominated by bedrock, could into the zone of discontinuous permafrost, while larger valleys in Svalbard are filled with more fine-grain sediments of glacial, fluvial and periglacial origin and far more ice-rich and with a higher content of organic material [*Christiansen et al. 2010*]. These areas would remain stable even at lower elevations.

The study provides important insights into the response of mountain permafrost in the north-atlantic region which outside Svalbard is dominated by bedrock overlain by relatively coarse and shallow sediment layers, resulting in a fast thermal response to climate variability. However, in Iceland we in many place can find a more fine-grained sediment cover because of high weathering rates, aeolian processes and ash accumulation [*Kellerer-Pirklbauer et al., 2007*].

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Snow Layering Across Rugged Topography on a Wind-affected Slope, In High Arctic, Central Svalbard

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Introduction

Snow stability focuses on the study of weak zones and interfaces internally present in the snowpack. It has long been understood that snow is a heterogonous substrate with properties that vary spatially. This characteristic makes the study of snow stability difficult and understanding spatial trends ever more important. In the past two decades snow stability studies focusing on the spatial variability of the snowpack have been conducted on sheltered uniform slopes in non-continuous permafrost environments. To better understand snow stability, it is important to gain a better grasp of how snowpack varies spatially over rugged wind-affected terrain, as this is more representative of mountainous slopes. The spatial variability of snow cover as a function of the terrain topography was highlighted as a key zone of uncertainty in avalanche forecasting [*Hägeli & McClung 2004*]. Likewise Schweizer *et al*. concluded in their 2008 review of the spatial variability in snowpack that “research to understand and analyze terrain-correlated patterns of weak layer formation is important”.

The aim of this study is to better understand seasonal snowpack development and how the geomorphological snow in-fill process influences weak layer evolution, most specifically depth hoar growth in a high arctic continuous permafrost environment. An objective of this study is to correlate topographic trends with the depth hoar formation to better understand spatial variations across irregular slopes. To fully understand the interactions between ground topography and snowpack stratigraphy it is important to monitor the geomorphologic process of the seasonal snowpack development, both through deposition and aeolian reworking. Better understanding of how weak layers develop and their evolution can provide valuable information as to snow stability and avalanche propensities.

Study Site

Svalbard’s high arctic periglacial environment exhibits a relatively mild climate, with a mean annual air temperature of -3.4°C at sea level in Longyearbyen [*2011*]. Despite the long winter season and maritime influence, mean annual precipitation is only 199 mm water equivalent [*in 2011*]. Thus snow depths are largely controlled by wind in the barren landscape, devoid of any high vegetation. The annual dominant wind direction is from the SE, but differs locally due to topographical channeling effects [*Humlum 2002*].

The study site is situated in the valley Fardalen, roughly 15 km south of Longyearbyen. It is a 30 x 30 m south facing slope characteristic of the region with rugged, irregular wind-affected terrain, comprised of talus and scree. The base of the slope sits at ~400 m a.s.l. and is part of a larger slope that rises up to 848 m a.s.l. The slope has a convex profile with a mean inclination of 39° and a maximum inclination of 55°. The wind activity drives both top and cross loading along the study slope. Although larger slopes in the region are often draped in talus and scree, the underlying topography on the study slope is *in-situ* weathered shale bedrock with scattered coarse sandstone clasts.

Methods

A trench was excavated from the bottom to the top, up the slope. On the trench sidewall, snow depth measurements were conducted every 50 cm totaling 20 measurements sites. Additionally, slab thickness and hardness as well as weak layer thickness and hardness were recorded at each 50 cm increment. Measurements of physical and mechanical snow properties were conducted at each of these sites to better understand the stratigraphy and the snowpack properties across the slope.

Results

Figure 1 displays a layer trace of the three persistent weak layers WL A, B and C. Weak layer A is an interface offacets overlaying a melt-form surface, WLB is a bed of surface hoar and WL C is a extensive layer of depth hoar. Total snow depth and slab thickness (package of snow that overlays each weak layer) were recorded for each weak layer. The image provides an overview of how the weak layers have formed in relation to topography. Weak layer C (lower most / red) is the depth hoar weak layer and naturally mimics the terrain, as it was deposited first. The greatest percentage of depth hoar to total snowpack (28%) was recorded at 250 cm up slope, coincidentally at the shallowest zone on the slope with 32 cm. At this spot, all persistent weak layers are virtually pressed together, resulting in possibly the weakest zone on the slope. Weak layers B and A were deposited consecutively and reflect the terrain profile incrementally less, as in-fill and snowpack development smooth the terrain irregularities.

Discussion

Eckerstorfer and Christiansen [*2011*] identify depth hoar as the second most abundant snow crystal form (and most abundant weak layer) found in the Longyearbyen region, representing an average of roughly 15% of the total snowpack. Depth hoar is a term used to describe large cup-shaped crystals (1-5mm scale) that bond poorly. This can be caused by early season snow that is followed by cold dry conditions. The snow crystal structure is formed by high temperature gradients between the cold air and the warmer ground surface temperatures. This process is more extensive on talus slopes where coarse porous clasts allow for thermally driven air circulation. Due to little precipitation and a slow onset of snow accumulation, depth hoar is common weak layer in central Svalbard. Depth hoar is widespread and persists through the entire season [*Eckerstorfer & Christiansen 2011*]. Permafrost conditions result in cold ground surface temperatures and cool snowpack. Due to the large air temperature fluctuations and thin snowpack, large temperature gradients within the snowpack initiate snow crystal metamorphism forming depth hoar, resulting in weaker snow structure. Study data displays that the depth hoar weak layer follows the bed surface, with slight variations in unit thickness. Variations are likely accredited to inconsistent snow depths across the irregular terrain. As the snowpack develops, snow surfaces exhibit greater deviation from the ground surface and begin to reflect ground irregularities less. This development results in the in-filling of ground irregularities. The in-fill process masks terrain and makes determining shallow and potentially unstable zones in the snowpack difficult. The influence of a continuous permafrost environment on the thermal regime of snowpack lacks significant investigations and therefore is not fully understood.

Preliminary Conclusions

Initial conclusions prove that the terrain plays a significant role in the seasonal stratigraphic development of the thin, wind-swept snowpack in central Svalbard. It is also clear that snow depths vary as a function of ground topography thus trends in the depth hoar weak layer exist. Preliminary data indicate that shallower zones in snowpack demonstrate a greater percentage of depth hoar and can result in zones of greater instability.

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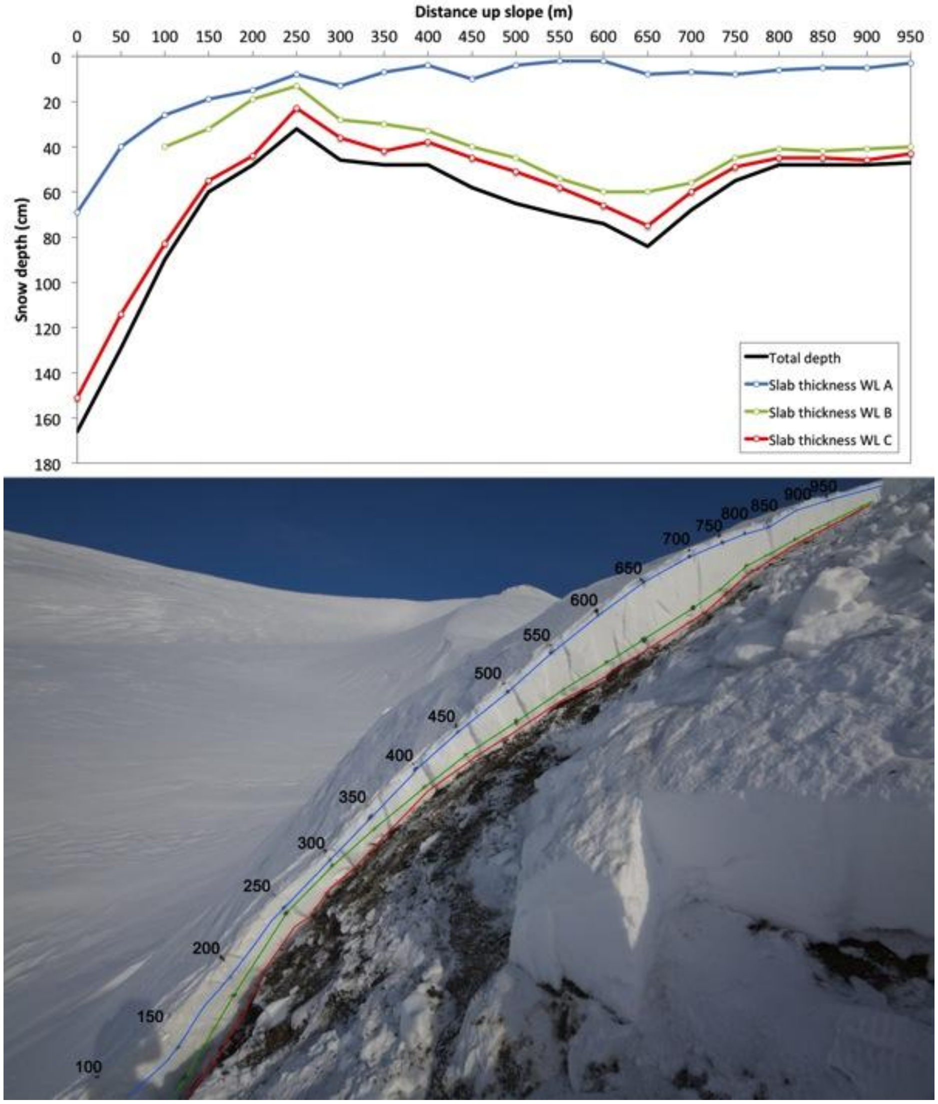

Figure 1:Stratigraphy and snow layer thickness of the investigated slope in Fardalen, Svalbard. The upper section displays a layer trace of the three persistent weak layers WL A, B and C. Total snow depth and slab thickness for each weak layer were recorded every 50 cm upslope. The lower section is an image of the trench seen from below, taken during fieldwork, April 2011.

Active Layer Dynamics in Landscapes of Northeast Yakutia at the Turn of the 21st Century

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Introduction

The period of observations in Northern Yakutia run as part of the CALM (Circumpolar Active Layer Monitoring) international program has been the time of notable climate change. The response of the active layer to changes in mean summer temperatures has been studied most comprehensively in the Kolyma basin. After a temperature minimum in 1998 (minus 8.3°C, measured at Chersky weather station), summer means increased since 2000 (11.3-14.7°C) and reached a peak in 2007; the summer seasons in the following 2008-2009 years were colder (9.2-10.7°C).

Results and Discussion

The active layer thickness correlates with mean summer air temperatures at 14 out of 15 monitoring sites (r = 0.59-0.89). Warming has shown up as greater thaw depths in zonal and most of intra-zonal soils of the Kolyma basin. The absolute active layer increment for the 2000-2007 period was the greatest in polygonal plateau bogs of the Khallerchinskaya tundra (R16, 47 cm), in a steep watershed slope near Lake Yakutskoye (R25, 42 cm), as well as in zonal sandy soils of tundra and taiga (R19 и R21, 32-45 cm). In other landscapes, the growth was 11-22 cm in zonal tundra and taiga ecosystems, with loamy soils, 25-35 cm in thermokarst sinkholes (alases, at R13A, R15A), and 17 cm in the floodplain (R17). The relative amounts of active layer increase were the maximum in intra-zonal ecosystems of polygonal plateau bogs (100% of the long-term annual mean) and in alas depressions (63-96%), as well as on the steep loamy watershed slope (91%). The relative increase was much lower in zonal tundra and taiga soils. Namely, it was 38-46% in sandy areas and decreased southward in watershed areas composed of the Late Pleistocene Yedoma loam, from 49% in typical tundra (R13) to 21-42% in southern tundra (R14, R15B, R22), and finally to 17% in northern taiga (R18).

This pattern has considerably smoothed out the latitude active layer zoning we revealed in the first years of the CALM Project. In the summer of 2007, the difference between the mean thaw depths in tundra soils in the East Siberian Sea coast (R13) and at the taiga boundary (R22) was as small as 2 cm.

The seasonal thaw depth grew also in the neighbor Yana-Indigirka basin. For instance, the increase reached 10 cm between 2004 and 2007 at site R31 in the Allaikha riverside. In 2007, the active layer thickened up in the Bykovsky Peninsula as well (R29A, R29B), southeast of the Lena delta, where it never occurred before.

In two cold years of 2008-2009, the active layer thinned down, following the patterns similar to those of its growth. The thinning was the maximum in alases (78-86%), in polygonal plateau bogs (68%), and on the steep watershed (50%). The active layer within zonal ecosystems was more stable, and its thinning was from 12 to 46%. The amount of thinning, as well as that of thickening, decreased from north to south. In spite of the cold summer of 2009, the active layer reached the value of 1996-1999 in none of the studied landscapes. The following warmer year of 2010 (mean summer air temperature 12.9°C) was again marked by deep ground thawing at all sites. Thus, there is a pronounced trend of active layer increase on the background of warming in Northeastern Yakutia.

The thickness of the active layer depends on air temperatures in a given summer season, as well as in previous summers. There appears a sort of a cumulative effect from several years of warm summers. One reason is, in our view, in the considerable warming of permafrost over the past decades which was recorded a few years ago. Another reason consists in progressive degradation of the ice-rich cover making a buffer in ecosystems of the loamy watershed. The anomalously high active layer increase on the steep watershed slope may be due to the lack of the cover layer and to free drainage that prevents the soil profile from excessive moistening.

Conclusions

1. Warming of summer air temperatures in 2000-2007 and their cooling in 2008-2009 caused changes in the active layer thickness in all zonal and most of intra-zonal landscape systems of Northeastern Yakutia.

2. The relative active layer increase in 2000-2007 was the greatest in ecosystems of polygonal plateau bogs and alases, as well as on the steep watershed slope. In zonal landscapes, the increment decreased from north to south, from typical tundra to northern taiga systems. The absolute amount of active layer thinning in 2008-2009 was less than in other years but generally followed the same geographic pattern as the increase.

3. There is a trend of progressive active layer increase on the background of climate oscillations. The increasing trend is caused by permafrost warming and degradation of the ice-rich cover which acts as a buffer in many watershed ecosystems in Northeastern Yakutia

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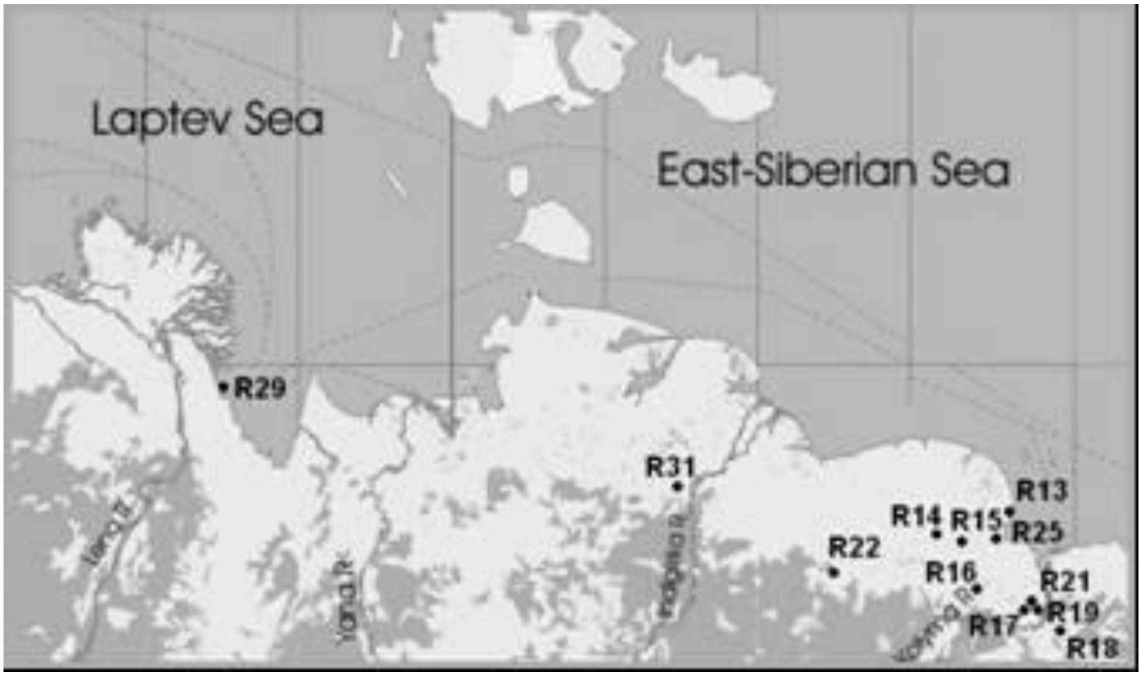

Fig. 1. Location map of key temperature monitoring sites in Northern Yakutia. R13 – Maly Chukochy Cape (watershed and alas); R14 –Bolshaya Chukochiya River; R15 – Malaya Konkovaya River (watershed and alas); R16 – Segodnya Buglunyakh; R17 –Ahhmelo River; R18 – Rodinka Mountain; R19 – Lake Glukhoe; R21 – Lake Akhmelo; R22 – Alazeya River; R25 – Lake Yakutskoe, R29 – Cape Bykovsky (watershed and alas); R31 – Allaikha River.

Quasi-Liquid Films in Glacial and Frozen Systems

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Abstract

Sorption experiments with dispersed ice were conducted. It is shown that the quasi-liquid film existing at the ice surface has solvent properties in relation to the substances dissolved in the organic solvent or water contacting the ice.

Keywords: ice; quasi-liquid film; substance sorption.

In nature, glacial formations (snow, glaciers etc.) consist of ice crystals. Ice inclusions are also characteristic components of permafrost. Their presence can influence re-distribution of soluble chemical substances in the system and define their migration capacity to one extent or another.

The role of the ice is preconditioned by the presence of particles of the disordered water molecules layer, the so called liquid-like film, at the surface. It exists within the temperature range close to the ice melting temperature (Fig. 1) [*Kvlividze 1974*]. The thickness of the film depends on the temperature and the nature of the material bordering the ice.

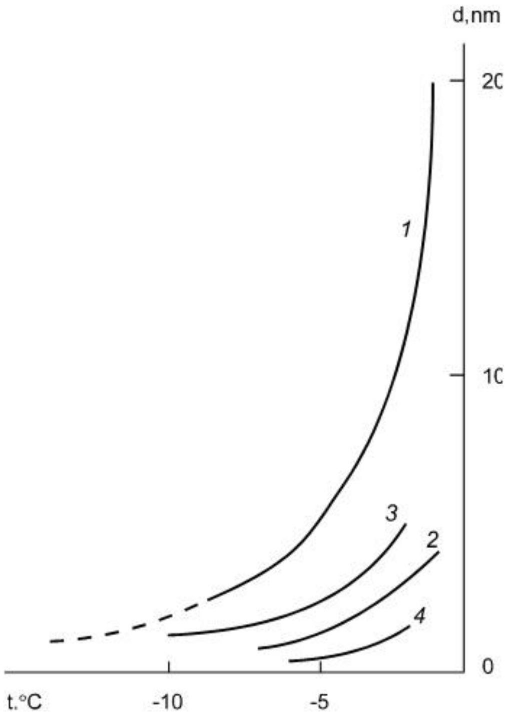

Figure 1. Dependence of the thickness of the liquid-like film in frozen specimens on the temperature at the ice border with air (1, 2), silica gel (3), teflon (4) with the specific surface 1 (1), 30 (2, 4), and 20 m^2/g (3) (calculated on the basis of the data of Kvlividze 1974)

The reliable quantitative characteristics of this layer were received in the 70s of the previous century with the use of the nuclear magnetic resonance method [*Ushakova 1975*]. It turned out that water molecules in this layer have the self-diffusion coefficient that is by five orders higher than the water molecules mobility in the ice volume and only by one order lower than the mobility in the liquid phase of water. Consequently, it can be assumed that the liquid-like film of the ice surface must have solvent properties.

We showed in sorption experiments with dispersed ice that the solvent properties of the film really occur, for example, in case of the ice particles interaction with organic substance solutions in hydrophobic solvents (Fig. 2).

It was found out that the sorption of dissolved substances is preconditioned by their transition from the organic layer of the solution to the volume of the liquid-like film in accordance with the coefficient of the substance distribution between two immiscible solvents: water and organic substance. The initial curve section in Figure 2 testifies to the transition of the substance to the liquid-like film. Further abrupt increase of sorption is preconditioned by the formation of the bulky water solution in the layer system, which was proved visually.

It is interesting that the quasi-liquid ice film disappears in case of long-term (about 2.5 months) keeping of ice specimens at the temperature below minus 40-45 °C.

Isotherms were obtained in the process of such ice interaction with solutions. The shape of the isotherms testifies to the manifestation of the surface properties of regular solid material by the ice (Fig. 3).

The results testifying to re-occurrence of the liquid-like surface film were received in case of further use of the ice specimens (preliminarily kept at low temperature) in sorption experiments. The duration of the time period required for such re-occurrence depends on the thermal conditions in sorption experiments and does not exceed 2.5, 15 and 48 hours at -2, -5, -10 °C, respectively.

Therefore, the liquid-like film of the ice crystal surface can represent a solvent medium in glacial systems and permafrost. Consequently, it can play a role of the migration medium in case of chemical substances dispersion in them. The natural experiments showed that the arrival of soluble substances from the underlying substratum (soil, ice) to the near-contact snow layer is observed at the temperature above minus 12 °C at the boundary of two media.

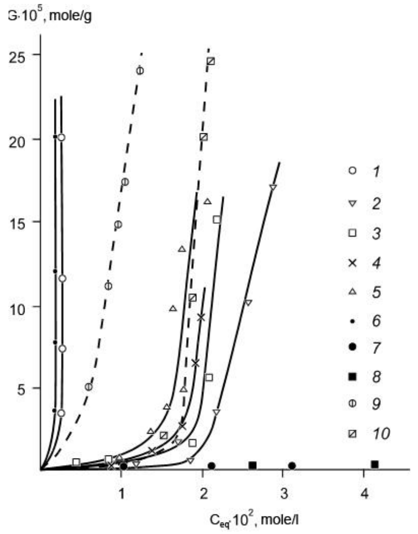

Figure 2. Isotherms of sorption at the dispersed ice surface from the solution in toluene (at -3°C) in the methanoic (1), acetic (2), monochloracetic (3), dichloroacetic (4), trichloroacetic (5), trifluoroacetic (6), acrylic (7), methacrylic (8) acids and methyl (9) and ethyl alcohol (10).

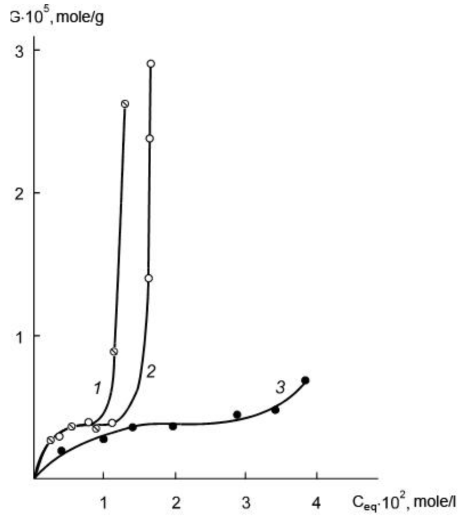

Figure 3. Isotherms of acid sorption on the snow kept at low temperature: methanoic at -15 °C (1), -20 °C (2) and acetic at -25 °C (3) without keeping the snow at the set temperature. Solvent: toluene (1, 2), hexane (3)

The ice particles behavior required studying in sorption experiments with the use of water solutions, in addition to real water-saturated systems including permafrost. The results of study of the microcomponents sorption (the base electrolyte KCl was used for provision of the ice co-existence with water solution) showed that the sorption of, for example, molybdate-anions is executed in a wide range of the pH values (Fig. 4).

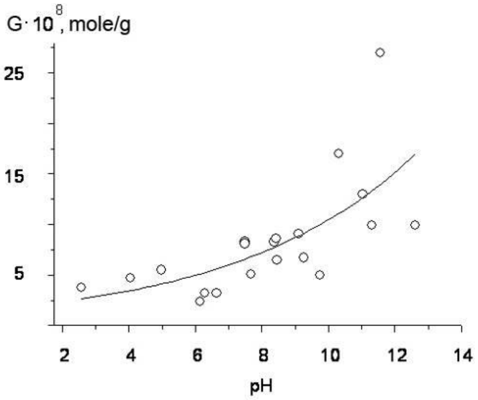

Figure 4. The dependence of molybdate-anions sorption by the dispersed ice surface on the pH value. Basic concentration of MoO_4^{2-} ions 10^{-4} mole/l. Temperature: - 1.7 °C.

The analysis of literature data and the results of additional sorption experiments allowed us to conclude that the base electrolyte ions capable of strong hydration are also capable of disordering the layers of the solid phase while penetrating into the liquid-like transient layer. In this case the thickness of the quasi-liquid film grows, and therefore the share of the microcomponent sorbed ions increases.

Thus, the ice liquid-like film shows solvent properties while contacting both with substance solutions in hydrophobic organic solvents and with solutions in water.

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The Buried Soils of the Kolyma Lowland: their Position and Role in the Landscapes of the Palearctic

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Abstract

Under the extremely cold arid conditions of the final stage of the Late Pleistocene (MIS 2-3) on the lowlands of Northeastern Asia accumulative soil formation with the development of highly productive landscapes took place in thermokarst depressions (alases and alas valleys) that currently represent "died out" oases of the Palearctic, the remote analog of the modern alases located in the Central Yakutian Depression

Keywords: lake thermokarst; Late Pleistocene; oases of the Palearctic; paleopedogenesis; tectonic processes

We investigated the buried soils in different geological and geomorphological areas of the Kolyma subarctic. In the Kolyma valley the Holocene soil formation is represented by the buried soils of different age. The soils are exposed in the cliffs of rivers, flood-plain lakes and lakes of a low and high floodplain, as well as of the 1st terrace above the floodplain that are related to Khallerchinskaya tundra [*Fominykh et al. 1986, Gugalinskaya & Fominykh 1988, Gugalinskaya et al. 1988*].

The Late Pleistocene soils were studied in the sediments area of the ice complex – Yedoma – on the maritime lowland and piedmont plain. These soils store the information on the granary of ancient landscapes that provided food for numerous herds of herbivorous animals of the "mammoth fauna" under the conditions of extremely harsh climate. Today they also arouse a great interest among a huge circle of naturalists, primarily in connection with the problem of the Pleistocene tundra steppe. There were identified the peculiarities relating to the genesis of these soils [*Fominykh & Gugalinskaya 1989, 1990, Fominykh 1991*], their age, the regularities in their occurrence rate and the position in the paleorelief of the investigated territory [*Fominykh et al. 2010*]. The buried soils having the Karginsk-Sartan age (MIS-3-2) are located in alases and alas valleys that were formed in tectonically active zones – the near-edge parts of the Yedoma massif – as a result of selective thermokarst. The cyclicity of cryolithopedogenesis of alas depressions reflects the sequence of processes of sedimentation and soil formation that determined the discrete nature of filling ancient thaw basins.

Now the major massifs of these alases are destroyed and occupied by modern river valleys on considerable areas. There remained only the rear part with abundant osseous material projected onto the towpath consisting of their crumbling walls, with the inclusions of buried wood residues and a series of buried soils in a number of places that (together with the sediments hosting them) reveal the signs of salinization [*Fominykh & Zolotareva 2008, 2010*]. The time of buried soils formation within an ancient alas of the Alazeya River (Fig.1), in the area of island distribution of Yedomas (40, 23 and 19 thousand years ago) corresponds to the main natural boundaries of the Late Pleistocene [*Svitoch 1987*]. The sediments at the base of the even-aged alas depression located downstream of the Alazeya River (exposure No. 82, [*Sher 1971*]) are characterized by the radiocarbon date of 37980±860; MAG-158 [*Sher et al. 1979*]. The date of 40 thousand years is the age of the buried soil above the head of the Pleistocene ice vein.

This date registers the time when the sedimentogenesis was completed, the Yedoma surface stabilized and the polygonal microrelief developed here. The process of soil formation in the interpolygonal grooves above the heads of the Pleistocene ice veins formed the peaty-gley soils. Similar soils of younger age (the end of MIS-2 – the beginning of MIS-1) were investigated by D. Brown at Cape Barrow, Alaska [*1965, 1967*].

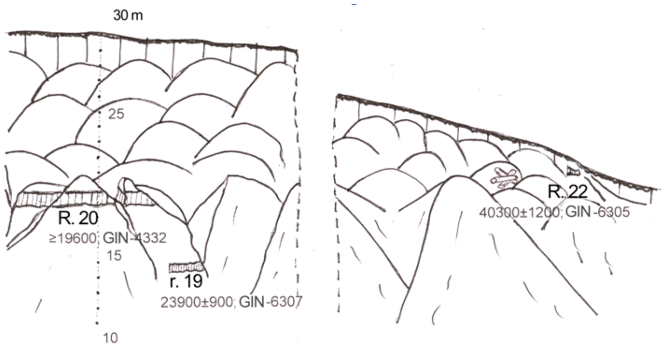

Figure 1. The topography of buried soils in the cliff of the right bank of the Alazeya River. The cliff is complicated by cemetery mounds.

Buried soils represent the benchmarks of biogeomorphological evolution of ancient accumulative landscapes. All the soils studied belong to non-forest soils. But at certain stages during which thermokarst depressions of different age were formed, the tree vegetation grew on these soils, while the surrounding areas were open. The results given by paleobotanical and palynological studies, as well as the fossil wood residues (*Betula alba, Alnus fruticosa* and others) identified in the alases of different parts belonging to the Kolyma tundra [*Kaplina & Lozhkin 1979; Arkhangelov et al. 1981, Kaplina 2011*] including the Arctic islands [*Ermolaev 1932*] are interpreted by researchers as the direct proof of climate warming in certain time intervals of the corresponding periods of the past. However, according to the new concepts of geothermal evolution of permafrost relating to the cryolithozone of Northern Eurasia, "The final stage of the Late Pleistocene (the period of 40-10 thousand years ago) is singled out as one cryochron with extremely harsh winters. Within this cryochron the oscillations of air temperature and permafrost temperature were inconsiderable, while the Holocene (the last 10 thousand years) was characterized by milder geocryological conditions by comparison with the Pleistocene cryochron due to less severe winters" [*Vasilchuk 1992*]. According to the data by Vaskovskiy and Kartashova [*1961, and other works*], the climatic and geobotanical changes in Northeast Asia during the postglacial time were inconsiderable, which does not give grounds for the concepts reflecting the possibility of a frontal advance of the forest to the north even in the interglacial conditions of the Holocene. The research on the regularities of the modern position of forest and non-forest ecosystems at the southern limits of the tundra of Northeast Asia [*Berman et al. 1998*] demonstrated the possibility of replacing tundra with forest (and vice versa) without radical restructuring of hydrothermal characteristics of the climate in the region and only due to the change in the wind regime and in the variations of temperature and humidity indicators of concrete habitats according to microrelief elements.

All the buried soils being different in thickness, humus properties and physical-chemical indicators have an accumulative view. As a rule, they are absolutely different from the primitive profiles of upland soils of modern permafrost landscapes in the Kolyma subarctic – the cryosols of Yedoma residues and/or diverse cryohydromorphic gley soils that dominate in area and are located in lake-swamp-tundra landscapes of the Kolyma valley, and the cryosols of secondary flat interfluves (the areas of development of the Holocene areal thermokarst).

The buried soils of natural landscapes of all time intervals characterize the soil formation only of accumulative and trans-accumulative habitats. The Pleistocene soils that we researched represent the central link between the landscapes of ancient alases – oases of the Palearctic. The analysis of the available data on the buried soils of the Pleistocene-Holocene time makes it possible to conclude that the reconstruction of the regional climatic characteristics (warmer-colder, drier-moister) based on the pedohumus method for the diagnostics of the paleoenvironment [*Dergacheva 1997*] should be treated with the understanding that the conditions in which these buried soils were formed are not adequate for those in the flat interfluves of a specific chron interval.

Acknowledgments

We are grateful to L.D. Sulerzhitskiy (GIN RAS) for determination of the radiocarbon age of our buried soils, constructive discussion of the results obtained as well as useful advice and valuable comments.

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Engineering Test Sections in Permafrost Environment: Performance of Permafrost Protection Measures and Mitigation Techniques to Permafrost Degradation

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The key success of infrastructure construction on ice-rich frozen subgrade depends on preventing the permafrost from thawing. Among the available mitigation techniques to prevent permafrost degradation, several categories of passive protection measures are available to the cold regions engineers for effective design of infrastructure built on ice-rich permafrost:

1) decrease in heat transfer and increase in thermal resistance in the subbase using insulation and/or thick subbase, or open air chamber between the infrastructure and subgrade,
2) decrease in absorption of solar radiation using high albedo surface or sunshade,
3) increase in heat extraction in the subbase using thermosyphons or cold air flow in porous and highly air-permeable subbase in winter (air convection embankment or ACE, or ventilated duct),
4) snow accumulation control using aerodynamic infrastructures or specific maintenance efforts to avoid thermal insulation effect of snow cover, and
5) drainage control to prevent water accumulation and avoid latent heat effect of water freezing delaying the freezeback of active layer and permafrost cooling in winter as well as preventing negative effects of convective heat transfer from groundwater flow.

As one of the activities of the Permafrost Engineering Working Group (PEWG) of the International Permafrost Association (IPA), a none-exhaustive inventory of engineering test sections in permafrost environment is presented. The main objective of this abstract, together with discussions during the TICOP 2012, is to show the range of designs used in different regions to mitigate the impacts of permafrost degradation on infrastructure performance. We will conclude this abstract on the lessons learned from these engineering test sections and on their effectiveness to protect permafrost even under climate warming based on test section monitoring. Due to page limitations, the references can’t be listed but the authors will be pleased to provide these references since many of them are involved in these engineering test sections.

Alaska, USA

The Alaska Department of Transportation and Public Facilities (ADOT&PF) constructed two 61-m long test sections in mid-1990, one ACE and one standard embankment with thermal insulation, on ice-rich permafrost subgrade near Fairbanks to test the passive cooling effect of ACE. The temperature monitoring was carried out from November 1996 to November 2001.

More recently, in 2003-2004, during the construction of Thompson Drive crossing in Fairbanks, three different cooling techniques, including two-phase hairpin thermosyphons, horizontal ACE layers, and ventilated shoulders were used in engineering test sections. Instead of being in the air on the roadway sides creating safety hazard and esthetic issue, the condensers of hairpin thermosyphons are buried close to the driving surface while the evaporators are deep in the subbase. These sections were also instrumented with temperature and heat flux sensors to assess the cooling effectiveness of these techniques.

Greenland

In 2008, three 10-m long engineering test sections were built in Sisimiut during road construction. The first test section is made of a 45-cm thick layer of lightweight expanded clay aggregate pellets for thermal insulation. Horizontal PVC tubes connected to intake and exhaust chimneys were installed in the embankment of the second test section to induce cold air convection in winter. The third section made of ACE according to Greenland standard construction practices is the reference one. These sections were also instrumented for temperature monitoring.

Northern Quebec and Yukon, Canada

At the airport of Tasiujaq along the west coast of Ungava Bay, four 50-m long sections to test three permafrost protection measures (ACE, heat drain layer and gentle slope) were built along the airstrip embankment slope and instrumented with thermistor cables. In addition to embankment slope made of crushed rock, horizontal heat drains connected to vertical chimneys were also installed at the bottom and top of the embankment slope to enhance the air convection in the layer of porous materials since the embankment sides are covered by snow. The heat drain layer is made of a geocomposite drainage layer to induce cold air convection in winter. Because a thick embankment with steep slopes acts as a snow fence allowing snow accumulation, a more aerodynamic embankment with gentle slope of 7.2° instead of 30° was constructed.

At the airport of Puvirnituq along the east coast of Hudson Bay, due to thaw settlement occurring along a 7-m thick airstrip embankment, a thick layer of porous materials was put on the embankment slope for cold air convection in winter and a berm was built for further stabilization. A small stream was also diverted to improve the drainage along the airstrip. The performance of these mitigation techniques is monitored with thermistor cables and inclinometer.

Four experimental cells with different cover concepts are currently tested at the Raglan Mine located on the Katinniq Plateau in Northern Quebec, for the development of long-term and sustainable solutions for tailings storage facility reclamation. These cells were constructed in fall 2011. The cover concepts are based on decreasing the thermal and/or hydraulic conduction to prevent the thawing and/or oxidation of the tailings. The four concepts are: 1) a multi-layer cover as the current design, 2) a convective air flow layer, 3) a thermal capillary barrier and 4) a geomembrane cover. Thermistor cables and sensors (volumetric water content, suction and gaseous oxygen content) were also installed in the cells for performance monitoring purpose. Settlements and snow cover thickness are monitored as well as water quality and quantity.

A series of different permafrost protection measures are currently tested at the Beaver Creek experimental road site along the Alaska Highway in the Yukon: thermal insulation, grass-covered slopes, light colored aggregates in asphalt pavement for higher albedo, sunshade, different designs of ACE, heat drain layers and longitudinal culvert to improve cold air convection, snow shade and removal, and drainage improvement. The performance monitoring of theses mitigation techniques is carried out with thermistor cables, thermistor sensors, heat flux sensors, and piezometers at different locations in the test sections.

Qinghai-Tibet Plateau, China

The Qinghai-Tibet Railway (QTR), from Golmud in Qinghai province to Lhasa, is an 1100-km linear infrastructure crossing several mountain passes in excess of 5000 m in altitude and stretches of warm ice-rich permafrost. An engineering roadbed cooling approach was adopted in the initial design of the QTR including land-bridge (the longest one is 11.7 km), sunshine-shielded and awning protection, thermosyphons, ACE, and ventilated ducts. The long-term monitoring system is composed of 23 sections with standard subbase construction, 13 ACE sections, 8 sections with embankment slopes covered with crushed rock, and one sunshine-shielded section.

There are two other major linear infrastructures on the Qinghai-Tibet Plateau: the Qinghai-Tibet Highway (QTH) and electric power line transmission. The same approach is also used along the QTH but other permafrost protection measures were also applied such as thermal insulation, thermosyphons and ventilated ducts. Several sections are monitored. Only thermosyphons are used along the power line transmission.

Russia

The Berkakit-Tommot-Yakutsk (Niznhy Bestyakh) railway in Yakutia crosses several ice-rich permafrost extents. Eight engineering test sections were built to study the thermal regime of permafrost along the railway embankment. Thermistor cables were installed after the right-of-way clearing and before building the embankments. Several types of railway embankment were built along the test sections using different protection measures: insulation boards underneath the embankment, thick embankment, berm on each side of the embankment, radiation and snow protection on the embankment slopes, thermosyphons on the berm, corrugated pipes beneath the berms and embankment for drainage and soil cooling, ACE, and partial removal or replacement of the active layer soil.

The ground thermal regime and vertical foundation displacements are currently monitored at the Yakutsk Combined Heat and Power Plant, an industrial facility built in 1937 using passive construction method in permafrost.

Prior to an infrastructure construction, the disturbance and/or removal of superficial natural ground should be avoided, the forest clearing should be done just before the construction, and the construction of any embankment should be made in winter when the aggregates and crushed rock are cold. These precautions will prevent harmful heat transfer to permafrost in the initial construction phase of an infrastructure.

Any use of permafrost protection measures should be included early in the stage of design and installed by knowledgeable people under close supervision. For example, heat drain layers made of geocomposite are susceptible to collapsing when covered with aggregates. Heat drains if they are not watertight can be clogged by water and ice. The closing of ventilated ducts in summer to avoid the warm air convection in an embankment is time-consuming and depends on devoted workers. They are doomed to fail if they are not closed in summer and open in winter. The cooling effectiveness of ACE can decrease over time if the pores in crushed rock are clogged with fines coming from the aggregates used for the driving surface and the abrasives used in winter. They can also be clogged by vegetation and snow in winter. The void ratio of crushed rock susceptible to weathering can decrease over time and the air convection becomes less effective.

In a context of climate warming, thermal insulation and thick embankment delay the permafrost thawing but don’t avoid it. An open air chamber between the infrastructure and subgrade, such as land-bridge, preventing any heat transfer is very effective but expensive to build. High albedo surfaces decrease the absorption of solar radiation but their long-term maintenance is problematic. Thermosyphons with condensers sticking out of the ground, vertical ventilating pipes located on the roadway sides and sunshade on embankment slopes create safety hazard. Embankments with gentle slopes prevent any snow accumulation in winter, a critical period to cool down a subbase, but they need more construction materials than embankment with steep slopes. Embankment can also act as a dam impeding the running-surface water and creating problematic water accumulation and thermal erosion of permafrost. The drainage design is critical for effective infrastructure not disturbing the permafrost stability.

Hairpin thermosyphons buried in subbase and air convection embankment are very effective permafrost protection measures. Their cooling effectiveness can be as much as 4 °C in comparison to standard subbase.

In summary, various engineering test sections exist through the world, but all the permafrost protection methods applied demonstrate that there is no simple solution available for this challenging engineering problem. However, knowledge gained and improvements made thanks to such tests help in extending service life and reducing maintenance costs of infrastructure.

Observational Station-Based Frozen Ground Feedbacks in the Eurasian High Latitudes

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Introduction

In response to climatic warming, soil temperatures are increasing, the active layer is thickening [*Frauenfeld et al., 2004; Zhang et al., 2005*], and taliks are forming in permafrost regions. These changes are resulting in a delayed freeze-up of soils, decreased freeze depths in seasonally frozen ground regions, leading to earlier spring thaw and reemergence of soil temperature anomalies [*Schaefer et al., 2007*].

These soil thermal regime changes potentially result in more and more heat storage in soils during the warm season and amplify frozen ground changes, thereby representing a terrestrial analog to Arctic amplification due to the loss of sea ice [*Serreze et al., 2009*]. Any anomalous soil heat flux to the atmosphere in the transitional and cold seasons from the increased soil heat storage potentially represents a previously unexplored land-atmosphere feedback, capable of altering the large-scale flow of the atmospheric circulation.

Data and Methods

We use monthly historical soil temperature observations at 423 sites distributed across the Eurasian high latitudes, available from the National Snow and Ice Data Center. These data span late 1880s–2000 for nine soil depths from 0.2–3.2 m. For more information, see Frauenfeld and Zhang [*2011*]. We focus on the most data-rich periods: 1956–2000, and 1930–2000.

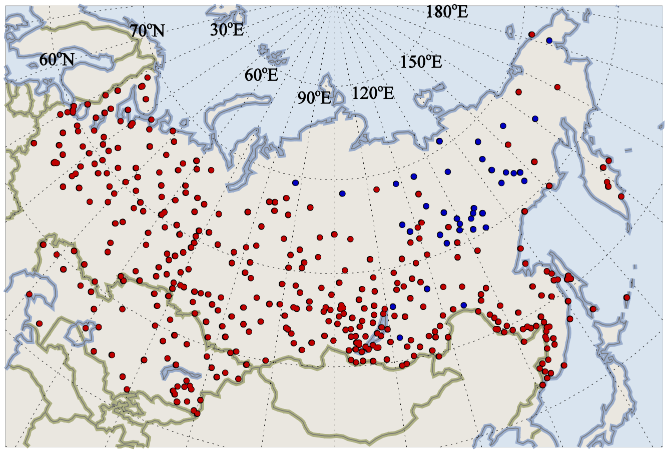

Figure 1. Map of 423 soil temperature station locations.

Based on the soil temperature gradient between the 20 cm and 40 cm depths, we calculate the soil heat flux, G, as:

$$G \approx -C_1\left(\frac{\delta T}{\delta z}\right) = -C_1\left(\frac{T_2 - T_1}{z_2 - z_1}\right) \qquad (1)$$

where C1 = thermal conductivity of the soil, δT = temperature difference (T2−T1) for a given change in depth, δz = between 40 cm (z_2) and 20 cm (z_1). For thermal conductivity we use assumed values of 1.2 Wm^{-1}K^{-1} for soil temperatures >0°C, and 1.5 Wm^{-1}K^{-1} for soil temperatures <0°C. However, we plan to calculate site-specific values of thermal conductivity based on soil properties from the Harmonized World Soil Database (HWSD).

Results

Comparing the early period to the later part of our record, we find that, indeed, significantly more heat flows into the soil during summer months, while less heat flows out of the soil during the winter months. This indicates a net storage of heat in the soil, and results in the observed increasing soil and permafrost temperatures. Long-term trends in annual net heat flux indicate statistically significant changes greater than 150 Wm^{-2} for the 45-year period. However, we find regions of increasing and decreasing annual heat fluxes. Locations where trends are positive are characterized by significantly more heat flowing into the soil during summer months. This indicates a net storage of heat in the soil and results in the observed increasing soil and permafrost temperatures. Stations where trends are negative indicate evidence of greater heat fluxes out of the soil during the cold season in the latter part of the record (1996–2000), likely from redistributed energy.

Summary and Conclusions

Statistically significant trends in annual Eurasian heat flux anomalies are evident at 108 of the 423 station locations. Trends are positive at 55 sites, indicating more heat stored in Northern soils. Trends are negative trends at 53 sites, potentially reflecting our hypothesized anomalous cold-season heat flux to the atmosphere. It must be emphasized that this study is preliminary. In our ongoing efforts, site-specific conditions are being considered: thermal conductivity is being calculated specifically for each station location based on local soil characteristics from the HWSD. Furthermore, soil moisture has to be estimated and included as part of the site-specific characteristics. Finally, the seasonality of changes has to be considered, i.e. changes during winter versus summer, as well as their specific timing.

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Ground Temperatures Near a Debris Slide Detachment zone in Signaldalen, Northern Norway

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Introduction

Evidence is growing that warming and degradation of permafrost are potential triggers for rock fall and rockslides. Davies et al. [*2001*] demonstrated in laboratory tests that the shear strength of ice-filled frozen joints is lowest slightly below the melting point. This led to the assumption that the stability of ice in rock discontinuities decreases when mixtures of rock, water, and ice exist simultaneously, i.e. when temperatures approach the melting point. Studies from the Swiss Alps indicate, indeed, that intense rock fall and rock slide activity during the last decade (especially pronounced during the extremely warm summer 2003) seem to be related to increasing ground surface temperatures [*cf., recent assessment by Fischer et al., 2012*].

The main scope of the presented study was to assess ground surface temperature conditions and stability characteristics at and near a rockslide in Signaldalen (Troms county, Northern Norway) that had been released in July 2008 in an area with suspected permafrost occurrence. Here, we report about the first available two-year series of temperature data.

Study site

The Signaldalen rock slide (Figure 1) detached on 26.7.2008 in the north-slope of Polvartinden, a 1275 m high mountain peak in Signaldalen (Troms county, Northern Norway).

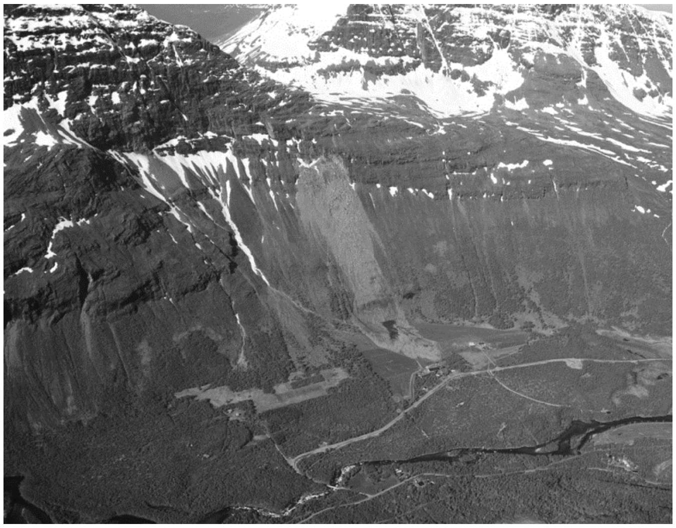

Figure 1. Signaldalen rockslide as seen on 28.7.2009. The slide detached at approximately 600 m a.s.l. (Photograph by courtesy of G. Kristiansen, NVE region nord).

The volume of the rock slide is estimated to be approximately 500’000 m^3. The upper limit of the detachment zone is located at 600 m a.s.l. The lower limit of permafrost in the area is estimated at 600-700 m a.s.l. [*Isaksen et al. 2011a*].

Measurements

Ground surface temperatures were measured with miniature temperature data loggers during two consecutive years at different localities along the NNW-ridge of Polvartinden and in the valley ground. Six M-Log5W data loggers (© Geoprecision GmbH) were installed in vertical rock faces on rock outcrops and along small cliffs, following the methodology outlined in Gruber et al. [*2004*]. Four UTL3 data loggers (© Geotest AG) were placed directly into the soil material of vegetated parts of the ridge. An additional UTL3 logger was installed one meter above ground in a stone cairn in the valley floor in order to monitor air temperature. Measurement depth for all loggers was around 10 cm below surface.

Results

Temperatures measured during 2009-2011 (Table 1) show mean annual ground surface temperatures (MAGST) between −1.4°C (coldest) and +1.7°C (warmest) in 2009/2010, and between −0.3°C (coldest) and +2.5°C (warmest) in 2010/2011. Temperature recordings in all loggers were considerably higher during 2010/2011 than in 2009/2010. For the vertical rock face sites, the lowest mean temperature was recorded at the north facing site in 2009/2010.

Table 1. MAGST (respectively MAAT for type ‘Air’) recorded with miniature temperature data loggers on the NNW-ridge of Polvartinden (respectively in the valley floor for type ‘Air’) during October 2009-September 2011.

Type	Elevation	Aspect	T 09/10	T 10/11
	m a.s.l.		°C	°C
Air	65	-	1.7	2.2
Soil	65	-	1.7	2.5
Soil	664	-	−1.3	−0.3
Soil	626	-	−1.0	−0.2
Soil	648	-	−1.2	−0.1
Rock	640	NE	−0.3	−0.1
Rock	657	NW	−0.8	0.3
Rock	630	E	−0.2	0.7
Rock	632	N	−1.4	0.4
Rock	646	SW	−0.4	0.5
Rock	598	NE	−0.5	0.2

The large inter-annual variability is in congruence with climate conditions in Troms and is confirmed by measurements in nearby mountain slopes [*Isaksen et al. 2011a*].

For the monitoring periods September 2009 to August 2010 and September 2010 to August 2011, mean air temperatures at the nearby Skibotn meteorological station were 0.6°C below and 0.2°C above, respectively, the 1961–90 mean annual air temperature (MAAT).

In 2010/2011 some of the sites were clearly influenced by a snow cover. Based on an analysis of wind direction, wind speed and total snow accumulation at nearby weather stations, we assume this to be caused by inter-annual differences in prevailing wind direction and preferential snow deposition.

Discussion and outlook

Based on our findings we expect a regional lower limit of permafrost at around 600-650 m a.s.l.; this is in agreement with earlier estimates in the inner fjord- and valley areas of Troms [*Isaksen et al. 2011a*].

In Scandinavia, the amount of direct observations about the influence of solar radiation on near surface temperatures in different aspects of steep mountain walls is limited so far. Generally, the influence of direct solar radiation is less pronounced at high latitudes than in mid-latitude mountain ranges. The aspect-dependent difference in the altitude of the lower limit of permafrost is, therefore, expected to be less pronounced than reported for the Swiss Alps by, e.g., Gruber et al. [*2004*]. Our results indicate an altitudinal difference of several tens of meters between northerly and southerly aspect, as compared to several hundred meters in, e.g., the Swiss Alps. Due to our small sample size this is, however, just a tentative estimate.

According to a study by Fischer et al. [*2012*] on potential triggering factors at 56 historical rock slide and rock fall events in the Alps, it seems to be the marginal permafrost zone where most of the recent changes concerning ice content and hydrology have taken place; parameters that are seen as having an important influence on slope stability. In southern Norway, permafrost degradation has been observed on gentle mountain slopes [*Isaksen et al. 2011b*]. The same study also showed that the greatest temperature increases at 5-10 m depth were found at sites with present mean annual ground temperatures (MAGT) slightly above 0°C. This may be caused by a gradual vanishing of ice due to recent permafrost degradation, leading to a drier near-surface layer and, thus, changes in the near-surface heat exchange. In addition, heat advection during the opening up of talik/water systems could have been an additional factor. Thus, recent changes in ground surface temperature could also have played an important role in the release of the Signaldalen rockslide.

The correlation between our air temperature measurements in the Signaldalen valley bottom (2009-2011) and data covering the same period from Skibotn meteorological station (10 km NNW from the slide area) is high ($R^2 = 0.97$). This will allow for modelling of the potential permafrost distribution and recent ground temperature changes in Signaldalen by coupling our in-situ data with regional and large-scale climate data.

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Dissolved Organic Carbon (DOC) in Ground Ice: Is It Significant?

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Introduction

Permafrost soils are believed to hold approximately 50% of the global soil carbon pool [*Tarnocai et al. 2009*], mostly as particulate organic carbon (POC). In the Arctic coastal lowlands of Eurasia and North America ground ice can occupy a large proportion of the soil volume. Calculations of permafrost organic C stocks usually substract the ground ice content [*Zimov et al. 2006; Tarnocai et al. 2009*] and therefore disregard the organic carbon, especially the amount of dissolved organic carbon (DOC) contained in massive ground ice bodies such as ice wedges and buried glacier ice. Although these numbers might be small compared to the POC stocks in peat and mineral soils, DOC is chemically labile and may directly enter local food webs. Due to its liability DOC is quickly mineralized and returned to the atmosphere when released due to permafrost degradation.

Here, we present the first results of a permafrost study on DOC in ground ice. We report DOC contents from different massive ground ice types, put them into context of the Arctic organic carbon pools and fluxes, and evaluate their contribution to the Arctic carbon budget against the background of increasing permafrost degradation and enhancing coastal erosion in the future.

Study Area

The study was carried out on the coastal lowlands of northwest Canada (Herschel Island), in Alaska (Barrow and Fairbanks region) and in Siberia (Laptev Sea; Fig.1).

Figure 1. Study area and sites (dots) for DOC sampling in the Arctic lowlands of Siberia and North America

These areas with continuous permafrost cover a wide range of geomorphological settings, terrain units and ground ice conditions. Massive ground ice (i.e. ice content >250%) such as ice wedges, buried glacier ice, and buried lake ice were used for this study. Pore ice and intrasedimental ice such as ice lenses were excluded due to their complex genetic processes and interactions with surrounding sediments. In some cases, massive ground ice occupied as much as 90% of 40 m coastal exposures where the coastline erodes at rates approaching 10 m/yr at its maximum (Lantuit et al. in press).

Material and Methods

Ice blocks were cut with a chain saw in the field. They were stored frozen until further processing with a band saw and a knife in a cold lab at −15°C for removal of the margins and cleaning of the edges. Samples were thawed in glass beakers covered with annealed aluminum foil. Resuspended meltwater was filtered with gum-free syringes equipped with glass fiber filters (pore size: 0.7 µm) and acidified with 20 µl $HCl_{suprapur}$ (30%) to prevent microbial decomposition. DOC concentrations (mg/L) were measured with a high-temperature combustion total organic carbon analyzer (Shimadzu TOC-V CPH).

Results and Discussion

While the riverine DOC export to the Arctic Ocean has been estimated to as much as 33 Tg/yr [*McGuire et al. 2009*], comparable numbers for the DOC input by coastal erosion are unavailable. This includes the DOC contribution derived from melting ground ice from ice-rich permafrost. Table 1 provides the summary of DOC contents in four different massive ground ice types from the North American and Siberian Arctic. Despite of the limited number of sampled ice bodies so far and their wide spatial distribution we suggest that ice wedges hold the greatest potential for DOC storage in massive ground ice with maximum values of 28.6 mg/L.

Table 1. Summarized DOC concentration of different massive ground ice types.

Ice type	DOC Mean [mg/L]	DOC concentration range [mg/L]	Stratigraphic affiliation
Ice wedge ice	9.6	1.6–28.6	MIS* 1, 2
Basal glacier ice	1.8	0.7–3.8	MIS 2
Buried lake ice	2.0	0.3–5.2	MIS 1
Snow pack ice	3.0	n.a.	MIS 1

* MIS = Marine Isotope Stage

This knowledge is even more important in the light of the widespread spatial distribution of ice wedges and their high volumetric proportion (up to 50 %) in near-surface permafrost in Arctic lowlands [*Zimov et al. 2006*].

Arctic permafrost coasts make up ~34% of the world's coastline (ca. 400,000 km) and are often made of ice-rich unconsolidated sediments. This makes them highly susceptible to coastal erosion, and it is likely that large quantities of carbon are released. Current estimates of the carbon release by coastal erosion focus solely on POC. DOC is generally not included in these calculations, as it is considered to be negligible in the equation. Estimations of DOC contents in ground ice, which is overwhelmingly present along Arctic coasts do not exist though this study aimed at investigating DOC contents in massive ground ice for the first time. Based on a classification of one fourth of Arctic permafrost coasts [*Lantuit et al. in press*], considering unlithified coasts only and adapting as well as simplifying an equation (Eq. 1) for the calculation of the POC flux by coastal erosion (Lantuit et al. in press) provides a preliminary assessment of the concomitant DOC flux:

$$DOC_{flux} = l \cdot h \cdot R \cdot \theta \cdot \rho \cdot DOC_{conc.} \qquad (1)$$

where $\mathrm{DOC_{flux}}$ is the released dissolved organic carbon from ice wedges in g/year, l is the coast length (66,386 km), h is the weighted average cliff height (4.4 m), R is the weighted annual coastal retreat rate (0.57 m/year), θ is the volumetric ground ice content (e.g. ice wedges: ~20%), ρ is the density of pure ice at 0°C (0.917 g/cm³), and $\mathrm{DOC_{conc}}$. is the average DOC concentration measured in ice wedges (Table 1). These conservative numbers for the background parameters lead to a first estimation of DOC flux derived from ice wedges of 0.293 Gg/yr. This number is expected to increase significantly if the whole Arctic permafrost coastline was classified, if other massive and non-massive ground ice types were incorporated, and if the DOC concentrations were weighted and upscaled for different terrain units (e.g. carbon-rich and ice-rich Yedoma uplands).

Estimating DOC stocks and the export of DOC into the Arctic Ocean related to coastal erosion has important implications. First, it will lead to an improved assessment of DOC contained in permafrost and potentially exported from permafrost during climate warming and enhanced coastal erosion [*Douglas et al. 2011*]. Second, DOC and other organic materials preserved in permafrost could participate in surface biogeochemical cycling if they are released due to permafrost degradation [*Douglas et al. 2011*]. A better knowledge about the quality of organic carbon in permafrost is desired because not all carbon is equally vulnerable to release and decomposition. In general, POC from both peat and mineral soil has a relatively slow decomposition rate after thaw compared to DOC [*Schuur et al., 2008*]. The greater lability and availability of DOC for biogeochemical cycling strengthens the importance in gaining knowledge of DOC stocks and fluxes along Arctic permafrost coasts.

Still, the rate of carbon release from permafrost soils, even for the particulate fraction, is highly uncertain and largely unknown for the dissolved fraction. However, robust estimations of much carbon will probably be released are crucial for predicting the strength and timing of carbon-cycle feedback effects, and thus how important permafrost thaw will be for climate change this century and beyond.

In this study, all ice types show high internal variations due to their complex interaction with host sediments, genetic processes and the DOC content in the parent water. We therefore highlight the need to collect samples from a range of different ground ice types with distinct stratigraphic affiliation and in areas with representative terrain units to get a comprehensive picture of DOC contents in ground ice along Arctic coasts.

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Interannual Variability in the Structure and Heat Conducting Properties of Snow Cover

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Snow cover affects heat transfer and temperature of soil in a winter period. Heat flows from underlying soil to snow cover were calculated using the data on total amount of atmospheric precipitation, average temperature and average thickness of snow cover.

Parameters of heat transfer to snow cover and then to atmosphere were calculated using the collected data on density of snow cover, average temperature gradient in it and thermal conductivity of snow cover. The gradient was calculated as a ratio of the average difference of air temperature above snow (atmosphere temperature) and that on soil surface and an average thickness of snow cover. Thermal conductivity of snow cover was determined on the basis of empirical dependence of heat transfer on density [*Iosida 1955, Sulakvelidze 1955, Pavlov 1979*].

Data on climatic conditions of two winter seasons (November - March, "warm" and "cold" relative to average multi-year values (1960-1990)) for three stations (Naryan-Mar, Salekhard, Yakutsk) located at the latitude of the Arctic circle in the European and West- and East-Siberian part of Russia. They are located in a permafrost zone with active layer thickness of 0.8-1.5 m. The climate of Naryan-Mar is subarctic, Salekhard is located at the border of subarctic and temperate climatic zones. The climate of Yakutsk is extremely continental, with a small annual amount of precipitation. Winter in Naryan-Mar is relatively mild for polar latitudes because of the Barents Sea influence but spring and autumn are long-lasting and cold, average temperature (November - March) Tav=-13.9 °C, total precipitation (November - March) Q_{total}=143 mm. In Salekhard Tav=-19.4 °C, Qtotal=119 mm. Winter in Yakutsk is extremely severe, T_{av}=-31.3 °C, Q_{total}=50 mm.

According to the calculated data, heat transfer through snow cover within one warm (2006/07) and one cold (2009/10) winter seasons, with due consideration of geothermal flow, amounted to: for Naryan-Mar - $31.56*10^6$ J/m^2 and $51.13*10^6$ J/m^2, for Salekhard - $47.78*10^6$ J/m^2 and $120.92*10^6$ J/m^2, for Yakutsk - $44.19*10^6$ J/m^2 and $45.75*10^6$ J/m^2. With such values of heat transfer the loam soil could be frozen to the depth of 22 cm (in winter season of 2006/07) and 36 cm (in winter season of 2009/10), for Salekhard – to the depth of 33.9 and 85.8 cm, for Yakutsk – to the depth of 31.3 and 32 cm accordingly.

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Integration of Methods in Engineering Prospecting in the Permafrost Zone

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Abstract

Complex engineering surveys for line structures in the zone of permafrost have their own characteristics and complexity. These include the need for optimization and aggregation types and volumes of work. In surveys of railways and roads and pipelines are optimal: multi-scan of the territory, collection and analysis of archival and stock data, complex engineering-geological and geocryological mapping, integrated geophysical investigation, driving minings and drillholes, hydrogeological studies, steady-state regime of observation (local monitoring components of the environment), laboratory studies, a survey of soil foundations of existing buildings and facilities, cameral work and preparation of materials of the Technical Report. As a result of these works it is possible to design the object and the development of measures to engineering protect the natural environment and structures.

Keywords: permafrost; engineering-geological, geocryological mapping.

Introduction

Transportation arteries: railways, roads, pipeline systems are the key to the development of vast expanses of the North. By implementing construction projects in the regions of the Far North of mankind is faced with problems of permafrost. The main objective of comprehensive engineering survey is to obtain the necessary and sufficient data for the design and construction of linear and other buildings in the zone of permafrost. For the successful solution of this problem requires optimization and aggregation of research methods with the use of modern equipment and software.

Further will be described the variant of problem solving for the Study of geotechnical and permafrost conditions in the light of experience on the findings of the railways and pipelines in the regions of Yakutia, the Khanty-Mansiysk and Yamalo-Nenets region.

Complex engineering surveys

In the first phase, in parallel with the collection and analysis of archival and stock data, carried out multi-channel scanning area (laser, infrared, etc.) that allows you to create a digital terrain model, followed by the construction of the preliminary maps and charts needed to clarify the main areas and volumes of research. Later in the cameral processing of the materials scanned results can not only draw maps and diagrams, but also create three-dimensional model of space for special tasks. For this purpose we used the program ArcGis (ArcMap), MapInfo and AutoCad are less convenient to construct maps of software packages.

Performing complex engineering-geological and geocryological mapping of the territory to conduct landscape-indicator research begins on the first phase of field studies and continues until they are completed, compiled by supplementing and complementing the earlier maps. In addition to route observations with the sinking of wells and probing small mines accounted for mapping the results of the entire complex of work performed.

Geophysical investigations begin immediately after the removal of the axis of the projected route of the object on the terrain. The most effective was georadar profiling along the axis of the road, with the performance of detailed seismic tomography and elektrotomographic research in areas watercourses (bridges, culverts) and areal objects (railway stations, sidings, compressor and pumping facilities). Georadar confidently shows profiling lithological boundaries and boundaries of permafrost at depths up to 10m (especially effective on sandy sections), Seismic tomography allows to specify the lithology and elektrotomograhy provides an opportunity to clarify the boundaries of frozen and thawed soils and structural features of the permafrost at considerable depths.

Penetration of mine workings and drill holes is the most reliable, but expensive method of studying the geological and permafrost conditions. Pits and clearing are passed to clarify the structure of the upper part of the section, the characteristics of the geomorphological structure, depth of seasonal thawing and freezing of soils, their chemical composition and properties of the full-scale experiments, sampling. Sinking of boreholes, as a rule, core method with the use of mobile drilling rigs. The best was the use of drilling rigs PBU-2, mounted on the base of the conveyor track GTT, also are very good rig URB 2A-2, mounted on the chassis of crawler transporters MTLB conversion, in areas accessible to wheeled traffic optimally use the same drilling rig mounted on a chassis a/m KAMAZ, Ural. For sinking of wells of small depth used in the UBSHM and “Openok”, mounted on the chassis of a/m" Trekol "and tracked all-terrain vehicle GAZ 73, less portable installation UCB 12/25. Drilling is carried out "dry", sometimes with the use of blowing compressed air. With the sinking of boreholes in frozen soils is an important feature of the conservation of soil in the frozen state and temperature of ground mass, which must comply with the technological parameters of drilling. Documentation of core holes has its own characteristics, it is very important indicator is the establishment of ground ice content and assessment of the soil during thawing, and the method of photographic documentation of the core.

Hydrogeological studies carried out both at route sinking and at the sinking of mine workings and drill holes. Here we fix the autopsy of groundwater and the steady level, mapped outputs of groundwater to the surface, produced records icings, sampling of groundwater and surface water and ice.

Conducting field research in the experimental conditions of permafrost also has many features commonly used in the final stages of the research facilities in the areas of bridges, culverts and areal objects (railway stations, sidings, compressor and pumping facilities).

Holding steady-state observations (local monitoring component of the geological environment) is a necessary part of the research. When finding a great extent on the facilities implemented in nodal areas: bridges, culverts and areal objects (railway stations, sidings, compressor and pumping facilities). Regime laid down the well and the frame on which a different time interval measurements are made the necessary parameters: the temperature of soil, depth of seasonal thawing depth of seasonal frost penetration, the growth rate of degradation, swelling hills, ground mass shifts, the rate of termoerozionnyh and other processes. Usually begins making observations in the early stages of research and further develop to the stages of construction and operation of facilities.

Laboratory studies of frozen, freezing and thawing of soil, ice, groundwater and surface water due to the length of the objects of research and changing during thawing of soil properties in a large volume produced in a field laboratory in stationary laboratory tests it is advisable to take out for the complex types of studies.

A survey of permafrost, freezing and thawing of soil bases of existing buildings and structures is used to determine the relationship structures and the environment, development of optimal solutions for engineering protection.

Off-site processing of all available material and preparation of the Technical Report is conducted on the basis of the enterprise using the software MapInfo, Arc Gis (Arc Map), Auto Cad and other Profiles and sections are built using Auto Cad, with thermal calculations we used the program "Teplo" – development of Cryology Department MSU, maps were created using the software package Arc Gis (Arc Map). Geophysical Data Processing is performed using special software developed in Russia and other countries.

Conclusions

As a result of the above-mentioned works it is possible to design an object, a forecast of changes of geotechnical and geocryological conditions, and development activities for the engineering protection of the environment and facilities.

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Small Glacial Features on the Balkan Peninsula as Indicators for Climate Variations

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Small glacial features on the Balkans

Although at present no classical glaciation is observed on the Balkans, researchers have discovered and described several firn/ice features that have proved to have had a permanent character at least for the last several centuries (i. e., since the beginning of the Little Ice Age). These forms, which have been preserved since the end of the LIA, are found on latitudes between 41º N and 43º N in some of the highest mountains of the Balkan peninsula (figure 1), at places situated well below the contemporary snow line, that have favorable topographic and microclimatic conditions - negative landforms, strong shading, great accumulation of avalanche snow, and carbonate bedrock that drains the meltwaters.

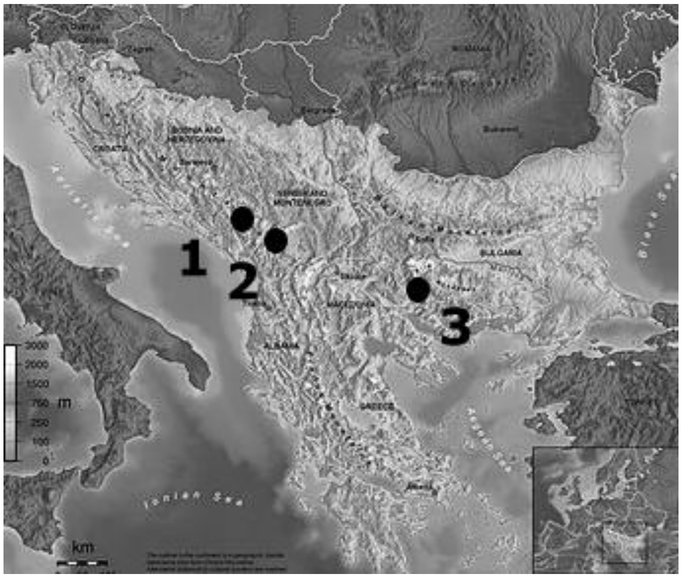

Figure 1. Location of the small glacial features in the mountains of the Balkan Peninsula. 1. Durmitor (Montenegro), 2. Albanian Alps (Albania), 3. Pirin (Bulgaria).

In the Durmitor massif in Montenegro (part of the Dinaric mountain chain) this is the Debeli Namet – a small glacier, which, although quite modest in size (between 2003 and 2011 the area has shown variations between 1.5 and 5 ha) demonstrates a classical glacier morphology at quite a low altitude – 2050 – 2300 m a. s. l. Further east, around the highest summits of Prokletije mountains (the Albanian Alps) in Albania several perennial show patches have been described at altitudes between 1980 and 2400 m a. s. l. Four of these (glaciated areas between 2.3 and 5 ha) were described by Milivojevic et al. [*2008*] and Hughes [*2009*] as active small glaciers, although they do not have well developed snouts. Two more perennial ice features are discovered and studied in the Pirin mountains in SW Bulgaria. These are Snezhnika and Banski suhodol, which are defined by Grunewald & Schetichauer [*2008*] as glacierets or microglaciers.

Snezhnika glacieret is situated at the NE foot of the highest summit in Pirin – Vihren peak (2914 m a. s. l.). At present it is considered to be the most southerly situated glacial mass in Europe [*Grunewald & Scheitchauer 2010*]. It is located at 2400-2450 m a. s. l. below a 400 metre marble rockwall. Its size in autumn is usually between 0.5 and 0.8 ha, the drilling in 2006 showed an ice thickness of 11 m [*Grunewald & Scheitchauer 2008*]. The other Bulgarian glacieret – Banski suhodol, is a little larger (about 1.2 ha in autumn – our observation) and is situated higher – at 2620-2750 m a. s. l. on northerly exposure. It is located 5 km northwest of Snezhnika.

Studies of small glacial features on the Balkans

Small glaciers on the Balkans are much less studied than those in the High Tatras, in Slovenia or in Italy’s Apennines. However, observation of Snezhnika glacieret has already had a 55 year tradition. It started in 1957, when the first mapping and measurements were done by the Bulgarian Academy of Science. Regular size measurements have been performed on a regular basis in each autumn since 1994 (except in 1995) by German scientists [*Grunewald & Scheitchauer 2008*], and since 2008 by the author of the present work [*Gachev 2012 in press*]. During the drilling in 2006, organic particles obtained from ice at the depth of 10 were ^{14}C dated at about 1810-1924 AD [*Grunewald & Scheitchauer 2008*].

The glacier Debeli Namet in Montenegro has been regularly monitored since 2003 by Ph. Hughes from the University of Manchester, who measured the area of the glacier in autumn and made a lichenometry dating of the moraine that surrounds the glacier.

The small glacial features in the Albanian Alps have been sparsely studied. Single descriptions with size approximation were done by Milivojevic et al. [*2008*] and Hughes [*2009*].

Inter-annual size variation of small glacial features

Two seasons are outlined in the annual cycle of the small glacial features – an accumulation season from November to April, and an ablation season from May to October. In the autumn of each year, the area and mass of the glacial features reach their minimum, and this state represents the result of the mass balance for the particular year. Each year the shape and size of any particular glacial feature are different – for example, in the period 1994-2011 Snezhnika glacieret showed a considerable variation of the size: from 0.3 ha [*1994*] to 0.77 ha [*2006*] and this is a result of the climatic characteristics of each particular year (temperature, snowfall and rain amounts).

A serious problem for the proper assessment of climatic variations is the lack of local meteorological data.

The small glacial features and the climate variations in the last 20 years

It is clear that the great differences the size of small glacial features are related to the variations of the local high mountain climate from year to year. However, at a regional scale the observed inter-annual variations of the size of the small glaciers are not absolutely synchronous throughout the Balkans, and have really different pattern from those of the small glaciers in the neighboring regions (the High Tatras, the Alps, the Apennines). Something more – the observed patterns of inter-annual dynamics for the last 20 years do not correspond to the overall trend of glacier retreat, but there has been a grow-up tendency since the 90s of the last century.

Importance of the studies of small glacial features on the Balkans

The glacierets on the Balkan Peninsula are among the most southerly located in Europe. They are quite sensible on the variations of climate and can serve as valuable indicators for the changes in local and regional climate, and as it has already been observed, these changes do not match global tendencies, but have their own unique patterns. Knowing these patterns will help us better understand and predict the future character of the regional climate.

As small glacial features survive still even the hottest and driest summers, they can be considered also as certain spots of permafrost, at least for the underlying ground. Therefore, it shall be a good idea to incorporate the observation of small glacier features into permafrost research, as it can be considered as a specific aspect of the latter.

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The Peculiarities of the Mechanism of Suffosion Processes in the Permafrost Zone (the Case of Central Yakutia)

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Introduction

In 2005-2006 suffosion intensification was observed in Central Yakutia at the sites of suprapermafrost and intrapermafrost taliks. This process most intensively occurred at the right bank of the Lena River near the ground water discharge area. Very high rates and scales of suffosion depression formation that were identified are hazardous for the federal Amur-Yakutsk Highway passing nearby. Special investigations were carried out in this connection the purpose of which was to identify the reasons for suffosion formation in the permafrost zone and to study its dynamics.

Various researchers understand the suffosion process differently. The author of this work interprets suffosion processes as mechanical destruction and removal of small-grained material by the ground water flow. Suffosion gains specific features in the permafrost zone.

The area of research

The area of research is located at 50 km to the south along the federal Amur-Yakutsk Highway from the village of Nizh. Bestyakh. This territory is located at the 4th above-floodplain (Bestyakh) terrace of the Lena River. The terrace surface within the area of research is complicated with the Ulanakh-Taryn Creek valley cut into the depth down to 30 m. The valley's width is 200 m on average and reaches 1 km at some sites.

The Bestyakh terrace is composed of middle- and small-grained sands with gravel and pebble deposits at the Middle Pleistocene bottom. The alluvium thickness within the area of research is 50-80 m. Unconsolidated Quaternary deposits are underlain with the Middle Cambrian limestone [*Ivanov 1984*].

The permafrost thickness within the area of research is 150-200 m [*Ivanov 1984*]. The seasonal thawing depth reaches 3-4 m. The permafrost temperature varies from -0.1 to -0.5 ˚C, and falls till -2.5 ˚C in the Ulanakh-Taryn Creek valley. Suprapermafrost and intrapermafrost taliks are locally developed within the terrace. Infiltration alimentation of ground water with precipitation, surface and suprapermafrost waters occurs in the first type of taliks, while via intrapermafrost taliks the water moves to discharge zones.

Therefore, the ground waters are referred to the suprapermafrost-intrapermafrost type in relation to alimentation and movement conditions. Their discharge occurs in the Ulanakh-Taryn Creek valley. Ground water sources have the same name and are conventionally divided into groups A, B, C, D and E.

The total source output is 280 l/sec on average and can vary, depending on the amount of summer precipitation. The ground water flow removes a lot of sand, and indistinct alluvial cones are formed in the creek valley. Depressions of the suffosion origin are developed at the terrace surface, above ground water sources. Some suffosion cones reach 30 m in diameter and 15 m in depth. In winter the Ulanakh-Taryn Creek valley is covered with icing (up to 3-4 m thick at some areas) in the ground water discharge area, and is referred to very large ones according to B.S. Sokolov's classification.

Research methodology

Key sites were chosen for the study of permafrost-hydrogeological conditions in the ground water discharge areas. A complex of investigations was carried out at the sites. It included: ground temperature measurements till the depth of 15 m near the ground water discharge zone and at some distance from it; the study of the hydrodynamic regime of ground waters near the Bestyakh terrace edge; and monitoring of icing formation in the Ulanakh-Taryn Creek valley. Tacheometric survey with a one-year time interval was carried out in order to study the dynamics of suffosion processes. Construction of area location plans was the result of it. We managed to calculate the volume of surface suffosion depressions in the area of research with the help of computer software. The reasons for the development of suffosion processes were identified as a result of mathematic modeling of heat-exchange conditions of thawed and frozen grounds.

Research results

Two conditions are required for the development of suffosion processes: 1) inequigranular texture of water-hosting unconsolidated grounds; and 2) presence of a removal zone of material [*Khomenko 2003, Anikeev 2006*]. If the ground water head gradient is sufficiently high, only the second condition is required for destruction of the water-hosting ground.

According to V.P. Khomenko's classification, the suffosion process can be divided into partial and complete filtration destruction and ground erosion [*Khomenko 2003*]. Partial filtration destruction occurs without the destruction of the ground structure when ground waters remove the material with dimensions smaller than those of the porous space. Complete filtration destruction occurs in case of high ground water head gradients when the ground transitions into the running state. Ground erosion is formed in case of presence of end-to-end ground channels connecting the water supply source with some vacant space. As a result, the channel bottom and walls are destructed by the ground water flow.

The suffosion process in the area of research is confined to the slope of the Ulanakh-Taryn Creek valley and develops into the depth of the terrace. Its mechanism seems to be as follows. The ground water discharge zone is localized due to more intensive freezing of the river valley bottom and of its slope, as compared to the adjoining terrace surface. The hydrodynamic characteristics of the ground water flow change near the terrace edge (the head gradient increases significantly). As a result, filtration destruction of the thawed area begins: at first, it is partial and then transitions into a complete destruction. Permafrost in the Ulanakh-Taryn Creek valley serves as the main obstacle for ground water flow. Apart from a mechanical impact, the ground flow also exerts a heat impact at the boundary of the water-hosting thawed zone and the frozen zone blocking the movement. The heat impact activates the thermal erosion process. The frozen roof of the aquifer is exposed to the suffosion impact here.

In winter the largest centers of ground water discharge (the maximum diameter of the water-discharge zone observed by the author is 0.5 m) do not freeze and the suffosion material removal occurs all year round here, according to the performed investigations. Small ground water outlets freeze, and the ground water flow "searches for" another weak zone for discharge onto the surface. Previous researchers also wrote about migration of ground water discharge centers [*Efimov 1952*]. Monitoring of the intrapermafrost water level in the well testifies to the increase in the hydrodynamic pressure in winter by means of the cryogenic head growth. Consequently, the suffosion process is not suspended in winter and can even intensify.

Well-washed cavities are formed in the aquifer roof as a result of formation of high hydrodynamic pressure in the ground water discharge zone. The higher the head gradients of a ground water flow are, the greater the magnitude of the cavities is. According to the research results, such "caves" can reach 5 m and above in length, and up to 3 m in height and in width. The dimensions of the formed cavity are defined with the strength characteristics of the ground mass. With gradual cavity increase the roof does not stand the weight of the above-lying grounds, and its failure occurs. Sink holes and cone-shaped depressions are formed at the terrace surface. Similar phenomena are traced at the distance of up to 300 m from the ground water discharge zone. The dimensions of the depressions of a suffosion origin can change in diameter from 1-2 to 30 m and reach 15 m in depth. Cone-shaped depressions merge into a single one eventually, and there forms a ravine. The data on rather high rates of suffosion process development were received as a result of the special geodetic regime works conducted by the author at the key sites connected with the study of the suffosion process dynamics [*Gagarin & Semernya 2011*].

Therefore, suffosion processes have specific features in the cryolithozone. The ground water flow has both mechanical and heat impact on permafrost. Permafrost is the required condition for suffosion activation at the area of research. The specific manifestation forms of this process and a very high rate of their development are hazardous for engineering structures during the development of the territory.

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Study of Seasonal Injury Rate at the Oil and Gas Enterprises in the North

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Keywords: energy inputs; injury rate; labor difficulty; temperature factor; the North.

The purpose of the study was to find out the correlation between the injury rate in the oil and gas industry and the climatic conditions, e.g. the temperature factor, in the region of oil and gas production.

The task was to confirm or disprove the hypothesis on the correlation between the injury rate and the seasonal temperature change that had been previously proposed. According to this hypothesis, one's energy inputs change proportionally to the ambient temperature and affect labor difficulty and intensity [*Galkin 2000*]. The two latter factors are also assumed to influence the industrial injury frequency rate to a great extent.

Results of the analysis of the accidents at one of the oil and gas enterprises located in the North indicated that a decrease in air temperature led to an increase in injury frequency. More than half of all the accidents considered (61%) happened in winter. The correlation found out confirms the regularity previously revealed for opencast mining enterprises in the North [*Galkin & Zabolotskaya 2008*].

Using the energy criterion for the evaluation of labor difficulty, it was found that there exist threshold temperature values that determined labor categories when fixing norms for labor difficulty. This is therefore obvious that the labor difficulty and intensity norms prescribed in accordance with the methodology of workplaces assessment are far from reality in the cases studied. This affects also the actual injury frequency rate [*Galkin & Khusainova 2010*].

In order to illustrate the change in labor difficulty as a function of the temperature factor in a better way, there were made maps similar to climatic zoning maps.

Total annual energy inputs for workers representing different occupations were found. The calculations were carried out considering energy input values used for labor difficulty rating during workplaces assessment. Based on the calculation results, there were coefficients found indicating the degree of energy inputs excess among the workers who performed labor operations of the same type in different temperature zones. The zones correspond to the new mining areas zoning system that had been previously developed. The numerical results obtained indicate that it is advisable to correct standard categories of labor difficulty in the major gas and oil producing regions of the North.

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Prediction of Hydrate Formation in the Producing Gas Well Borehole

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Abstract

The today's world has huge available explored reserves of natural gas that is one of the main types of fuel. Formation of hydrate deposits (obstructions) in the producing gas well borehole is one of the urgent problems facing the gas industry in the northern regions. This paper studies the method aimed to predict this event based on calculation of pressure and temperature distribution along the wellbore in accordance with the general equations of fluid dynamics and thermal physics. The sections where hydrate formation is possible are predicted by means of hydrate-existing condition diagrams in the “pressure-temperature” coordinates, if we know the PT conditions in a wellbore and natural gas composition. The produced gas flow within these sections may slow down or stop completely, which is unacceptable for the field development.

Keywords: gas-hydrate, hydrate, hydrate formation, hydrate deposit.

Introduction

The today's world has huge available explored reserves of natural gas that is one of the main types of fuel. Such fields are intensively developed in many countries. During gas production, hydrate formation conditions may occur under certain pressure-temperature conditions, which leads to formation of a hydrate deposit slowing down or stopping the flow.

The gas-hydration control and advanced hydrate-prevention methods are urgent topics for drilling engineers and other research and technical specialists of the gas industry. In order to predict the hydrate deposit formation, one should determine the pressure and temperature distribution along the wellbore and then to compare the obtained data with the hydrate-formation condition diagrams for the gas in question.

Pressure and Temperature Distribution in the Producing Gas Well Borehole

Under certain PT conditions, all known gases form hydrates with the structure depending on the gas composition. These hydrates may exist in a wide range of temperatures and pressures. For example, methane hydrate exists under pressures from $2\cdot10^{-8}$ to $2\cdot10^{3}$ MPa and temperatures from 70 to 350 K [*Makogon 2010*]. Such conditions may occur in a wellbore during natural gas production.

Let us consider the schematic structure of a producing well (Fig. 1). The pay formation’s occurrence depth may vary from hundreds of meters to several kilometers. The non-uniform pressure and temperature field occurs inside the wellbore. Generally, in the absence of phase transitions or external impacts, the P-T gradient is directed from the well head towards its bottom. Hydrate formation is a phase transition, so, it leads to abrupt jump in these parameters.

Most gas-producing wells within the Russian territory are located in the permafrost zone. Gas flowing from the bottom hole to the well head gives rise to heating of the adjacent grounds and, consequently, to formation of the thawing zone around the well. The flow itself is being cooled in the process. It should be noted that the gas is cooled exactly for the amount of heat received by the environment surrounding the well.

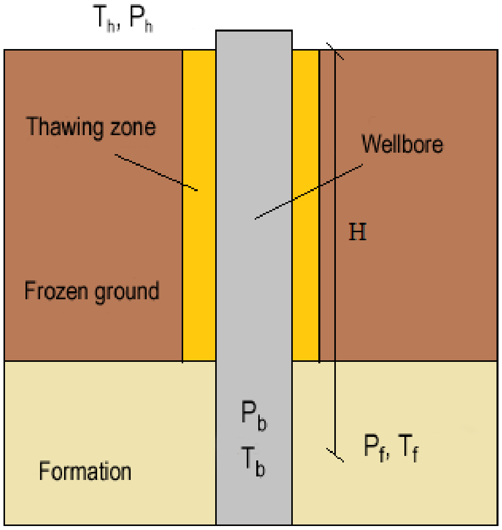

Figure 1. Scheme of a producing well in the frozen ground: H – formation occurrence depth, P_b and T_b – bottomhole pressure and temperature, P_h and T_h – wellhead pressure and temperature

To calculate temperature distribution along the wellbore, one should use the basic heat transfer equation:

$$Q= \alpha\cdot S\cdot \Delta T_{lm} \qquad (1)$$

where Q is heat transfer intensity, α is overall heat-transfer coefficient, S is square of surface available for heat transfer, ΔT_{lm} is mean log temperature.

Overall heat-transfer coefficient is represented by a sum of four members [*Carroll 2007*]: 1) convection heat transfer due to fluid movement; 2) heat conductivity through the pipeline’s material; 3) heat conductivity through the insulation material; 4) heat-transfer resistance of the ground.

In order to calculate pressure distribution along the wellbore, let us use the generalized Bernoulli equation [*Loytsyansky 1988*]:

$$P=_{Pb}+\rho\{\alpha\kappa(_{Vb2}-V^2)/2 + gh - l_{fr}\} \qquad (2)$$

where P, P_b are pressures in the current cross-section and on the bottomhole, ρ is gas density; α_κ is kinetic energy coefficient, V, V_b are flow velocities in the current cross-section and on the bottomhole, g is free fall acceleration, h is distance from the bottomhole to the calculated cross-section, l_{fr} is friction work.

To calculate pressure and temperature distribution along the wellbore, one should solve the set of equations (1), (2).

Hydrate Formation in the Wellbore

Solving the previously obtained set of equations, we get pressure and temperature distribution along the wellbore. Using the obtained data, one can easily determine if the zones of potential hydrate formation can exist under these particular conditions. For that, we should know the gas composition, since it critically influences the forms of phase transition curves. Figure 2 [*Makogon 2010*] shows the diagram of methane hydrate existence conditions in the “pressure-temperature” coordinates.

Hydrate existence diagrams for different gas compositions may be found in the published sources [*Carroll 2007*].

The hydrate formation phenomenon is observed not only in the producing well boreholes, but in the line pipes as well. Formation of hydrate deposits also occurs in the oil flowlines, if watercut is high. The emulsion containing formation water as well as associated gas and oil, which is formed in the process of crude oil production, may be hydrated under certain P-T conditions [*Turner 2005*]. The previously considered equations (1), (2) are correct for these cases as well, under some assumptions.

Conclusions

This paper studies the method aimed to predict the formation of hydrate deposits that may put obstacles to the flow of produced gas.

To calculate pressure and temperature distribution along the wellbore, one should solve the set of equations (1), (2). This is a complex task if solved by analytical methods, so, computer-aided techniques of numerical solutions may be considered a matter of topical interest.

Different gases correspond to completely different pressure and temperature ranges when hydrate formation becomes possible. So, the chemical composition of the produced gas is important.

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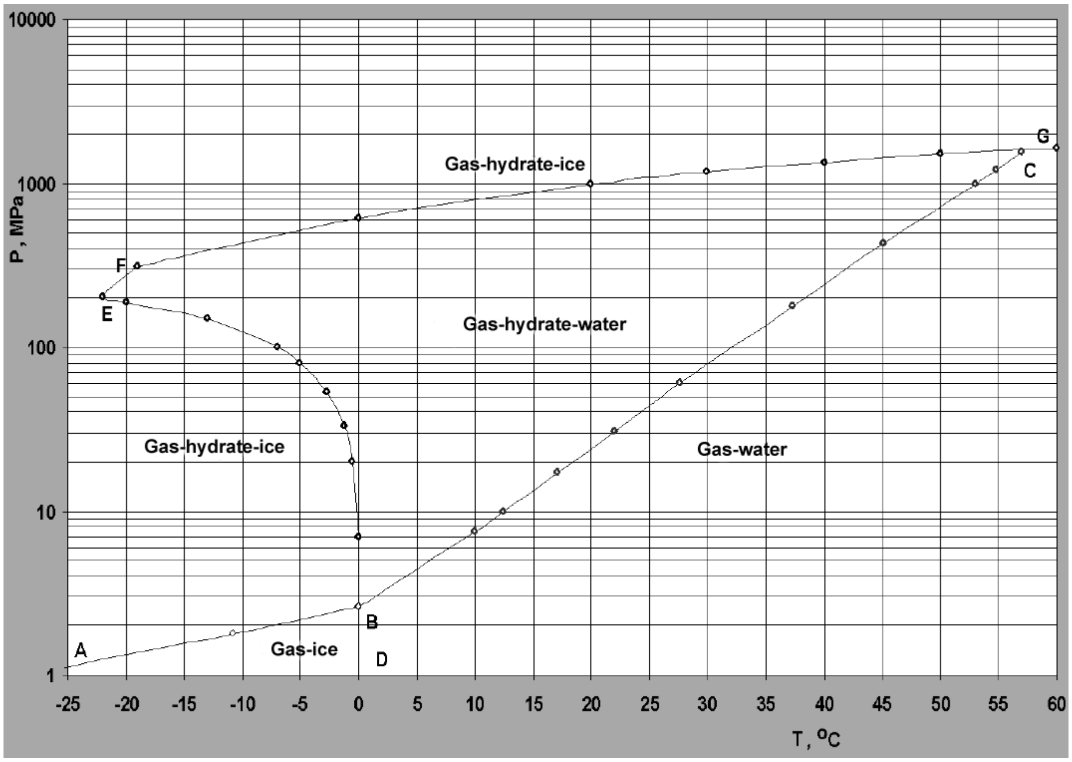

Figure 2. Existence of “CH_4 – water” system in the hydrate-formation conditions (Makogon 2010)

Monitoring the Thermal and Mechanical Behaviours of Puvirnituq Airstrip, Nunavik, Northern Quebec, Canada

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Puvirnituq Airstrip Research Project

Location

The Northern Village of Puvirnituq is located in Nunavik, Northern Quebec. Puvirnituq is one of the two Nunavik's administrative centers with Kuujjuaq. The airport has a major role for supplying the village but also serves as a gateway to more remote communities of Nunavik.

Problem statement

The airstrip is mostly constructed on bedrock but crosses a valley oriented NW–SE. Water seepage has been observed in this valley during summer until late fall. The valley is mostly filled with fine-grained sediments [*Allard et al. 2009*]. A thick embankment was needed to fill the valley. The embankment, with a maximum height of 8 meters, tends to subside and has been monitored for several years. Many factors may explain the observed subsidence. The creep of warm permafrost under the weight of the embankment combine with the permafrost degradation appears to contribute to the problem observed. The permafrost degradation may be related with the snow accumulation on the slope of the embankment and water seepage under the embankment.

Construction work

The Puvirnituq airstrip has been extended and upgraded in order to allow landing of a Boeing 737. In this context, thermal and mechanical stabilization of the embankment were needed. The design of the convective embankment and berm constructed on the Puvirnituq airstrip is showed on Figure 1.

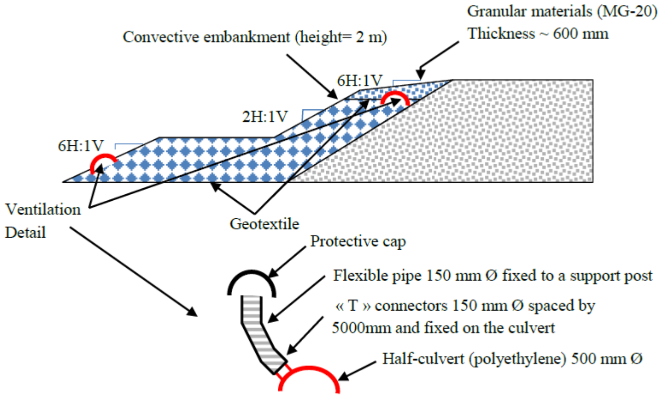

Figure 1. Convective embankment and berm design (modified from Verreault 2010)

Stabilization measures were taken during the construction work in 2009. These measures include the deviation of the water source upstream (west side of the airstrip), the extraction of heat from the embankment and the mechanical stabilization of the embankment by the construction of a berm. The time allowed to proceed with the construction work was unfortunately not long enough to allow optimization of the thermal design of the mitigation method. The mitigation method used at Puvirnituq was first study in the context of other research projects [*Beaulac 2006, Voyer 2009*].

Instrumentation

In order to evaluate the effectiveness of the system constructed, several measuring instruments were installed in the embankment during the construction work. The instrumentation consisted in five thermistor strings installed in the convective embankment and berm (29 thermistors), four thermistor strings installed in the natural ground (33 thermistors) and one thermistor string placed horizontally at the interface natural ground/ convective embankment (8 thermistors). An automated inclinometer was also installed at the foot slope of the embankment where the movements were the most likely to occur.

Research project objectives

The research project focuses on the thermal and mechanical monitoring of the Puvirnituq airstrip embankment. The evaluation of the effectiveness of the mitigation method constructed on the site is one of the major objectives. The study need to assess if the solutions applied were appropriate under the conditions prevailing on the site. Furthermore, many questions related to failure mechanisms of an embankment construct on degrading permafrost and the applicability of the stability analysis in this context remain to be documented.

Biannual Permafrost Evolution

The thermal monitoring of the Puvirnituq airstrip has begun in September 2009. It is therefore possible to comment on the evolution of the permafrost two years after construction.

Climatic data comparison

In order to compare the climate record from the two first monitoring years, the freezing index (I_{af}) and the thawing index (I_{at}) were calculated using the Boyd's method [*Boyd 1976*]. These indexes are showed in Table 1. It is possible to see that the second monitoring year temperature was more favorable for the permafrost with a higher freezing index and a lower thawing index.

Table 1. Freezing index (I_{af}) and thawing index (I_{at}) for the first two monitoring years

Year	I_{af} (° C ·day)	I_{at} (° C ·day)
2009-2010	2 546.5	1 320.7
2010-2011	2 844.9	1 058.1

Permafrost table evolution

The permafrost evolution has been observed with the depth of the permafrost table. The Table 2 summarizes the depth of the permafrost table and the permafrost table depth variation for the thermistor strings placed in the natural ground. The permafrost table depths have been extrapolated when the depth was beyond the length of the thermistor string. It is possible to observe that the permafrost table significantly rises for two thermistors strings (F and G). The observed rise is less for the thermistors string F2, but is also important. Finally, the last thermistors string (F5) indicates a steady permafrost table.

Table 2. Depth of permafrost table and permafrost table depth variation

Thermistors string	F (m)	G (m)	F2 (m)	F5 (m)
2009-2010	3.41*	4.08*	4.33	6.92
2010-2011	1.78	2.11	3.74	7.00
Variation	1.63	1.97	0.59	-0.08

* linear extrapolation from the last two temperature

Convection movements

The thermistors strings installed in the convective embankment shows some interesting results during the winter 2010-2011. The temperatures recorded show warmer temperature at the top and colder temperature at the bottom of the embankment. This gradient, opposite to the one expected, is a good indicator of convective movements that occurs in a part of the embankment. This reverse gradient lasts for about two months.

Conclusion

The first two monitoring years have helped to do some interesting observations on the thermal behavior of the embankment. The soil is generally colder during the second monitoring (2010-2011 comparing with the first monitoring year (2009-2010). It was also possible to observe an uplift of the permafrost table on three of the four thermistors strings installed in the natural soil. The colder winter and cooler summer cannot by themselves explain the differences between the two monitoring year. The deviation of the small creek upstream certainly played a major role. Finally, evidences of convection have been noticed in the thermistors strings placed in the convective embankment.

Upcoming work

A stability analysis of the embankment before and after the construction work (after the installation of a counterweight) will be performed. This analysis will allow discussing about the costs and the benefits gained from the construction of the convective embankment and berm.

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The Assessment of Permafrost and Ecological Environment during Construction and Operation of Facilities in the North

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Introduction

65% of the territory of Russia is occupied with permafrost areas [*General Geocryology 1978*]. Permafrost is one of the most sensitive and "capricious" components of the nature in the North; it sensitively responds to technogenic impacts causing changes in the environmental situation, which leads to occurrence of a number of negative consequences. Area urbanization, erection and exploitation of living, public and industrial facilities in it, construction of motor roads and underground utilities change the thermal regime of grounds fundamentally, mainly towards the increase of the mean integral surface temperature [*Grebenets & Rogov 2000*].

Research methodology

The following procedures were carried out for assessment of the consequences of the anthropogenic loads impact on the permafrost state: analysis of the literature on this problem and natural investigations in the north of Siberia. The anthropogenic impact on the environment in the process of permafrost development can be disastrous from the perspective of stability of the permafrost and ecological environment. The differences in technogene types must be taken into account in this case: a) construction and operation of facilities on rather large areas, i.e. urbanized sites; b) laying of linear structures.

Results and discussion

Cities in permafrost zones are the centers of concentrated technogenic impact on the natural environment. Specific natural-technogenic geocryological (permafrost) complexes are formed in urbanized areas. The permafrost dynamics differs from natural conditions in them.

Technogenic barren lands-badlands (slurry and slag dumps as well as ash and tailings ponds) and large settling ponds of treatment facilities are most unfavorable. Permafrost is destructed and natural landscapes are destroyed in them. An evident increase in the seasonal thawing depth is observed even in tundra and forest tundra zones hardly influenced by technogenesis and falling into the pollutant dispersion zone. Here, an increase in the ground heat conductivity occurs as a result of acid rain falling and of the increase in the ground technogenic salinity. This causes more intensive summer heat penetration into the grounds.

The main factors influencing the natural conditions during construction and operation of facilities within urbanized areas in the cryolithozone include [*Grebenets 2003*]:

1) Changes in natural landscapes that suffered various anthropogenic disturbances prior to their development, and environmental degradation.

2) Imperfection of the existing methods of area engineering preparation: first of all, filling of thick poorly sorted and well-filtrating technogenic pads.

3) Heat supply to grounds in the process of drilling and pile driving;

4) Multiple violations in the exploitation of undergrounds and other cooling geotechnical systems;

5) Automated re-distribution of snow deposits at the built-up area;

6) Heat impact of the underground collector system on permafrost;

7) Change in the heat conductivity of grounds during their technogenic underflooding and salination.

Technogenesis causes thermokarst, sand running, icing formation, ravine formation, cryopeg formation, solifluction and so on.

As compared to dense urban development, the construction of linear facilities causes changes in geocryological conditions, depending on the type of impact. It is evident that the roads requiring filling influence permafrost differently, as compared to elevated pipelines.

Accidents (see Fig. 1) are possible in the "underground gas pipeline - permafrost" system, when ground thawing around the underground pipeline is accompanied with irregular settling (in the process of thawing) of grounds with different ice content, particle size distribution, etc.

Figure 1. Thermal erosion at the construction site of the underground gas pipeline at the Yamsovey Field, the north of Western Siberia. July 2009. The photo by V. Grebenets

Underground gas pipeline construction has the maximum adverse impact on the permafrost and ecological environment. Hazardous cryogenic processes frequently develop in this case: thermokarst, thermal erosion and formation of ravines.

Particularly complex permafrost and ecological conditions are formed at the areas of pipeline crossings across rivers and temporary watercourses.

Conclusions

The impact of the anthropogenic activity on permafrost complexes creates specific natural and technogenic conditions under which the permafrost dynamics differs from natural conditions: the seasonal thawing depth increases and a number of processes may occur, including activation of thermokarst, sand running, icing and of ravines, formation of cryopegs and of solifluction, area underflooding, vegetation alteration and others. A human factor influences the undesired effect negatively as well: imperfection of the existing methods of area engineering preparation and multiple violations in the exploitation of the underground and other cooling geotechnical systems worsen the technogenic impact.

The best technology for the area should be chosen for preservation of the natural permafrost conditions or reduction in the undesirable impact of the human activity. For example, open pipes about 80 cm in diameter are laid in some places of the embankment for water passage through the road, in order to reduce the risk of area underflooding in the process of road filling.

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Mapping of Hazardous Hydrometeorological Phenomena of the Cold Period in Order to Differentiate Their Assessment Criteria

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Due to the active development of new areas and an increased pressure on the environment, human population and economic activity are increasingly exposed to hazardous natural processes and phenomena. The analysis of the development of natural catastrophes on the Earth shows that the security of people against natural hazards is not improving.

The territory of Russia is located in different climatic zones. Due to the variety of landscape and climatic conditions the number of natural hazards that occur in our country is very high.

The problem of the re-evaluation of the hazardousness criteria of hydrometeorological phenomena based on the analysis of the natural emergencies that actually took place over the course of many years is quite acute nowadays. In Russia the differentiation of the hazardousness criteria of natural phenomena is almost nonexistent. At the legislative level a standard list of natural hazards and their criteria was designed. But most of hydrometeorological services use it without taking into account the climatic features of the territory.

The lack of spatial differentiation of the criteria is clearly seen in the developed maps. The exceptions are temperature-related natural hazards – "severe heat" and "severe cold". There are no standard criteria for these types of natural hazards in the list proposed by the Federal Service for Hydrometeorology and Environment Monitoring. The analysis showed that not all hydrometeorological services point out such natural hazard as severe frost. For example, in Yakutia, the notion of "severe prolonged cold" is used instead of the term "severe frost", whereas in Sakhalin Region the natural hazards list does not contain it at all. The concept of "abnormally cold weather" can be considered similar in meaning. However, it is not identical.

To offer reasonable innovations one needs a developed mapping technique for natural emergency cases occurred ("patterns"), as well as a comprehensive social and economic, on the one hand, and physical and geographical, on the other hand, zoning of the territory in order to allocate identical regions (where the same hazardousness criteria can be applied).

Based on the database of natural disasters in Russia complied in the research laboratory of snow avalanches and debris flows, the author developed various techniques for natural disasters mapping depending on the tasks and the final consumer of mapping products.

The Scenario Assessment of the Changes in the Water Resources of the Lena River Basin in the First Third of the 21st Century

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Introduction

For a number of years Institute of Geography of RAS develops a methodology of the long-term scenario prognosis of changes in runoff resources. The methodology makes it possible to obtain a long-term scenario prognosis of: (1) the changes in runoff resources of large river basins occurring due to the global and regional climate changes; (2) the transformations of hydro-economic system caused by socioeconomic changes in a country and their impact on water resources.

Scenario assessment methods

Scenarios of changes in a river runoff in the basins of large transboundary rivers of European territory of Russia and Siberia caused by climate changes possible at the consecutive stages of the global warming in the 21st century are constructed on the basis of: 1) the model of a monthly water balance adapted for the conditions of the permafrost zone [*Georgiadi, Koronkevich, Milyukova et al. 2011*]; 2) the results of simulation of climate changes and the methods of their adoption by the IPCC-2007; 3) the results of calculations of changes in permafrost characteristics; 4) the method of scenario assessments of the future hydro-economic system transformation [*Koronkevich 1990; Koronkevich et al. 2008 and others*]; 5) geographic information systems.

Scenario assessments of changes in river runoff based on ensemble climate scenarios

The range of possible climate changes is used as a climate scenario. The range is estimated according to the results of numerical calculations of climate elements' deviations from their modern values. The numerical calculations are based on the ensemble of 10 climate models derived from 2 contrast scenarios of the world socioeconomic development (A2 and B1) that were included in the program of the last experiment of 20C3M-20th Century Climate in Coupled Models (Meehl et al. 2007). The experiment was conducted within the framework of the Intergovernmental Panel on Climate Change (IPCC). The contrast models were selected on the basis of the comparison between the observed and the modeled modern climate for the East European Plane [*Kislov et al. 2008*].

Climate changes

According to both scenarios (A2 and B1), rather a similar rise of the mean annual air temperature (within the range of 1.6-1.7°C) may be expected at the central plain part of the Lena River basin under the condition of the first third of the century. The scenarios of changes in the mean annual atmospheric humidification predict its increase within 28-54 mm.

The peculiarity of the intra-annual distribution of changes in atmospheric humidification in the Lena River basin consists in the fact that precipitation rate can reach its highest values during the warm part of the year. At the same time, the highest rise of the air temperature is typical of the cold part of the year, while during the warm part of the year its rise is likely to be much lower and regular in time.

Changes in river runoff

The calculations based on the monthly water balance model of Institute of Geography of RAS showed (Fig. 1) that most probably there will be a slight increase in the annual runoff (not higher than 3-4%) at the central plain part of the Lena river basin if scenarios A2 and B1 are realized in the first third of the current century. However, climate warming can cause a certain transformation in the intra-annual distribution of the river runoff. The transformation is characterized with a compact runoff redistribution during a flood the peak of which will shift towards earlier terms. Besides, there will occur an inconsiderable decrease in the maximum monthly runoff during the flood period, according to both scenarios.

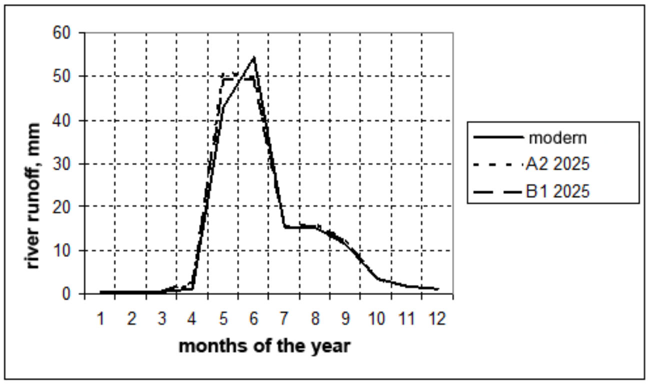

Figure 1. The modern and the mean ensemble average monthly values of the river runoff averaged over the cells of a regular grid for climate warming conditions in the period of 2010-2039. The grid covers the central plain part of the Lena River basin.

The scenario changes of the water consumption characteristics in the future

The general algorithm of a scenario development

The algorithm of a scenario development consists of the following stages. First of all, research is carried out at the pre-prognostic stage. This stage should precede the development of scenarios. The pre-prognostic stage includes:

- general focus of the method development;
- analysis of natural conditions and of spatial and temporal regularities in the water resources distribution and the analysis of natural quality of the water resources;

- analysis of the economic activity and of its impact on the water systems;
- analysis of the dynamics of the water systems state;
- selection of operational units.

The prognostic stage consists of:

- consideration of the expected natural hydroclimatic situation;
- consideration of the prognostic population and economic development;
- evaluation of the possible changes in the water usage technology;
- consideration of the complex of anthropogenic and natural climatic factors;
- verification of scenarios based on hydro-economic balances.

The results of scenario assessment of the changes in water consumption.

There are several possible scenarios of the development of water consumption systems in the Lena river basin. The scenarios derive from different variants of demographic and economic development of the region as well as from different technologies of water consumption. They include the variants of: preservation of the present level of the specific water consumption, its significant reduction and the complete cessation of wastewater drainage into rivers. At any rate, water intake and irretrievable withdrawals will not exceed 1% of the mean annual runoff of the Lena River in 2015 and 1-2% in 2025-2030. The most probable range of the prognostic change in the water intake in 2015 is 245-500 mln m^3, while for irretrievable losses of water in water bodies (with regard to the water losses due to its evaporation from the water storage basins) it is 400-500 mln m^3 per year. By 2025-2030 the irretrievable discharge may be close to the value of 1 km^3. For some of the most lived-in areas (especially during the low-water period), there may arise difficulties in determination of the hydro-economic balances; and hydrotechnical runoff regulation can become one of the most workable ways of their solution. These areas may face even a more acute problem of prevention of the qualitative exhaustion of water resources due to the possible increase in the water removal including the removal of the wastewater. The aforementioned quantitative recommendations on the separate components of scenarios should be regarded as approximate. They need to be corrected in the course of their more detailed development.

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The Study of Spatial Distribution of Permafrost Indicators and Landscape Structure of Central Yamal (the Case of Vaskiny Dachi Geocryological Station)

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In September 2011 members of the scientific expedition of Earth Cryosphere Institute SB RAS conducted a topographic survey of the modeled area in the course of their comprehensive research. The area examined lies within the territory of Vaskiny Dachi geocryological station in the central part of the Yamal Peninsula. Activities conducted at the modeled area included a permafrost survey, landscape description and measuring of the moisture content in the seasonally thawed layer the lower part of which was in the frozen state during the survey.

The purpose of the presented work is an analysis of the peculiarities of a spatial distribution of permafrost characteristics, depending on landscape structure, position in the relief, vegetative cover and ground composition.

A part of the fieldwork was a construction of a 1.5 km long transect crossing the main geomorphological levels of the examined area and most of the landscape facies at watersheds of the station.

Due to the conducted research it was ascertained that a seasonally thawed layer of the transect part lying at the watershed area of the fifth marine plain (**V**) that is the highest at the area examined with its absolute height of more than 46 m is mainly composed of sandy and clayey slits.

Moisture profiles constructed for the specific points of the fifth marine plain demonstrate an even distribution of ground moisture content along the depth of the seasonally thawed layer (20-30%), while the moisture content in the permafrost table increased up to 45-60%. The average shrubbery height at the watersheds of this geomorphological level is 30-40 cm, the moss cover thickness is 7-10 cm and the average moisture content is 40%. These parameters define the thickness of the seasonally thawed layer equaling 46-60 cm.

The watershed is cut by a thermal erosional ravine with a thawing depth of more than 160 cm. This is connected with the sandy composition of grounds and their low moisture content (10-30%).

The seasonally thawed layer at the area of the fourth coastal-marine plain (**IV**) is mainly composed of sandy and sandy silt materials. The average shrubbery height is 20 cm but at some points it can reach 70 cm. There is a significant area without shrubs, with the moss cover of 2-10 cm and the seasonal thawing depth of 80-100 cm. The third alluvial-marine terrace (**III**) is represented by isolated buttes. Low shrub and moss covers at this surface are thin, 3 and 1 cm, respectively. The seasonally thawed layer is mainly composed of sand and its maximum depth makes up 101 cm.

The low shrubbery height at the slopes of Terrace III and Plain IV increases from 28 cm near the edge of the slope to 150 cm near the terrace joint of the Panzananayakha River valley (this river is the main drain of the modeled area); the slope is composed of sand. The gradual increase is observed in the seasonally thawed layer depth from 56 cm near the edge of the slope to 128 cm near the terrace joint of the river valley. The data obtained indicate that in winter time a thick snow cover is formed here with the thickness of up to 150 cm.

These data served as a basis for composing a landscape-permafrost profile reflecting the vegetation, ground composition and moisture content as well as the depth of the seasonally thawed layer (Fig. 1).

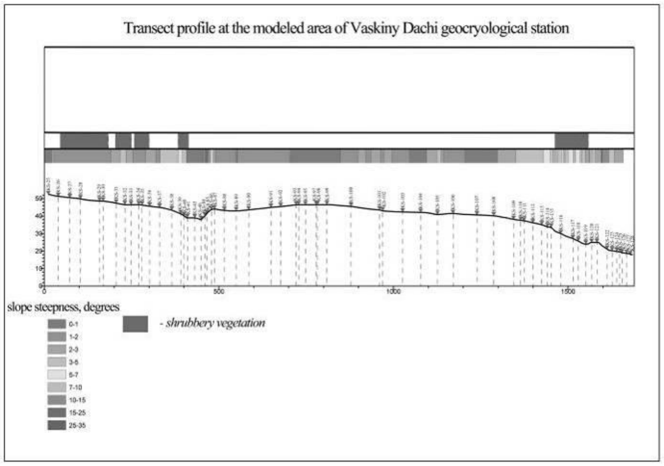

Figure 1. Transect profile at the modeled area of Vaskiny Dachi geocryological station.

Spatial data analysis conducted on the basis of the profile studying leads to certain conclusions. The deepest thawing is observed at the areas with a high vegetation cover, which is caused by the snow cover distribution (heat-insulting effect), and at the areas composed of sandy grounds (due to the moisture infiltration into the lower horizons, which contributes to thawing). Relatively small thawing depth is observed at the areas composed of clayey silt and sandy silt grounds with relatively low undershrub and moss cover or without it. The determining factors in the spatial distribution of the thawing depth are the winter distribution of a snow cover marked by the low shrubbery height, and the structure of the seasonally thawed layer grounds.

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The Bipolar Symmetry of Permafrost Temperatures in Arctic and Antarctica and Synchronism of Permafrost Age in Cenozoic

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Both poles of the Earth are favorable for permafrost existence, but on their surface there is none. North Pole with surrounding space is located in the ice-covered Arctic Ocean, and the South Pole with adjacent areas - in the center of the Antarctic Ice Sheet. Due to such geological situation permafrost is widespread on the periphery of the Cold Poles only: inland from the Arctic coast in the Northern Hemisphere and in ice free Antarctic oases in the Southern. As the high elevation is caused by the thick Ice Sheet mean annual air temperatures on the South Pole and adjoining areas are by ~25°C lower than on the northern one with surrounding space (fig. 1).

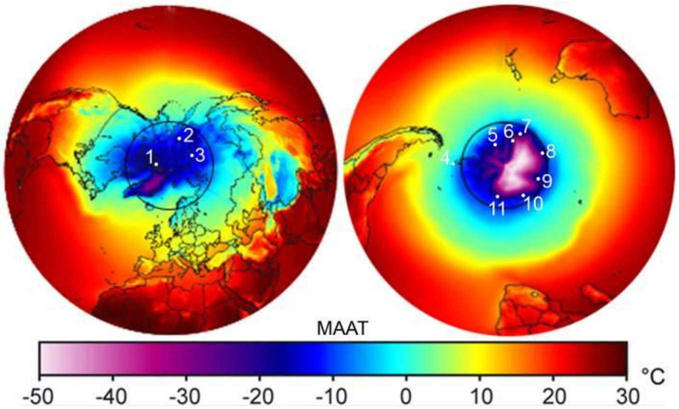

Fig. 1. Present day mean annual air temperatures (modified from Robert A. Rohde). The points of MAGT measurements mentioned in the text are shown by numbers: 1- Eureka station, 2-Kolyma river, 3-Lena river, 4-Antarctic Peninsula, 5-Mary Byrd Land, 6-Dry Valleys, 7-Victoria Land, 8-Bunger Hills, 9-Larsemann Hills, 10-Schirmacher Hills, 11-Thala Hills.

At the same time data obtained in the frame of the IPY projects (ANTPAGE, TSP, and ANTPAS) show similar values of the mean annual permafrost temperatures (MAGT) at the same latitudes and elevations in the Southern and Northern Hemispheres. The permafrost thickness in Arctic and Antarctica are close to each other too. According to temperature profiles from DVDP boreholes, permafrost in Dry Valleys can reach the depth of 300-1000 m and it's a well-known fact that Arctic regions have the same permafrost thickness. Active layer monitoring often indicates the same order in Arctic and Antarctic seasonally thawing depths. This demonstrates a bipolar symmetry of the permafrost state. The question is "How long does this symmetry exist?" The answer to this key question is the high priority for the global climate history and paleoreconstructions.

Permafrost temperatures

During the IPY the first boreholes have been drilled and tem-perature measurements have been made [*Abramov et al., 2011*] in the coastal ice free oases of East Antarctica (fig. 1) around the Polar Circle (66-71°S: Schirmacher Hills, Larsemann Hills, Thala Hills, Victoria Land, Mary Byrd Land). At the elevations of the first hundred meters above the sea level the MAGT varies from -7.8ºC (Bunger Hills) to -9.8ºC (Thala Hills). For comparison, in the Eastern Arctic coastal lowlands (fig. 1) along the Polar Circle (68-72°N, between the Lena Delta and the mouth of the Kolyma River) the MAGT varies from -7 …-9ºC (in depressions) to -10 …-12ºC (at the late Pleistocene tundra watersheds). Minimal MAGT (-18 and -16ºC, respectively) have been recorded at sea level in the Antarctic Dry Valleys (Taylor Valley, 78ºS) and the high Canadian Arctic (Eureka station, 79ºN). Maximum values close to -1ºC have been observed on the South Shetlands archipelago (King George and Deception islands, 62ºS) near the Antarctic Peninsula and the Signey Island (60ºS). This marks the northern permafrost boundary in Antarctica, and the south permafrost border is located at the same latitudes in Siberia, Alaska, Canada. The higher and inland you go into Antarctica - the lower the MAGT. The lowest MAGT (-23 and 27.9°C) were observed on 77-78ºS in the Beacon Valley and on the Mt. Feather (1270 and 2570 m) and at the same latitude, at the elevation of 3.5 km above the sea level, the mean annual temperature of the Ice Sheet in Vostok borehole is -55°C. The estimated minimal MAGT for the highest summits of the Transantarctic Mountains at 85ºS is -60…-65°C, and -30…-40°C, which is not so cool, - for the highest summits of Greenland and Elsmere Island at 83°N. Thus, summarizing data from the Arctic and Antarctic boreholes [*Romanovsky et al., 2010; Viera et al., 2010*] at the same latitudes and elevations the bipolar symmetry of the permafrost becomes obvious. But does it correlate with the bipolar synchronism of the permafrost age?

Permafrost age

The permafrost is the most stable end-member of the cryosphere. Its degradation is only possible when MAGT rise above freezing. In the interior Antarctica a significant warming, 25°C or more, is required to degrade the permafrost once it's formed. There is no evidence of such significant variation of temperatures, which indicates that the Antarctic climate and geological history were favorable for formation and persistence of the permafrost for more than 30 Ma [*Gilichinsky et al., 2007*]. At the same time it is believed that location and configuration of the climatic zones of Eurasia in the Cenozoic were similar to the modern, general system of the atmospheric circulation has not changed, income and expenditure of the solar energy was the same as now, and the northern part of the continent has always been characterized by warm temperate climate. In Arctic the oldest continuously frozen layers with traces of cryogenesis date back to the late Pliocene (3 Ma) only, with some evidences of the glacial deposits dated back to 5 Ma. The Eocene-Miocene pollen spectra show here the domination of the warm climate vegetation. This allows to suggest that the Antarctic permafrost has existed for the last dozen of millions of years, greater than the duration of the present Arctic permafrost by a factor of ten and also that during the major part of the Cenozoic period our planet had only one Cold Pole, in the South Hemisphere. It can mean either the global asymmetry of the permafrost thermal state or missing of the climate record for the 30 Ma. How can it be? The serious step to answer this question is recovery of the first Cenozoic sedimentary sequence from the Polar Ocean by Arctic Coring Expedition indicating the existence of seasonal ice in Eocene (47 Ma) and perennial sea ice in the middle Miocene (15-17 Ma). The second is synchronous with the terrestrial evidences of cooling throughout Alaska, Canadian Arctic Archipelago and NWT but not consistent with the data indicating mean annual temperatures that were much higher than today [*Tripati et al 2008; Backman, Moran 2009*]

Conclusion

The available geological information indicates the bipolar symmetry of the permafrost thermal state at the high latitudes in Southern and Northern Hemispheres for the last 5 Ma. The previous 30 Ma, including the entire Oligocene and Miocene, are characterized by the global asymmetry and even existing of the only one Cold Pole in the South Hemisphere. The explanation of this situation is very important for global climate history. If the climate record spanning these 30 Ma is missing this requires additional deep boreholes in the key locations of the Polar Ocean.

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From Snow Depth Distribution to Small-Scale Variability of Soil Temperatures – a Probabilistic View on Permafrost in Norway

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Introduction

Permafrost is a temperature phenomenon on the local scale. Soil temperatures are not only influenced by atmospheric conditions varying on scales of kilometers, but are also determined by the land cover and soil properties, which vary on the meter-scale in many permafrost areas. In mountain areas the seasonal snow cover is crucial for the ground thermal regime, and the redistribution of snow through wind drift can create a pattern of different snow depths, which results in spatially variable permafrost temperatures [*e.g. Isaksen et al. 2011*]. Available ground temperature models (e.g. CryoGRID 1.0) are implemented at 1x1km spatial resolution for Norway, showing good correlation with observations of permafrost distribution [*Gisnås 2011*]. One of the principal uncertainties of these models is the effect of the sub-grid variability in snow cover [*Gisnås 2011*], so that procedures for downscaling of snow depth are needed. We present measurements of the effect of different snow depths on the thermal regime of the underlying permafrost. Furthermore, we outline a probabilistic approach for including sub-grid variability of snow depths in grid-based permafrost models.

Study site and Methods

Three research sites are chosen for this project: (1) Finse, a low alpine site in southern Norway (1222 m a.s.l.), (2) Juvflye, a high-mountain site in central southern Norway (1800-1900m a.s.l.) and (3) Ny-Ålesund located in the high Arctic environment on Svalbard (0-100m a.s.l.). All sites have heterogeneous topography and a seasonal snow cover dominated by heavy wind redistribution. For these sites, both measurements and modeling approaches are employed to evaluate the probability density function of snow depths.

An extensive dataset including 7 boreholes and 5 stations measuring snow depth and air/ground surface temperature is available from the Juvflye area.

Monthly ground penetrating radar (GPR) surveys are run over a 1 km^2 area on Finse during the winter season of 2011/2012. Snow depth using GPR-surveys will also be run at Juvflye and Ny-Ålesund at the end of the winter season. Ground-based digital cameras are installed at all sites to estimate snow distribution during melt-out season.

SnowModel [*Liston & Elder 2006*] is a spatially distributed snow-evolution system designed for applications in all landscapes, climates and conditions where snow occurs. It includes a sub-module, SnowTran-3D accounting for the wind-driven redistribution of snow. The model is designed to run on grid-resolutions from 1m to 200m with temporal resolution from 10 minutes to 1 day. Studies show that the model needs to be calibrated for the environment of implementation [*Bruland et al. 2004*]. It is therefore crucial to have good calibration areas to test the model.

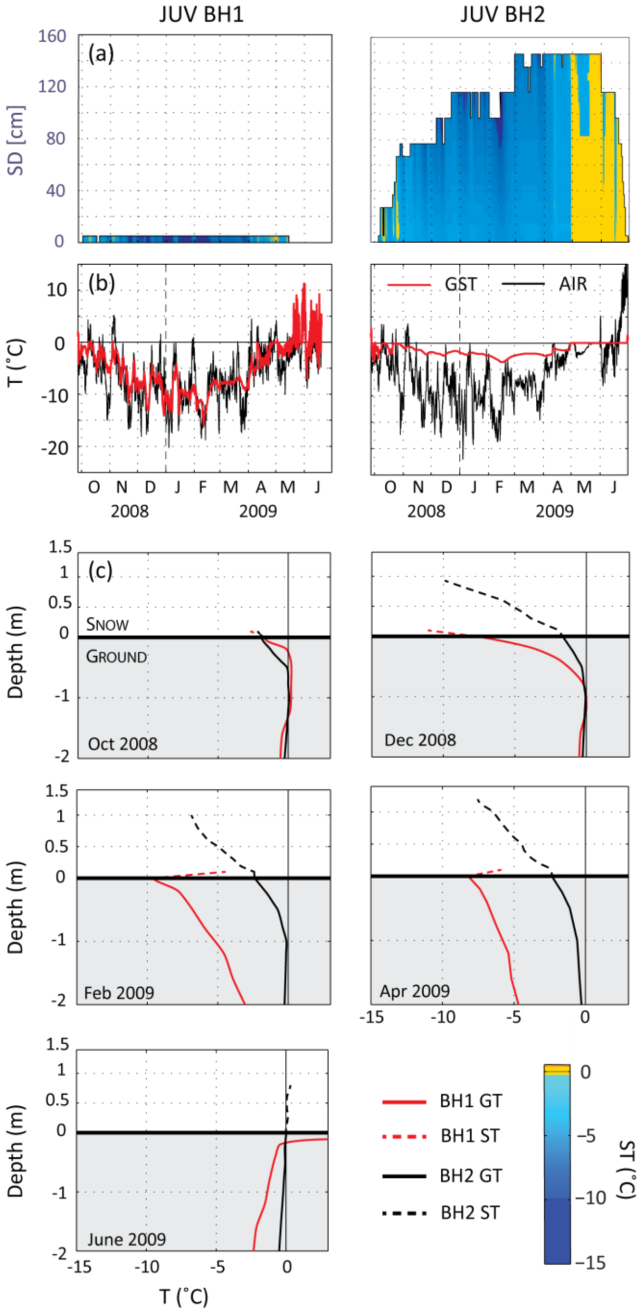

Figure 4: Data from borehole 1 (left) and 2 (right) at Juvflye in central southern Norway from 2008/2009. a) snow depth and snow temperatures above the boreholes, b) temperatures from air (black) and ground surface (red) c) snow and ground temperatures from selected months.

Results

We show combined ground temperature and snow depth data from monitoring stations measuring these parameters with hourly resolution at several sites at Juvflye, southern Norway (Figure 1). The two sites “BH1” (1851m a.s.l.) and “BH2” (1771m a.s.l.) are located within only one kilometer distance with the same air temperatures and similar ground properties. BH1 has a very thin snow cover, while the snow pack at BH2 is more than one meter thick during much of the season (Figure 1, a). The differences in snow cover cause major differences in the thermal regime at the ground surface: the ground surface temperature follows the air temperature at BH1, while it remains stable around 0°C from October to June at BH2 (Figure 1, b). This effect propagates down into the ground, and the temperature difference at depth between the boreholes increases during the winter season. In April, there is a difference of up to 5°C at 2m depth (Figure 1, c). In mean annual temperatures this implies a 2°C difference at the ground surface [*Farbrot et al. 2011*]. These data demonstrate the decisive effect snow cover variations have on ground temperatures in mountain permafrost environments.

Outlook

Modeling of ground temperatures in mountain permafrost environments is challenging due to the high spatial variability of snow. Existing permafrost models (the CryoGRID models) have proven to capture the regional distribution of permafrost in Norway. However, there is a substantial sub-grid variability of ground surface temperatures due to variations in snow depth. Sub-grid approaches are therefore required to get a satisfactorily representation of the ground thermal regime. The goal of this project is to develop a framework for downscaling of snow and ground temperatures.

The first step is to develop and calibrate a snow model for the specific environment of interest. This is currently being done at the research site at Finse. Probability density functions (PDFs) of sub-grid snow depths can be derived from the snow model, which will be used to force the CryoGRID permafrost model (Figure 2). This will be tested at the Juvflye and Ny-Ålesund sites. The result is a downscaling routine providing PDFs of mean annual ground temperatures (MAGT). Such procedures are required to provide sound predictions for the response of the mountain permafrost in Norway to future climate change.

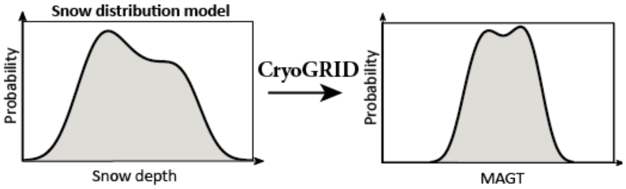

Figure 5: Downscaling framework producing PDFs for sub-grid variability of snow cover and mean annual ground temperatures (MAGT).

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Soil Temperatures Over a Latitudinal Gradient in the Ross Sea Region of Antarctica: Preliminary Results

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Introduction

There is interest in the Antarctic climate and its relationship and response to global climate drivers. Antarctica contains 90% of the world's ice and exerts an influence on the global atmospheric and cryospheric systems, suggesting that any change in the Antarctic climate may have far-reaching consequences [*Viera et al. 2010*]. In 2007 The International Panel for Climate Change (IPCC 2007) predicted that by 2099 global temperatures could increase by as little as 1.1˚C or as much as 6.4˚C. Global temperature increase is predicted to be magnified in the polar regions as snow and ice melts, reducing ground surface albedo, and increasing solar radiation absorption thereby exacerbating the heating process [*Kane, Hinzman & Zarling 1991*].

It is important to understand how the mechanisms of the Antarctic climate and subsurface thermal characteristics vary both spatially and temporally before trying to predict how the whole system will respond to global climate change. Longer records and more observations are needed to properly show any trends in inter-annual air and soil temperatures [*Guglielmin et al. 2011*].

The objective of this study is to investigate soil and air temperatures at 8 sites across the latitudinal gradient from 72.3°S to 78.3°S, and at altitudes ranging from 5 m to 1670 m, at depths of up to 1.2 m.

Data collection and site information

Data is downloaded and maintenance undertaken at 8 soil climate stations (Table 1) each summer season. Soil temperatures are measured using an MRC (Measurement Research Corporation, Gig Harbor, WA) multiple thermistor temperature probe installed as close to 120 cm depth as possible. Each MRC probe measures temperatures at 11 depths over the 120 cm length of the probe. Single thermistor temperature sensors (model 107; Campbell Scientific, Logan, UT) were also used.

Air temperature was measured between 1.6 meters and 2 meters above the ground surface either with a single thermistor probe, R.M. Young RTD Probe (model 43347; Campbell Scientific, Logan, UT), or platinum resistance temperature detector (model HMP45C or HMP35C; Campbell Scientific, Logan, UT). Atmospheric measurements were made at 10 second intervals, whilst soil measurements were made at 20 minute intervals. All measurements were averaged hourly and recorded on Campbell data loggers.

Detailed descriptions for all sites, except Cape Hallett, are provided in Adlam et al. [*2010*].

Table 1. Soil climate station network information.

Site	**Est.***	**Alt* (m)**	**Lat* (°S)**
Cape Hallett	2006	<5	72.3
Granite Harbor	2004	6	77.0
Victoria Valley	1999	408	77.2
Marble Point	1999	55	77.3
Wright Valley	1999	155	77.3
Mt Fleming	2003	1670	77.3
Scott Base	1999	51	77.5
Minna Bluff	2004	28	78.3

*Est. = Date site established, Alt = Site altitude, Lat = Latitude.

Mean annual temperatures

There is marked inter-annual variability in the mean annual air and soil temperatures (Figure 1). The marked variability does not show any obvious increasing or decreasing trend over time.

The air and soil temperatures all show a similar trend– a cool year in 2002 followed by warming in 2003. 2006 was particularly cool, and was followed by a markedly warmer year in 2007. The coolest mean annual air and soil temperatures were recorded in 2008, whilst the warmest mean annual soil temperatures were recorded in 2009.

Mean annual air temperature for complete year datasets ranged from -24.73°C at Mt Fleming in 2008 through to -14.37°C at Cape Hallett in 2010 over the period from 1999 to 2010 (Figure 1a). The warmest mean annual soil temperature at 5-10cm cm depth was -14.14°C at Granite Harbour, and the coolest -24.94°C at Victoria Valley (Figure 1b). The mean annual temperatures recorded at 75 cm - 120 cm depth ranged from -13.66°C at Granite Harbour to -23.79°C at Mt Fleming (Figure 1c).

Maximum recorded air temperature at the climate stations over the recording period from 1999-2010 was +11.88°C at Wright Valley in 2002. The minimum recorded air temperature was -53.21°C at Wright Valley in 2004.

Acknowledgements

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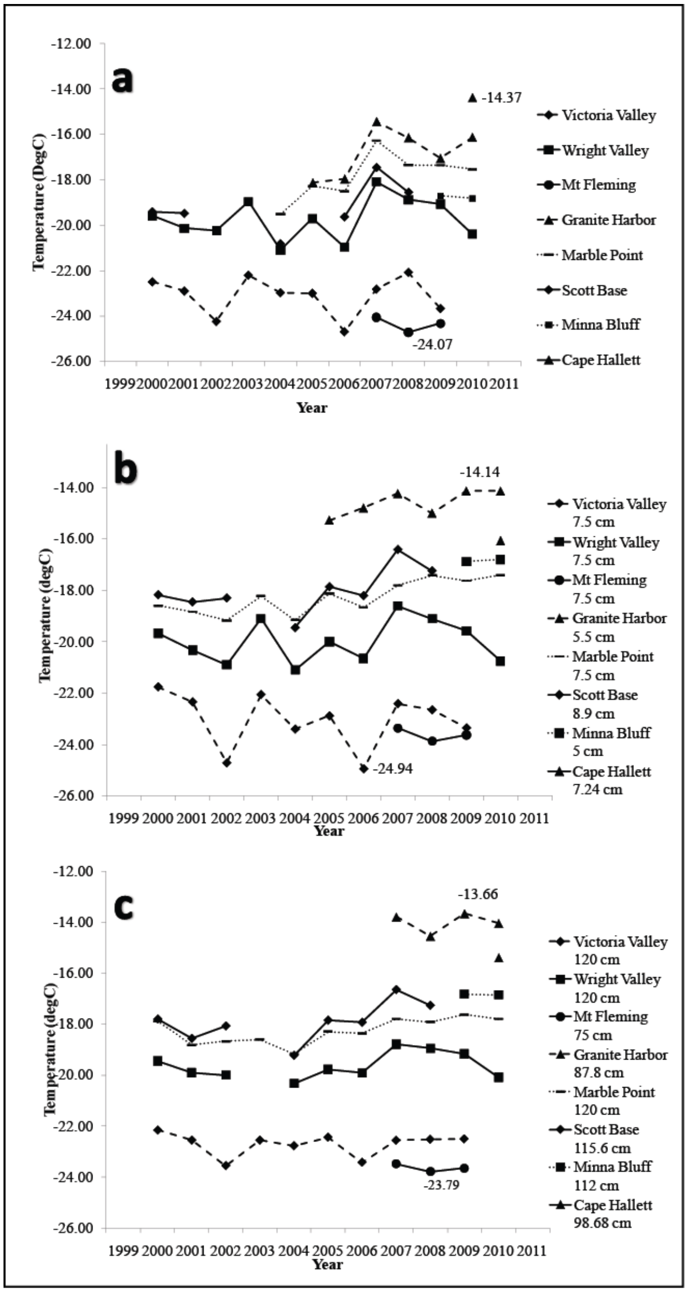

Figure 1. Mean annual temperatures from 1999-2010. a. air temperature. b. 5-10cm soil depth. c. 75-120 cm soil depth.

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Hydrologic and Biogeochemical Responses of Lakes to Fire and Thermokarst Formation in Arctic Alaska

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Introduction

Arctic air temperatures have been observed to rise 0.5-1.5°C in the past 50 years [*Bowden et al., 2008*] and are expected to continue to rise. Warmer temperatures are expected to lead to warmer permafrost, deeper soil thaw depths, and are also likely to increase the occurrence of fire. Both fire and thermokarst can have a substantial local effect on terrestrial and aquatic ecosystems. Fire has a substantial effect on local vegetation, and can cause shifts in species diversity and abundance, including observed increases in shrub density during the decades of post-fire recovery [*Joly et al., 2010*]. Thermokarst formation has been observed to cause increases of up to 2-3 orders of magnitude in total suspended sediment loads to downslope receiving streams [*Bowden et al. 2008*] as well as increases in nutrients. Because Arctic streams are often so nutrient-limited, we ask whether nutrient addition will promote increased stream productivity or whether the large sediment addition will preclude light penetration and utilization of the added nutrients.

Here we discuss the evolution of disturbance impacts over the first 3-5 years following both fire and thermokarst disturbance. We first discuss physical changes observed in permafrost temperature and hillslope flow rates. These changes led to shifts in biogeochemistry in lakes affected by either disturbance, with implications for lake biota. Recovery from both disturbances is non-linear.

Site Description and Methods

A lightning-ignited fire – the Anaktuvuk River Burn – burned over 1000 km^2 of tundra in 2007 on the North Slope of Alaska. A retrogressive thaw slump subsequently formed in 2009 on a burned lakeshore adjacent to Horn Lake (Figure 1). Beginning in the summer of 2010, we measured ground temperatures at hourly intervals at six sites inside and outside the thermokarst in burned regions and compared these to measurements in unburned areas near Lake NE-14 and the Toolik Field Station. We also measured thaw depths at 50-150 sites along transects along the axis of the thaw slump and across its width. In 2009 and 2010, we completed repeat topographic surveys of the retrogressive thaw slump to estimate its headwall retreat rates. Finally, in 2008-2010, we collected water samples during the snowmelt and summer periods from burned and unburned regions as well as areas affected by the thermokarst, and characterized Horn Lake's response to sediment and nutrient loading with depth.

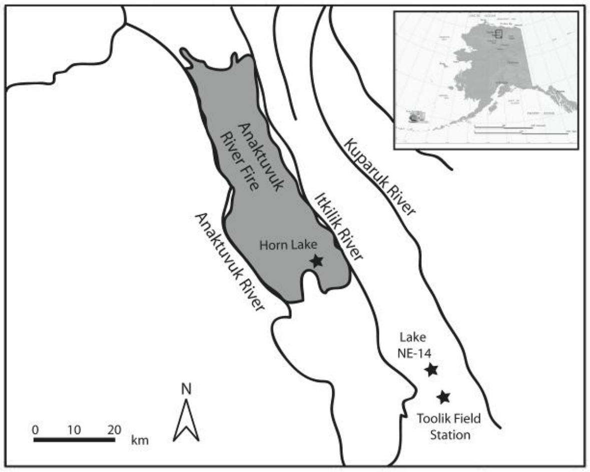

Figure 1. Location of the Anaktuvuk River Burn and the retrogressive thaw slump on Horn Lake that is the focus of this study.

Results and Discussion

Ground temperatures were higher and more variable inside the thermokarst than in the burned area in summer 2010. Ground temperatures were most variable at the surface with a diurnal range of ~20°C within the thermokarst and ~5°C outside of the thermokarst during summer 2010. Variability at 20cm depth dropped to ~3°C inside the thermokarst and to ~1°C outside the thermokarst, and variations damped to <1°C below 20cm depth. These surface temperature trends suggest that the fire no longer influenced the energy balance at the ground surface in 2010. This is consistent with observations that albedo in the burned area recovered to pre-burn status during the 2010 summer [*Rocha & Shaver, 2011*]. Thaw depths were at least 20 cm deeper inside thermokarst features compared to slopes on which no slumps occurred. At mid-summer 2010, at an adjacent location where no fire or thermokarst had affected the hillslope, median thaw depths were 33 cm whereas in the burned area, they were 57 cm. Inside the thermokarst, regardless of whether the area had burned or not, the thaw depths were deeper (78 cm in unburned regions, 84 cm in burned regions). Based on repeat surveys, we estimated headwall retreat rates at the Horn Lake retrogressive thaw slump of ~2cm/day to ~18cm/day in 2009 and 2010. Daily transport rates from the headwall toward the lake varied with mean daily temperature. Based on interpretation of repeat photography, mean daily temperatures of ~15°C led to near-headwall transport rates that increased to over 2.5x the average transport rate.

We found that both fire and thermokarst activity led to increases in nutrient loading. Peak dissolved organic carbon (DOC) concentrations during snowmelt in burned regions were ~2-6x higher than those observed in regions that were not burned (Table 1).

Table 1. Peak DOC concentrations during snowmelt runoff in regions of continuous permafrost in Arctic Alaska

Site	Peak [DOC] (mg C/L)	Source
Dimple*	62	unpublished, C.R. Johnson
Birthday*	52	unpublished, C.R. Johnson
Imnaviat	27	Oswood et al. 1996
Kuparuk	15	Holmes et al. 2008
Colville	11	Holmes et al. 2008
Sagavanirktok	8	Holmes et al. 2008

* First snowmelt following fire.

Thermokarst formation also led to increased nutrient loading, but primarily of particulate matter rather than dissolved matter. Total loading from the Horn Lake retrogressive thaw slump was nearly 2.5x higher for carbon, ~6x higher for nitrogen, and ~3x higher for phosphorus compared to the snowmelt loading for a burned catchment without an active thermokarst. However, in late summer 2010, particulate loading dropped dramatically even though the thermokarst headwall continued to retreat at similar rates to earlier measurements, and dissolved loading increased slightly. We hypothesize that more material was stored in the depositional area within the thaw slump floor instead of being exported to the lake. Lake responses at different depths varied as the form of nutrient loading changed. Carbon concentrations in the lake epilimnion increased slightly as the particulate load decreased and dissolved load increased whereas hypolimnion concentrations decreased as the particulate load decreased.

Conclusions

Both fire and thermokarst can impact tundra and arctic lake ecosystems. Fire adds an initial large pulse of nutrients from the terrestrial to the aquatic system in the first post-fire hydrologic event, and can continue to add elevated nutrients for at least 3 years. The secondary post-fire disturbance of thermokarst formation leads to larger, but less persistent, physical and biogeochemical effects than the initial fire.

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New Technologies for the Recultivation of Disturbed Lands in the Far North

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Abstract

Oil and gas field development works in tundra result in formation of the sites with destroyed vegetation and mobile sandy substratum. Such territories are subject to mandatory recultivation. Recultivation methods used in other natural zones cannot be adapted to local conditions. There is a severe shortage of recultivation methods for disturbed tundra lands. This work presents the results of development of new recultivation technologies ensuring fast restoration of vegetation cover in tundra and forest-tundra conditions.

Keywords: disturbed territories; recultivation; sand; grass mixtures; tundra.

Introduction

During the development of tundra territories, oil and gas industry activities result in formation of sand-desert sites. Exposed sandy substrata appear as a result of disturbance of natural moss-vegetation cover and formation of artificial earthworks. Sand is the main material for construction of drilling sites, sites for crew facilities, stations and other different technological platforms, as well as for commercial roads. In this case, sand quarry development, backfilling of slopes and earth cuts with sand, earth filling works and sand stacking increase the area occupied by exposed sandy substrata.

Speed of revegetation at the barren sites is extremely low. Due to active deflation processes, the unfixed sands begin to drift, which significantly reduces the rate of formation of a natural vegetation cover.

However, all lands disturbed in the process of economic exploitation are subject to mandatory recultivation. There is an objective necessity for conducting works connected with recultivation of anthropogenic sandy substrata. At the same time, the deficit of recultivation methods for disturbed tundra lands becomes obvious already at the design stage. Methods used in other natural zones are not applicable in tundra conditions. Delivery of materials to a work site is very expensive.

The project novelty consists in the creation of a new technology for recultivaion of disturbed lands, with employment of the material that provides plants with moisture and nutrients without using peat and prevents driving seeds out of the soil and development of adverse exogenous processes.

The modern state of the problem and the level of applied technologies

Till the end of the 90s no particular attention was devoted to recultivation of disturbed lands in tundra regions of Western Siberia. In the 2000s the volume of works connected with recultivation and transfer of lands to permanent land users substantially increased. Nevertheless, the growth of disturbed land area noticeably exceeds the rate of its recultivation. This is a consequence of an acute deficit of adequate technological solutions.

Basic measures taken in the course of recultivation traditionally include designing of slopes, anti-landslide and anti-erosion works, formation of a fertile soil layer and planting grasses.

The issue regarding recultivation measures in tundra conditions remains disputable. A special position is occupied by the notion that recultivation works in tundra conditions are low-efficient and that it is reasonable to leave disturbed lands for self-restoration [*Maksimova 1972; Vasilevskaya & Kirilishin 1993*]. In this case, such approach is often prompted by the usage of another extreme method – intensive recultivation with large-scale engineering preparation of the territory and insertion of large doses of organic substances and fertilizers. As a rule, such activities are planned without any preliminary investigations in conditions of extreme shortage of data. The planned works include various activities based on the off-chance that some of them might work and, therefore, are realized with much effort and do not produce the desired result. The cost of such complex of works turns out to be unreasonably high.

Thus, when selecting and developing recultivation methods, the following principles should be adhered to:

- taking due account of a complex of nature-related data about the disturbed site and the surrounding landscape;
- the use of minimum required and sufficient volume of fertilizers and structure formers;
- the use of only technical solutions that are efficient in the Far North conditions;

Special emphasis is placed on the development of a new technology of restoring sandy substrata without application of a fertile soil layer, i.e. without use of peat, as peat reserves in the Far North are very limited. Additionally, the transfer of a thin peat layer to the sand substratum causes disturbances of water- and temperature-related properties of the surface, which results in the evolvement of permafrost degradation.

Nowadays, several groups of methods specifically developed for the Far North conditions can be distinguished. The first group comprises methods based on insertion of a significant amount of grass mixtures (including those with complicated phytocoenotic structure) and significant volumes of fertilizers. Their efficiency is impaired because of the absence of activities for improvement of mobile grounds.

The second group of methods provides for formation of a protective layer composed of materials of rather large fractions (debris, crushed stone and slag). But the shipment of these materials to tundra in large quantities is connected with high expenses.

The third group of methods is connected with the use of liquid polymeric compositions or waste bentonite compounds for consolidation of the upper layer of mobile grounds. Such coating form a firm, slightly water-permeable crust that creates unfavorable conditions for vegetation growth. Some of such methods represent just trivial spreading of drill mud and cuttings over the tundra.

The fourth group of methods is based on the use of geosynthetic materials, gabions and network structures. The main drawback of such methods is the high price of materials and of their delivery.

Thus, the developed technology must solve two problems at the same time: the reduction of mobility of sandy grounds and the increase in their fertility. Particular importance is attached to the economic efficiency of the proposed solutions.

The Ecopolymer technology

In the course of studies relating to the restoration of disturbed lands, the specialists of the Technology Park of Tyumen State University developed a new technology for recultivation of disturbed tundra lands. The technology ensures consolidation of mobile sandy grounds, increase in fertility and creation of sustainable vegetation cover.

A fundamentally new recultivation mixture "Ecopolymer" was developed. The new recultivation mixture includes polymeric granules with seeds attached to them. The granules are saturated with water containing dissolved fertilizers, then these granules are applied to the recultivated surface covered by sand and are mixed with this sand by a tiller. Moisture and fertilizers contained in the granules are used by plant seeds and ensure their stable sprouting and rooting. The recultivation grass mixture includes all types of plants of arctic grass mixtures.

This technology ensures stabilization of mobile grounds without formation of solid surface crusts. A comparatively small quantity of fertilizers is used. These fertilizers are bound in a form accessible for plants and are not driven out by natural waters into the environment. There is no necessity to use expensive geosynthetic materials in sheets or rolls.

All materials used in the Ecopolymer technology are fully safe for the environment.

Application of the new technology of the disturbed land recultivation will make it possible to significantly reduce the costs of works and the labor input as well as to increase the efficiency of such works.

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Influence of Interannual Variability and Trend Changes in Snow Cover’s Structure and Properties on the Thermal Regime of the Underlying Surface

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Contribution of snow cover into thermal interaction between the atmosphere and the lithosphere is determined by its radiative and heat-transfer properties, first of all by heat conductivity of snow that, in turn, depends on its density, structure, and thermal regime. Thickness, structure and properties of snow change with space (regional and local changes) and time (trend and interannual changes in climate conditions, seasonal changes in the process of snow accumulation and metamorphism). These changes in the snow cover's structure, properties and duration affect the heat exchange conditions and cause the corresponding variations in the depth of seasonal freezing of underlying soils and in duration of their frozen state.

Perennial changes of temperature, winter precipitation and thickness of snow cover are accompanied by their interannual (quasi-two-year) variations that are higher than that of trend variations for more than an order of magnitude. In all climatic zones of Russia, correlations between the interannual variation modules of winter values of air temperature, precipitation and snow cover thickness to the corresponding values of trend changes have the similar order of magnitude. This allows to consider (with certain corrections, of course) the interannual anomalies in seasonal snow cover’s characteristics as a certain prototype of its response to possible perennial climate changes.

Performance of the regional assessment of the heat and mass exchange of the underlying surface with snow cover and atmosphere will require the data on the snow cover properties and structure (stratigraphy), as well as their possible interannual and spatial variations. These characteristics can be assessed based on the parameters determining water content and average density of the snow layer, possible runoff of melt water generated during thaws, presence of layers and crusts of various geneses (total amount of solid precipitation, snow cover thickness, frequency and duration of snowfalls, thaws, wind and radiation impacts). These parameters, in turn, may be obtained by means of standard meteorological data analysis.

The maps were created showing climate conditions, snow cover thicknesses and their anomalies compared to average perennial values and demonstrating their peculiar changes within the territory of Russia in winter periods of late 20th – early 21st centuries. The identified characteristics include: 1) correlation between changes of temperature and winter precipitation; 2) dependence of snow cover's thickness and density from winter precipitation and temperature.

Simulation of the regional structure and average density of snow cover on the territory of the Russian Federation was based on the maps showing average winter temperature, winter precipitation and frequency of meteorological events: snowfalls, thaws, winds with velocity more than 10 m/s, and surges (exceeding 10ºC) of air temperature in the negative-value area. During map building, we took into consideration the snowfalls with daily intensity more than 0.01 g/sq.cm and thaws with air temperatures rising over 0ºC for more than one day. Model sections are based only on meteorological phenomena that took place during formation of snow cover and do not reflect the timing of events or possible spatial variations of its accumulation on the meso- and micro-levels. Verification of the sectional simulation results performed based on the field observations and published sources showed that, in spite of the schematic nature of model sections, they are identical to actual ones in principle and can be used to identify interannual variations of the snow cover’s structure.

Characteristics of winter climate conditions, model sections and identified relations, correlations and dependencies help to estimate average density, heat capacity and heat conductivity of snow cover, as well as its average winter thermal gradient. As a result, it is possible to calculate (re-construct) the heat flow from snow cover and underlying soil to the atmosphere and, if the data on moisture content and thermophysical properties of soil are available, to calculate possible depth of freezing and its interannual variations determined by snow cover.

Calculations for three climatic zones of Russia located near the Polar circle were carried out for the coldest and warmest seasons of the 21st century based on the proposed freezing depth calculating algorithm and program. The obtained results correspond with the field observation data for relevant regions.

The Landscape-Permafrost Conditions and the Cryogenic Processes at the 5th Salekhard Marine Terrace

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Abstract

This work is based on the field routes laid in the north of Western Siberia in the summer of 2009. The main part of the routes was laid upon the 5th Salekhard marine watershed terrace with the absolute heights from 70 to 90 m. The terrace deposits were formed during a cold sea transgression at the end of the Middle Pleistocene (Baulin et al. 1989). Later, they were exposed to different types of processing: with alluvial, eolian, erosion, cryogenic and soil-forming processes. On the territory of the Yubileynoe Field there were conducted landscape-permafrost studies at the 5th Salekhard terrace in the area of Lake Nashe-to and Lake Klene-to, at the frost heaves and in the valleys of the Khalmer-Yakhi and the Sedi-Yakha Rivers.

Keywords: cryogenic processes; landscape-permafrost conditions; 5th Salekhard terrace.

Introduction

The main geographical complexes within the watershed surface were studied; they are confined to three main types of meso-relief [*Baulin et al. 1989*]:

a) inter-hasyrey areas – watersheds between basins, small rivers and gullies;

b) lacustrine-hasyrey type of locality;

в) valleys of the small modern rivers.

Methods

The research at site 1.1 can be used as an illustration of the landscape-permafrost particularities (Fig. 1)

Low-angle wavy, slightly inclined (not more than 1-3° northward), mound-shaped, relatively drained tundra with spot-medallions at some places; the average mound height is 30 cm. The mounds are slightly stretched along the slope. The length is 143, 126 and 189; the width is 125 and 230.

The grounds are thixotropic. Many trees are deformed (wind and snow).

Figure 1. Larch sparse stands on the relatively drained surfaces (photo by V.V. Rogov, 2009).

The vegetation was represented with the following types: the tree layer – *Larix sibirica*; the low shrub layer: *Vaccinium vitis, Empetrum nigrum, Vaccinium uliginosum*;

the herb layer: Carex; mosses – *Sphagnum balticum*; lichens – *Cetraria islandica*.

By July 5, 2009, the average depth of the seasonally thawed layer was: 77 cm between the mounds and 90 cm on the mounds.

Test pit 1.1 was dug out and described at this site:

0-2 cm – the depth of the tow layer.

2-16 cm – the depth of TH, slightly decayed dark-brown peat intertwined with plant roots.

16-27 cm – the depth of BF, light-brown dusty sand with ferruginized spots; a border between medium and coarse grains is distinctively colored.

27-70 cm – the depth of BC, wet sand with manganese adhesions; stratification and plant root inclusions are observed.

We also noted the boundary of the permafrost transition into the talik. This is the area of initial formation of a seasonal thawed layer at the beginning of the winter. At the bottom of the hasyrey covered with sedge-moss vegetation (from where snow is blown out), ground freezing occurs faster and, at the same time, the permafrost shifts upwards; there is no permafrost within the sparse stands but in the upper horizon there is an active water filtration (which is confirmed by the presence of *Salix pulchra* and *Salix lanata*). The water encounters an impervious wall on its way (permafrost at the beginning of the hasyrey) and then embosses it with a heaving of a liquefied mass. There were formed linear heaving cracks filled with a fresh thawing ground during the observing period (the beginning of July).

At site 1.2 located within the territory of a large hasyrey we registered a lacustrine-hasyrey landscape. At the south-western end of Lake Klene-To. This lake of a thermokarst origin basically has a regular round shape. Certain banks, especially in the southern and south-eastern part, are exposed to thermal abrasion. This process occurs most intensively at the areas where heaved peatlands are underwashed. At the description site, the bank is represented with mound-shaped heaved peatlands; the elevation above the water boundary makes up 1 m. There are separate frost cracks at the peatland surface. Peat blocks sliding into the lake and fragments of the cliff cracks are observed in the direction parallel to the lake. The height of mounds was 30 cm and the subsidence depth reached 25 cm. The width of the typical frost crack was 30 cm and its depth was 50 cm by July 13, 2009. The crack became covered with moss and cloudberries. The average thawing depth was 25 cm between the mounds, while on the mounds it made up 40 cm. Along the crack it was 30 cm. Test pit 1.1 was dug out:

0-2 cm - the depth of O, the tow layer.

2-25 cm - the depth of TO, sphagnous lichen peat of different decay degrees.

The vegetation was represented with the following types: the low shrub layer: *Vaccinium vitis, Vaccinium uliginosum, Empetrum nigrum, Betula nana*; the herb layer: *Carex*; mosses - *Sphagnum balticum*.

Anthropogenic disturbance at the examined area exerted a great impact on the geographical complex. It can be easily observed in the changes in the vegetation cover of some areas. For example, construction of the underground pipeline with ground backfilling led to the transformation of the hummocky bogged sedge-moss tundra typical of this area into the bogged surface covered with *Eriophorum vaginatum* (www.planetadisser.com). It is characteristic that there were formed linearly stretched lakes and strips of excessive bogginess along the underground pipeline. The processes of erosion, wind impact, uneven freezing (ground heaving) and of thawing (subsidence) are active here.

The 5th Salekhard marine terrace is characterized with a great variety of the landscape-permafrost conditions on the territory of field routes. Here we encountered open taliks (within a larch sparse stand), typical northern tundras (Lake Nashe-to - an area of the burnt-out tundra) and the lacustrine-hasyrey locality type that is rather typical of this natural zone.

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Ice-Wedge Polygons in Central Asian Highlands. A Geographic Synopsis

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Ice-wedge polygons have been studied mainly in high-latitude plainlands but remain poorly explored in the highlands, especially in southern areas. With the advent of *Google Earth*, it became possible to compile a geographic synthesis of these structures in the mountains of Central Asia. Some data have been collected in the course of field studies by the author and his colleagues.

Tien-Shan Mountains

A special variety of polygonal pattern was discovered in the *Turgen' River catchment, Zaili Alatau* (43º11´ N, 77º01´ E, 2600 – 2950 m asl). The polygons are from 2 to 10 m across and occur within flat interfluves (*plakors*) and low-angle slopes composed of Neogene clay. Soil wedges penetrate as deep as 118 cm along cracks while relict cracks may reach 145 cm. According to their ages, the wedges were formed in two events of 4500 and 2500 yr BP. Currently there is no permafrost in the area, the mean annual air temperatures at these elevations are from 0 to minus 1.6ºC.

Polygons near *Kol-Almaty pass, Zaili Alatau* (42º59´ N and 77º01´ E, 3400 m asl), under 8 m wide, occur in permafrost which lies about 1.5 m below the ground surface, and consist of wedges penetrating no deeper than 1 m [*Gorbunov et al., 1996*].

In the eastern and southern sides of *Lake Chatyrkul* (40º42´ N and 75º25´ E, 3500 m asl), polygons are 8-10 m wide active tetragons. Cracks reach permafrost at a depth of 0.9 m and continue into it for 30 cm deep as a family of thin (about 1 mm) ice veins. Similar active tetragons, but as large as 40 m, were found in the deposits of Lake Dod-Nuur in the Darkhat basin in Mongolia [*Gorbunov, 1991*].

Several polygons were detected in satellite images from the *Jonggar Alatau* (44º44´ N and 79º32´ E, elevations about 2700 m asl) and *Ketmen* (43º14´ N and 79º56´ E, ~3000 m asl) but have not been studied in the field yet.

East Pamirs

The *Lake Kukjigot* watershed (37º28´ N and 74º00´ E, 4290 m asl) is cut by polygons, from 5 to 20 m wide, more often 10 m.

Polygons are often reported from China, from *Tibet and Kunlun* [*Tun Boliang & Li Shude, 1998*], but the published evidence is insufficient to judge about their geography. According to satellite imagery, active polygons are widespread above 4600 m asl in the north and above 5500 m in the south of the area. There are at least ten large polygons that cover 2-3 km^2 to tens of square kilometers, each from 5 to 30 m across, most often 10 m. The mean annual air temperatures in the places of polygonal ground are minus 5 - 6ºC.

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Permafrost as a Habitat for Microorganisms

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The existence of relict biological objectswith unusually long lifespan was and still is the topic of lively scientific and pseudoscientific disputes. Recently, this debate has become particularly acute in connection with the possibility of sequencing a genome and genetic manipulations with the remnants of ancient DNA, such as the study of DNA from the hair samples of prehistoric man, who presumably lived in Yakutia four thousand years ago, or genome sequencing in the remnants of cyanobacteria found in the crystals of limestone about six million years old. The study of different permafrost ground samples of northeastern Siberia and Alaska formed in the interval from 20 thousand to 3 million years ago made it possible to identify dozens of species of microorganisms that can survive in permafrost. As expected, these microorganisms were mainly oligotrophic, i.e. characterized by low level of metabolism and the ability to survive in the habitats that are extremely poor in nutrients. The number of species and the geographical distribution of the studied microorganisms is rapidly growing. In recent years, an interest in permafrost ecosystems in relation to global warming and the possible release of large amounts of different gases by thawed grounds, primarily methane and CO_2, is increasing. Of particular interest is the mechanism that ensures phenomenal life time of these microorganisms.

On the one hand, a number of publications by authors who claim that they were able to identify new species' cultures of relic organisms or DNA is rapidly growing. Moreover, such papers come from very reputable institutions. Unfortunately, they are often poorly grounded, as, for example, a claim that a 250 million year old bacteria was identified in the salt crystals of rocks. It was emphasized that the most stringent measures to ensure the sterility of the samples were taken (the probability of contamination was less than 10-9). Another paper of the same kind demonstrates that using a combination of laser technology, plasma mass spectrometry and PCR makes it possible to detect amplicons of bacterial 16S ribosomal DNA of up to 425 million years of age. Naturally, it is difficult to accept the idea of the possibility of the existence of living systems, or even DNA, during such long periods of time. It is known that DNA without an active repair process must have much shorter periods of maintaining its functional integrity due to a variety of spontaneous (chemical) and fermentation disorders, primarily of the thermal, the hydrolytic, and the oxidative nature. Relic microorganisms that preserved their viability for hundreds of thousands and perhaps millions of years are often found in places where DNA replication and let alone cell division seem impossible – namely, in salt crystals extracted from ground, amber, permafrost, or ice.

Permafrost especially stands out among these systems, and not only due to its wide distribution. In is known that in Russia, for example, about 65% of the territory is occupied by permafrost. Permafrost is a unique ecosystem that provides isolation and preservation of relic microorganisms at relatively moderate and stable negative temperatures (often around -2...-5°C). Moreover, in such circumstances DNA repair and replication and even the division and growth of at least some types of microorganisms cannot be excluded. For example, a comparative evaluation of the organisms that exist in ordinary grounds, in permafrost and in massive ice formations of high latitudes of Canadian segment of the Arctic showed that permafrost is characterized by a great variety of species that maintain microbial activity at temperatures down to -15°C. About a half of the isolates from Siberian permafrost maintained a certain level of metabolism at a temperature of –10°C, but with no signs of growth. The overview of rapidly growing research leaves no doubt as to the uniqueness of the ecology and protective features of permafrost microorganisms.

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Fundamentals of the Method for Determination of Thermophysical Properties of Soils

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Abstract

Issues reviewed are the basics of methods for determining thermophysical properties of soils with the help of an instrumental and methodological complex based on the methods for the optical scanning and linear source that were used in the field of engineering geology for the first time. Methods for a prognostic assessment of the thermophysical properties according to the composition, the state and the physical properties of ground on the basis of a multiple correlation analysis are examined as well. The regression equations obtained are presented.

Keywords: soils; correlation analysis; modeling; volumetric heat capacity; thermal conductivity; physical properties.

Investigations of the thermophysical properties of frozen and thawed grounds used as foundation grounds of buildings and facilities is an important task in studying of the heat transfer processes in the foundation-ground system that define the conditions for construction and operation of the engineering facilities.

The main problem today is the measurement of parameters of the thermophysical properties of soils with the given accuracy.

Thermophysical ground properties in the course of geotechnical site investigations are at present determined according to the SNiP table 2.02.04-88 (bases and foundations on permafrost) but the parameters determined cannot be sufficiently reliable and accurate because there is no information on determination methods and reference to the regions as well as no regard to the genetic particularities and age of the ground or to the conditions of occurrence.

For this reason, one of the acute problems is the improvement of quality of experimental thermophysical ground research by laboratory methods with the possibility of determining the other indicators of composition, state and physical properties in the same samples.

Another important issue is the development of engineering theoretical models for ground thermal regimes of the bases and foundations, creation of approaches to the prognosis of thermophysical ground properties according to the determined indicators of composition, state and physical properties.

Today there is a huge variety of methods and means of determining thermal properties of different natural and industrial materials but all of them have certain significant disadvantages. At the same time, the problem in the field of engineering geology becomes more complex because grounds are characterized by the significant non-uniformity and some of them are in the unbound state.

The experimental comparison of the possibilities of various modern devices for measuring of thermal properties of grounds revealed that the most effective method for the geotechnical site investigations is the application of the following system: 1) the method and the device for the optical scanning developed in RSGPU and exceeding all other analogous devices in Russia and abroad in its characteristics; 2) the linear source method for the measuring of thermal properties on friable samples. Particularities of the indicated methods and devices allow to determine not only thermal properties of specimens but also other physical properties (density, moisture content, particle size distribution, plasticity characteristics, etc).

Knowledge of the dependences of thermophysical properties of foundation grounds on other physical characteristics offers new possibilities in determining thermal conductivity and volumetric heat capacity during geotechnical site investigations.

The main object of the research on thermophysical properties was more than 300 specimens of soils of Moscow region that were selected at different facilities in the process of geotechnical site investigations.

Another particularity of the study was a development of methods of application of the unique geothermal equipment that measures the thermal properties of rocks in the drill core for determining thermophysical properties of grounds for geotechnical purposes. The methods developed served as a base for the comprehensive experimental studies of the thermophysical properties of Moscow region grounds. The results obtained were processed and analyzed. There were constructed diagrams and nomograms of a dependence of thermophysical properties on the indicators of composition, state and physical properties. The estimated constraint equations were obtained.

A commercial simulator (Comsol Multiphysics) helped to design models of a thermal regime of foundation grounds of the engineering facilities.

The main scientific and practical conclusions and results obtained in the study are:

1. It was shown that at present the only reliable source of data on the thermophysical properties of grounds is the laboratory specimen measurements.
2. In terms of determining thermophysical properties of soils, the system with the best characteristics is an instrumental and methodological complex based on the methods and devices of optical scanning and linear source.
3. It was demonstrated that detailed experimental studies of the thermophysical ground properties by the optical scanning method allow to compose spatial images of the distribution of heat and thermal conductivity, volumetric heat capacity and thermal inertia throughout the area of a specimen studied.
4. There was developed an original methodology of study of the thermophysical properties of soils with an instrumental and methodological complex based on the methods of optical scanning and linear source that were used in resolving of geotechnical problems for the first time.

5. The developed methods of the thermophysical measurements became a basis for mass experimental studies of the thermophysical properties and indicators of composition, state and physical properties of Moscow region soils.

6. The representative database of the thermophysical properties and indicators of composition, state and physical properties of Moscow region soils was created.

7. The correlation and regression analysis of the interconnection between thermophysical properties and indicators of composition, state and physical properties of soils produced mathematical equations of their interrelation.

8. The optimal mathematical constraint equations for the soils studied are the equations of the following structural form:

surface clayey slits - $C\rho = f(Sr)$, $\lambda = f(Ln(Sr))$;
lacustrine-glacial clayey slits - $C\rho = f(Sr)$,
$\lambda = f(Ln(Sr), \rho, W_p)$;
moraine clayey slits - $C\rho = f(Sr)$, $\lambda = f(Ln(Sr))$;
all clayey grounds - $C\rho = f(Sr)$,
$\lambda = f(Ln(Sr), \rho, W_p)$;

where $C\rho$ – volumetric heat capacity, $J/(m^3 \cdot K)$; λ – thermal conductivity, $W/(m \cdot K)$; Sr – moisture content degree, u.f.; ρ - density, g/cm^3; ρ_d - dry ground density, g/cm^3; W_p - moisture content at the plasticity boundary, u.f.

9. According to the purposes of the study, verification of adequacy of the obtained mathematical models proved their effectiveness as the correlation coefficients are significantly high.

10. The correlation and regression analysis established a possibility of the prognostic assessment of thermal conductivity and volumetric heat capacity according to the indicators of composition, state and physical properties of different varieties of soils.

11. The researchers developed numerical and visualized models of prognosis and calculation of the thermal regime in ground mass and foundation that allow to determine the temperature in a foundation-ground system on the basis of the detailed experimental data on thermophysical properties of the grounds and construction materials.

12. It was revealed that the results of a prognosis for ground mass temperature significantly depend on the possible error in the determination of thermophysical properties of grounds and construction materials of the engineering facilities.

13. Mathematical modeling resulted in describing the processes related to freezing and thawing, in finding the ways to localize these processes and in giving recommendations on reducing the negative consequences during the engineering facilities operation.

The direction of further scientific and practical studies is connected with widening the database on other genetic types and varieties of grounds as well as with adaptation of the instrumental and methodological complex for determining thermophysical properties of frozen grounds, which is especially important in connection with the development of new territories and construction of the engineering facilities under complex climate conditions.

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Experimental Study of Water Saturation Influence on the Cryogenic Pressure in Saline Soils

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Introduction

Until now, thermodynamics of cryogenic pressure formation during saline soils freezing has not been studied. This project aims to carry out systematic experimental laboratory study of thermodynamic conditions of cryogenic pressure formation in saline soils in dependence with their moisture content during freezing of these soils according to the closed scheme of tests.

As a result of previous tests with non-saline soils, we found that cryogenic pressure values in non-saline soils differ substantially from the theoretically calculated thermodynamic value of 13.3 MPa/deg (133 atm/deg) – the pressure of distilled water freezing in the closed non-deformed volume [*Ershov et al. 2009, Grechishchev et al. 2006, Grechishchev et al., in press*].

Research Technique

Laboratory tests included creation of samples with given salinity and moisture content and their directional upward freezing in a refrigeration chamber in two types of specially developed dynamometer devices. The first one, installed into the relaxometer, provided tightness, side heat insulation, heating of the bottom and cryogenic pressure measurement. In addition, sample heaving deformation was measured independently. The second device for water-saturated soils is designed for larger-sized samples and is used without the relaxometer.

The studies were carried out for two types of soils: clayey silt and sandy silt, with initial salinity 0.21% and 0.24%, correspondingly. Hydrophysical properties and particle size distribution were identified for the soil in question. Phase moisture composition and initial freezing point [*Motenko 1997, Grechishchev et al. 2007*] are also important for saline soils. These parameters were identified as well. Soil samples were taken in Yamalo-Nenets Autonomous District. The clayey silt sample was taken on the Bovanenkovo landfill, the sandy silt sample was taken on the Zapolyarnoye oil, gas and condensate field. The given salinity value was achieved by adding the calculated amount of NaCl relative to the dry soil weight with its dissolving in the required volume of distilled water in order to create the given moisture content in the sample [*Grechishchev et al. 2007*]. Salinity values, which were lower than initial (natural) salinity, were achieved by means of washing of the samples in distilled water; precipitation was accelerated by centrifugation. The frozen sample was used only once. Moisture content of soil samples in the initial state varied from 0.75 u.f. (unit fraction) to 1 u.f. Soil samples were previously compacted under pressure 0.024 – 0.05 – 0.1 – 0.2 MPa during two days in the sample frame of the developed device. Tests were carried out according to the closed and open schemes and under ambient temperatures (of the sample top) – -2; -4; -7, and -10°C; temperature of the sample bottom in all tests was maintained at the level of +2…+4°C for the first device and +1…+1.5°C for the second device. The duration of the soil tests was 2-5 days. Freezing was followed by the study of distribution of frame density, moisture content and moisture saturation in soil samples. Total number of tests was 56. Tests on directional soil freezing with incomplete moisture saturation on the first device with the sample volume ~37 cub. cm were carried out using dynamometer DOSM-3 for 3 tons; dynamometer DOSM-3 for 1 ton was used in the second device with sample volume 0.5 cub. dm. Dependency of cryogenic pressure on the moisture saturation factor of initial samples within the range from 0.8 u.f. to 1.0 u.f. with initial moisture content of the samples – 0.3 – 0.35 u.f. was studied using the first device.

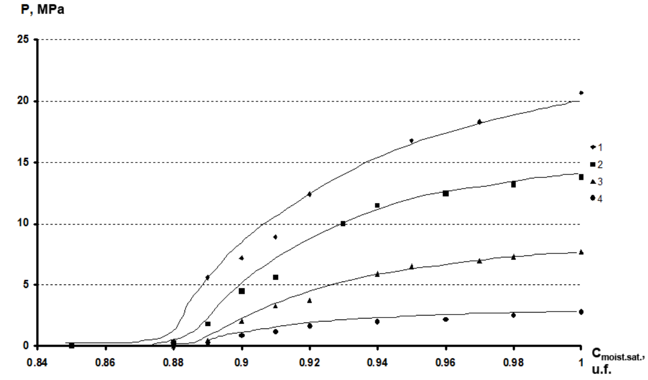
Total number of tests was 37, including 19 tests for clayey silt and 19 tests for sandy silt with different degree of salinity. Duration of the soil tests was from 2 to 5 days. After freezing, the soil sample was split in order to study the distribution of frame density, moisture content and moisture saturation of samples. Individual tests studied vertical salinity distribution in the sample after its freezing. Tests were carried out under ambient temperature (sample top) -7°C and sample bottom's temperature +2…+4°C.

Test Results

The obtained dependencies of the vertical cryogen pressure component from the saline soil moisture saturation (for sandy silt and clayey silt) are shown in Figure 1. The registered cryogenic pressure in the freezing clayey silt was something higher than in the sandy silt. This can be explained by the larger volume of the silty clay fraction in the particle size distribution. While the moisture saturation of saline soils decreases from 1 u.f. to 0.9 u.f., the cryogenic pressure formed during freezing of samples decreases flatly. Then, when moisture saturation falls below 0.9 u.f., pressure decreases sharply and, with moisture saturation coefficient that is equal to or lower than (0.86-0.88) u.f., becomes zero equal. The maximal cryogenic pressure value was reached after 0.5 days from the beginning of freezing. Increased duration of the saline soil freezing was accompanied by certain drop of the pressure value: it reached average 2-3% per day in the first five days, then the decrease almost ceased. The zone of thin-layer cryogenic structure up to 1 cm thick was formed above the boundary surface of frozen and melt sections of the saline soil samples.

Freezing of the soil with moisture saturation coefficient from 1 u.f. to 0.9 u.f. and salinity (0.21-0.24)% was accompanied by substantial increase in volume moisture content in the frozen part of samples in the zone 1.5 to 2 cm thick above the boundary surface of frozen and melt sections and proportional decrease in volume moisture content in the melt part. Soil salinity in this zone of the frozen sample remained approximately equal to or insignificantly higher than the initial value. Decrease of volume moisture content in the melt part could reach 30%. Simultaneous decrease in salinity did not exceed 10% of the initial value.

Freezing of the moisture-saturated soil with salinity 1% was accompanied by minor increase in volume moisture content in the frozen part of samples in the zone 1.5 to 2 cm thick above the boundary surface of frozen and melt sections. Vertical distribution of moisture content values was uniform.



(i)

Figure 1. Dependencies of vertical cryogenic pressure component from the saline soil moisture saturation coefficient: 1 – Yamal clayey silt, salinity – 0.21%; 2 0 Urengoy sandy silt, salinity – 0.24%; 3 – Yamal clayey silt, salinity – 1%; 4 0 Urengoy sandy silt, salinity – 1%.

During directional freezing of soil samples with initial moisture saturation coefficient less than 0.92 u.f. the values of the normal component of cryogenic pressure decrease sharply (according to hyperbolic law) and equal zero at moisture saturation coefficient 0.86-0.88 u.f. and less.

Conclusions

In the conditions of a gradient temperature field, lack of moisture saturation and the closed nature of the environment the soil freezing is characterized by the following parameters:

cryogenic pressure in the saline (moisture saturated and non-saturated) soil subjected to freezing under the closed test scheme formed in proportion to ambient temperature and initial volume moisture content of the soil;

cryogenic pressures occurring in saline moisture-saturated soils with moisture saturation coefficient more than 0.9 u.f. (with salinity level up to 0.24%) are rather high and can exceed 5-8 MPa; however, they do not reach the limit thermodynamic values;

freezing of fine-grained non-saturated soil with moisture saturation coefficient less than 0.9 u.f. and salinity more than 1% is accompanied by sharp cryogenic pressure drop; pressure values do not exceed 1-2 MPa at moisture saturation equaling 0.9 u.f.;

under the increase of the salinity of fine-grained moisture-saturated soil, the boundary value of the moisture saturation coefficient that determines the starting point of cryogenic pressure formation during soil freezing increases to 0.9 u.f. (at salinity 1%, the point where cryogenic pressure may be registered is 0.88 u.f.).

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Geocryological Conditions at the Yurubcheno-Tokhomskoe Field. Geotechnical Monitoring at the Site of an Oil Treatment Unit.

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Abstract

This study examines the particularities of geocryological conditions at the Yurubcheno-Tokhomskoe Field. It is determined that considering grounds as foundations in the thawed state does not fully allow us to take all the parameters of geological environment into account. Recommendations are given on geotechnical monitoring of the state of a geological environment.

Keywords: construction principle; geocryological conditions; geotechnical monitoring; permafrost.

Introduction

According to various data, permafrost occupies approximately 25% of all the dry land of Russia and approximately 75% of all the Russian territory [*Geocryology of the USSR. Central Siberia 1989*]. The relevant problem in this relation is the assimilation and development of oil and gas fields in the area of permafrost spread.

The purpose of the study: to examine particularities of geocryological conditions at the Yurubcheno-Tokhomskoe Field on the basis of the conducted investigations in relation to further project solutions.

Tasks:

- to generalize the investigation results (from 2008 to 2011);
- to characterize geocryological conditions of the field on the basis of the investigations conducted;
- to give recommendations on the selection of a principle of the development of geological environment;
- to substantiate further monitoring of a geological environment after thawing.

The main points

Geotechnical site investigations at the Yurubcheno-Tokhomskoe Field were conducted in 2008 by TomskNIPIneft VNK OJSC at the feasibility (project) stage for the project "Comprehensive development of the first-stage site at the Yurubcheno-Tokhomskoe Field with the external oil transportation. Construction of a system for collecting oil and gas. Construction of industrial site Yur-5. Complex utilization of the associated gas into the formation". Then, the investigations were conducted at the stage of working documentation.

Selection of a construction principle as well as the specific character of the permafrost zone development and determination of the engineering and geocryological conditions for further project solutions are generally related to the particularities of engineering and geocryological conditions determined by the properties of frozen and thawing grounds, the development of permafrost-geological processes, freezing of the groundwater horizons and by active dynamics of all the geocryological characteristics linked mainly with the temporal variability of the temperature field of grounds. According to what was stated above, all the studies at the Yurubcheno-Tokhomskoe Field were aimed at determining the local geocryological conditions. The investigations results revealed some of their particularities.

Engineering and geological conditions at the Yurubcheno-Tokhomskoe Field area are generally assessed as complex. The researchers discovered here the whole range of signs of the unfavorable engineering and geological processes typical of the areas with permafrost development: swamping, icing, heaving, thermokarst, thermal erosion, solifluction and landslides.

The identified engineering and geological elements are extremely inconsistent in their stretch and their section. Coarse material inclusions contribute to the heterogeneity of the structure of ground masses.

The general preliminary prognosis for this area is the following: at present, the permafrost of this region has a trend to degradation, and further anthropogenic impact during the construction of field facilities will lead to even more rapid acceleration of the permafrost thawing processes.

After the engineering investigations, due to the discontinuous permafrost spread, high permafrost temperature and its unstable thermodynamic state, it was recommended to use grounds as the foundation for design and construction works according to the 2nd principle – in the thawed state. It was also recommended to use the pile type of the facility foundations for the construction.

Due to a certain complexity of geocryological conditions, the impossibility of reliable consideration of all the parameters of the engineering and geological environment, the impossibility of offering a valid prognosis of its development as well as due to the general insufficient degree of the performed study of the territory, it is planned to organize and conduct a geotechnical monitoring at the Yurubcheno-Tokhomskoe Field.

A geotechnical monitoring program was developed for the site of an oil treatment unit at Yur-5.

The geotechnical monitoring system consists of an organizational structure, the facilities under control, a network for regime observations, means and methods of measurement, processing, analysis, transfer and storage of data, and a team of qualified experts.

The geotechnical monitoring system is implemented at three stages:

- control over the parameters characterizing the state of engineering facilities and development of negative processes;
- geotechnical prognosis;

- control over the geotechnical monitoring state.

The tight deadlines of construction cause a need to conduct a pre-construction thawing of permafrost at the sites of Yur-5 to accelerate the process of soil settlement at the foundations of construction sites during a transition of soil from the frozen state into the thawed one.

At the operation stage of the geotechnical monitoring system, the following types of works are conducted:

- thermometric observations in wells;
- hydrogeological observations in wells;
- leveling of ground benchmarks;
- horizontal and vertical positioning of deformation marks;
- leveling of ground marks network;
- visual observations;
- calculation of the stressed state of elements of engineering constructions;
- geotechnical prognosis;
- assessment of the general state of natural-technical systems;
- development of recommendations on elimination of destructive processes.

Geotechnical monitoring network at the site of the oil treatment unit consists of:

- thermometric wells;
- ground benchmarks;
- surface ground marks;
- internal ground marks;
- deformation marks.

The result of the completion of construction stage is:

- a developed geotechnical monitoring network;
- regime data on the parameters of a geotechnical system and their compliance with the norms of the state;
- a database on the temperature observations during the works;
- data on the soil settlements according to the surface and internal marks;
- results of the laboratory studies on the physical properties of thawed grounds.

The result of the completion of separate types of work during the geotechnical monitoring is the information on the current and prognostic values of parameters characterizing the state of a geotechnical system and of engineering facilities.

Information is collected, stored and transferred in the form of the corresponding electronic databases or complex text and graphic documents reflecting the state and reliability of geotechnical systems and engineering facilities.

Conclusions

It is determined that the geocryological conditions at the Yurubcheno-Tokhomskoe Field are complex and rather unstable. Therefore, economic development of the examined area of permafrost spread is related to certain difficulties.

Considering grounds as foundations in the thawed state does not fully allow us to take all the parameters of a geological environment into account. This is why, in the most important cases, organization of geotechnical monitoring during the construction and during the first years of facilities operation at such areas is economically reasonable.

The information obtained during the geotechnical monitoring will allow us to follow the development of an engineering and geological environment in time and promptly influence some of its components to prevent emergencies.

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A Database Synthesizing Published Data on Thermokarst and Thermal Erosion Processes

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Introduction

Thermokarst and thermal erosion

Thermokarst and thermal erosion are major processes of ice-rich permafrost degradation with widespread occurrence in northern high latitude permafrost zones. It is important to understand the vulnerability of permafrost to such processes in a warming Arctic [*Jorgenson et al., 2010*]. Contrary to gradual and relatively slow top-down thawing of permafrost, these processes can tap into deep permafrost-stored carbon pools and may result in the rapid release of organic carbon in gaseous, particulate, and dissolved states. These processes, triggered by natural or anthropogenic disturbances [*Grosse et al., 2011*], are highly variable in space and time and depend on local permafrost, hydrology, geomorphology, vegetation, climate, and geology. Though often small in spatial scale, they are widespread in many permafrost landscapes and can be very dynamic on time-scales ranging from weeks to decades. Currently no pan-Arctic database exists that synthesizes existing data on process rates, spatial dimensions, and spatial distribution of thermokarst and thermal erosion features. Detailed inventories of associated landforms only exist for local to regional scales resulting in difficulties to quantify their current impact on the permafrost-stored organic carbon pool.

To understand the current and future impact of such processes it is also necessary to develop model approaches capable of capturing their spatial and temporal dynamics and impacts on carbon fluxes between different pools in permafrost regions. First order assessments of thermokarst/thermal erosion impacts could be achieved with projections of known process rates based on currently available published data and a book keeping model approach to enhance tracking and understanding of permafrost carbon budgets and fluxes. A comprehensive thermokarst database would greatly aid such modeling efforts and provide useful modern day boundary conditions for processes based on field measurements across many regions.

Research Coordination Network on Vulnerability of Permafrost Carbon: Thermokarst Working Group

Funded by the National Science Foundation in 2010, the Research Coordination Network (RCN) on Vulnerability of Permafrost Carbon organized several international working groups aimed at advancing knowledge about carbon dynamics in permafrost regions through expert meetings, fostering international and cross-disciplinary collaboration, joint data synthesis and analysis efforts, and advancement of permafrost carbon dynamics models [*Schuur et al., 2011*]. Within the RCN one working group focuses on thermokarst and related processes. The Thermokarst Working Group, consisting currently of 36 international scientists, established several short and long term working goals during two formal meetings in Seattle and San Francisco in 2011. Ultimately, we plan to integrate these goals with the other four working groups of the RCN (Aerobic/Anaerobic Processes, Modeling, Carbon Quantity, and Carbon Quality).

Short-term goals of the Thermokarst Working Group

A) Synthesis of literature and meta-analysis of physical process rates of various thermokarst types (expansion/thaw rates, frequencies, return intervals, magnitudes, environmental settings, etc.); Identification of data gaps.

B) Synthesis of literature and meta-analysis of thermokarst landform properties and inventories (primary data from local studies on distribution of various thermokarst and thermal erosion features as well as their morphometric characteristics; Characterization of distribution within different ecoclimatic/permafrost regions); Identification of data gaps.

C) Development of a book keeping framework for carbon fluxes for various thermokarst types, regions, and landscape types (upland, lowland, yedoma, slopes, peatlands), including the timing of C release/fluxes between relevant pools; Review of thermokarst model approaches (Review of approaches for various 1-D, 2-D, and 3-D local-scale thermokarst models; Identification of needs for parameterization of thermokarst in Community Land Surface Models and Earth System Models).

Long-term goals of the Thermokarst Working Group

D) Development of a quantitative inventory for thermokarst features in selected northern high latitude permafrost regions; landscape unit-based upscaling of local inventories.

E) Future projections (Development of simple scenarios for future development of certain thermokarst types as a first order assessment, for example summary of plausible projections of limnicities for each grid cell/soil polygon/land cover).

We here report on the progress and status of Goal A of this working group, the establishment of a database synthesizing information of thermokarst and thermal erosion processes.

Thermokarst Database

Initial database population was aided by the selection of thermokarst features in Alaska as reported by Jorgenson et al. [*2008*]. Currently more than 160 references have been compiled in our evolving database. Initial assessment of the literature indicates that many early studies do not provide quantitative data but have more descriptive character. About 80 studies in the database so far contain quantitative data on thermokarst or thermal erosion process rates, some for more than one study site or area (Table 1).

Table 1. Processes covered in the database with quantitative data on expansion, growth, or thaw rates.

Setting	References
Thermokarst lakes	19
Thermokarst subsidence	5
Talik formation	12
Retrogressive thaw slumps	15
Active layer detachment slides	8
Regional permafrost thaw rates	15
Other thermokarst-related processes	4

Most data is available for features that are relatively easy to repeatedly measure over time, such as thermokarst lakes and thaw slumps. For numerous other features, we identified no or limited literature data, and as such found critical data gaps that should be addressed by future field studies. This likely is also connected to challenges in adequately measuring rates of thaw and morphological change for features such as ice wedge collapse, sinkholes, collapse scar fens and bogs, or even thermokarst basins and thermal erosion gullies, calling for the development of appropriate repeat measurement methods and more of a focus on land surface subsidence. Since these processes are connected to a change in the thermal state of the ground and the loss of ground ice followed by surface subsidence, ground temperature and surface elevation are likely the best indicators that should be measured with high precision.

For all covered features, the database contains information about region, permafrost domain, geology, cryolithology, glacial history, ecoregion, coordinates, observation period and/or intervals, observation method, and the data source.

For thermokarst lakes, specific data were extracted on the number of analyzed lakes, lake characteristics (depth and size), and mean and maximum expansion rates. For thermokarst subsidence, thaw settlement rates were extracted.

Talik formation and growth underneath water bodies are generally reported as model results in the literature. Parameters extracted here in addition to general environmental settings were model specifics (such as inclusion of convective/advective heat transfer and initial conditions), talik thickness for different simulation year time steps, and mean talik growth rates.

For retrogressive thaw slumps and active layer detachment slides, slump morphology (area, depth, and length), mean and maximum headwall retreat rates, and known or estimated age were extracted.

References that report regional or local thaw rates by area or percentage of permafrost were listed separately. For example, permafrost loss in peatlands have often been described this way. Rates from other thermokarst-related processes, such as ice wedge tunneling, sinkhole formation, and pingo collapse were included on a case-by-case basis.

Next Steps

Based on the database entries for Goal A, a meta-analysis will be conducted taking into account permafrost and substrate conditions, climate, and rates of thaw, expansion, and growth, to identify potential correlations and to provide boundary conditions for modeling and book keeping efforts.

Initial data have also been compiled to accomplish Goal B of this working group, the development of local inventories of thermokarst and thermal erosion features, which also includes inventories at different observation periods for the same location to cover changes in feature inventories, for example due to lake formation and disappearance. We continue this compilation over the first half of 2012.

We look forward to receiving feedback from researchers at TICOP, and are interested in actively involving more scientists in the Thermokarst Working Group that are studying thermokarst processes. We also hope that during TICOP the database will be strengthened through the addition of more references and datasets, in particular the non-English literature.

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Laboratory investigation of the freezing point of clay soils under high loads

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Along with the energy problem and the urban land demand pressure became more and more apparent, the exploitation of underground space is becoming a tendency, and amount of underground projects will need to be construct in the future. To built those engineering, such as extract minerals deposited, which is under the ground surface at a depths of hundreds meters or even a thousand meters, frequently will affected by complex geotechnical conditions. Artificial ground freezing, an environmentally friendly technique, is routinely used as a means of groundwater control and soil support for the construction of shafts and underground openings. In the artificial freezing method, the in situ pore-water converts into ice, which becomes a bonding agent, fusing together adjacent particles of soil or blocks of rock, increasing their combined strength and making them impervious. Excavation can then proceed safely either within or adjacent to the barrier of strong, watertight, frozen earth.

The design of the frozen wall is a key factor that determines the success or failure of construction involving artificial ground freezing technology. And the soil freezing temperature is a determining factor to confirm the thickness of the frozen wall. Now, 0°C surface is often used as the interface of the frozen soil and unfrozen soil in the frozen wall design. The study of the physical characteristics of frozen ground has revealed that the soils water content, salt content and imposed loads all have consequences for its freezing point. The results of project measurement showed that the soil freezing point in deep alluvium is always below 0°C as a result of the ground pressure. Specially, its can reach to -4°C. So investigation of the freezing point of the soils under high loads is prerequisite for designing a suitable frozen wall.

In this paper, how water content, imposed load affect the freezing point of clay soil, which collected from deep alluvium in a coal mine, were investigation by use of a self developed laboratory instruments.

Detail steps of experiment is: 1) reach the desired pressure at a rate of 10N/s; 2) keeping the test pressure for 30min;3) dropping the temperature to -20°C and keeping the temperature until the centre of the sample’s temperature down below -10°C. The temperature date were collected continually by the computer.

The freezing point measurement tests were performed at water content of 25%, 30%, 34% and 38% (saturated water content) under the imposed load of 0～10MPa.

The investigating leads to the following conclusions:

(1)On the same loading condition, the ice formation stage of the soil cooling curve became more unidentified as the water content decreases; and when the sample water content was defined, this stage get more clear as the external loads increases.

(2)Within the investigation loads scope of this study, the water content of the samples has an effect on the different stages of the soil cooling curve. The duration time of the free water freezes stage of the curve increases with the water content increases, and on the bound water freezes stage, the soil cooling rate heighten as the water content increases.

(3)When the external load was defined, the soil freezing point increases with the water content get higher. In other words, as the water content increase, the freezing point of the soils close to the freezing temperature of the pure normal water.

(4) As sample water content constant, the imposed load had influence on the sample freezing point. And the freezing point has positive linear relationships with the imposed loads. (Fig.1). The relationship can be written in the following form:

$$T_f = aP + b$$

Where T_f is the sample freezing point(°C), P is the imposed load(MPa), a and b are the test parameters which relate to the water content in this study. (Table.1)

(5)For different sample water content, the reduce rate of the freezing point has varied little with the imposed load increases, between -0.074～-0.093°C /MPa.

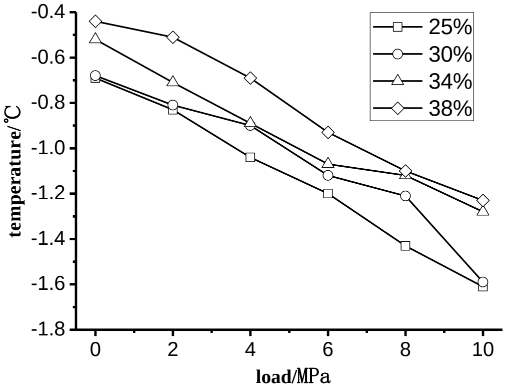

Fig.1 Variation of freezing point with load

Table.1 Fitting value of parameters a and b

Water content	a	b	R²
25%	-0.093	-0.664	0.996
30%	-0.083	-0.644	0.936
34%	-0.074	-0.559	0.978
38%	-0.085	-0.391	0.983

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Paleocryogenesis in Late Pleistocene Period of Pedogenesis in the Center of the East European Plain

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Abstract

Cross-spectrum analysis of pedological cryogenic and non-cryogenic features helps to achieve significant detailing of the history of formation of the buried Late Pleistocenic soils. Interglacial and interstadial soils consist of several individual soil profiles, while pleniglacial (interphasial) soils have simple texture.

Keywords: paleoecological informativity; periglacial zone; stage of pedogenesis.

The genetic and evolution soil science actively facilitates the investigations into the effect of paleocryogenesis on soil formation, since paleocryogenic features demonstrate resistance to diagenetic processes and, consequently, are highly valuable in terms of paleoecological information. According to our observations, the memory of buried soils formed in the natural conditions of Late Pleistocene glaciation registered with high precision the disturbances of their state caused by transition from the periods with warmer climate (interglacial, interstadials, and interphasials) to those with more severe colds and harshly continental climate (glacial, stadials, and phasials).

The studies covered the periglacial area of last glaciation. The paleocryogenic features in buried soils help to update the taxonomic ranks of soils. The most diverse paleocryogenic features were found in the Mikulinsky interglacial soil profiles (Fig. 1).

Figure 1. Paleocryogenic deformations of the Mikulinsky interglacial (Sangamon, Eemian, MIS 5e-5c) soil of the Likhvinsky section (Tula Region; 54.1055 N 36.2572 E) are complex, fissured in profile, formed on a plain ancient surface (1), and soilfluction in profile on a sloping ancient surface (2).

This complex and differentiated soil profile is similar to that of the modern sod-podzolic soils with thick horizon Bt. Morphological paleocryogenic features corresponding to the early permafrost-hydromorphic stage of soil development were preserved in the lower part of the Mikulinsky soil profile. These features are expressed in the form of platy structures with whitish powdering on the edges of aggregates. This platy structure (coarse, uniform in size, with even horizontal edges covered by clayey films, with whitish powdering on the edges) is typical of the near-permafrost horizon with insignificantly excessive moisture content in the modern permafrost soils studied by us in the East Transbaikalia [*Alifanov 1978, Gugalinskaya & Alifanov 1979*]. We believe that the formation of such platy structure was caused by the development of cryogenic microschistosity that, according to cryolithological data, was formed in the process of freezing of excessively moist soils.

The formation of the Mikulinsky interglacial soil was completed in the same cold and harshly continental climate conditions during seasonal soil freezing. Continental nature of the climate is confirmed by frost fissures formed by the humus soil horizon's material. In addition to numerous micro-morphological cryogenic features, the evidences of cold climatic conditions include former presence of permafrost in the soil profile. Here, its level of occurrence is clearly registered at depth 40-50 cm, evidenced by thickness of the soilfluction layer and depth of shoulders in frost fissures. In total, we identified six stages of pedogenesis in the development history of the Mikulinsky interglacial soil in question.

The Bryansk interstadial soil has lower thickness, more simple structure, and poor expression of the illuvial horizon. However, this soil is clearly seen on the background of host surface loess clayey silts (Fig. 2). The most frequent paleocryogenic features observed in the Bryansk soil are deformations with the morphology similar to that of soilfluction. However, we cannot submit any direct evidence of the solifluction flow of the material along the slope, as we could not fix the former permafrost boundary, though its signs, if present, are easily found in the soil profile. We concede that turbation processes developing at the post-Bryansk stage of cryolithogenesis were caused by cryodiagenesis (Fig. 2.1).

Figure 2. The Bryansk interstadial (32-24 thousand years) soil (1, 2) and overlying Pushchinsk (pu) interphasial (17-18 thousand years) soil (2) on the Late Palaeolithic settlement Sungir (Vladimir Region; 56.1780 N 40.5077 E).

This assumption is supported by archeological investigations: turbation deformations disturbed the normal occurrence of cultural residues; i.e., those deformations developed after the formation of the cultural layer. During the period of settlements' existence, the Bryansk soil suffered no cryoturbation deformations.

However, the humus horizon of the Bryansk soil suffered the impact of syncryolithogenic processes related to its seasonal freezing, since micro-morphological features of cryogenesis are clearly seen in the soil.

Cross-spectrum analysis of the pedological cryogenic and non-cryogenic features helps to achieve significant precision in the history of formation of the Bryansk interstadial soil. We identified three stages of pedogenesis in the history of its development. Each of them corresponds to an individual soil profile, and all profiles were partially developed on new alluvium. Soil formation in the Bryansk period took place in the conditions of gradually cooling as well as harshly continental and dry climate through the whole soil-formation époque.

The Pushchinsk (pu) interphasial soil, which we were the first to describe (Fig. 2.2), has the most simple structure, consisting of light-gray humus horizon A, gradually transforming to gley horizon G. The soil shows notable morphological intensity in the relief depressions existing on the day surface 17-18 thousand years ago.

The post-Bryansk stage of cryolithogenesis comprised the formation of large cryogenic soil structures filled by loess clayey silt (Fig.2.1) and the material of one more overlying interphasial soil. Radiocarbon age of this soil (we called it "Serpukhov") is 14 100±370 (3809IGAN). So, taking into consideration the time needed for the Serpukhov soil formation, we may say that the post-Bryansk stage of cryolithogenesis came to its end approximately 15 thousand years ago.

In the south of the studied periglacial area, large cryogenic soil structures that represent stratigraphic benchmarks in the modern chernozem (black soil) profiles may be absent, being replaced by smaller fissure deformation accumulations. The interpretation of peculiar fissure deformations in complex objects, e.g. in a series of overlying buried soils, will help to identify individual soil profiles in this complex strata (Fig. 3) and to restore the soil formation ecology. In the series of the buried soils of the section shown on Figure 3, the only soil studied by now is the Pushchinsk one (17850±650 years). Two lower buried soils were identified in the area of investigations for the first time, so, they have no names by now.

Figure 3. Series of interleaved buried soils forming the profile of modern chernozem that is typical in the Kamennaya Steppe reserve (Voronezh Region; 51.0361 N 40.7359 E).

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Resumed Temperature Monitoring of Permafrost in Northeastern Russia

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Introduction

Paleoclimate reconstructions have received increasingly greater attention lately because of global warming concerns. Permafrost is commonly assumed to be especially sensitive to warming-related changes. The available permafrost monitoring records are no longer than 80 years being generally much shorter than meteorological observations that continue for at least 200 years. There is, however, a record from Sharga mine in Yakutsk where the temperature of frozen ground has been measured since 1830 to as deep as 136 m. Temperature logging to these depths provides important evidence of permafrost thickness and deep heat flow, though warming effects are well detectable in shallow data within the zero annual amplitude depths where air temperatures already have no influence.

Temperature monitoring

In 2007 the Melnikov Permafrost Institute SB RAS (Yakutsk) resumed permafrost monitoring in the Verkhoyansk-Chukchi area covering the territory of the Magadan region and Chukchi Peninsula (Fig. 1) as part of the project “The Present Thermal and State and Composition of Permafrost in Northern Asia. Paleoreconstructions and Prospects”. The final goal of the project is to assess permafrost responses to current climate change, both at the local (study area) and global levels.

The study began with inventorying data available in archives of institutions which anyhow ran air and ground temperature measurements in Northeaster Russia. From 2007 to 2011, we inspected all geological, engineering geological, hydrogeological, and other reports available at R&D and Geological Survey institutions of the region (VNII-1, *Magadanenergo, Dalnenergosetproekt, SVKNII*, and Anadyr *TISIZ* corporations; Magadan Geological Surveys, TFI Chukotka, Anadyr Permafrost Station) that contained data on temperature logging in boreholes deeper than 10 m. As a result, a database was compiled consisting of more than 200 reports on measurements all over the Magadan (102 boreholes) and Chukchi (298 boreholes) areas from 1940s through 1990s. Each borehole was documented, with indication of location (coordinates), maximum hole and logging depths, bottom circulating temperatures, depth of 0 C° temperature, elevation of the hole head above sea level, relation to river catchments, terrain, direction and angle of slope, soil cover, presence of shrub and trees, downhole lithology, logging instruments used, thicknesses of snow and active layer, state of borehole, temperature logs (with depth and time of measurements), and references. The data have been synthesized in the catalog “Technical and Thermophysical Characteristics of Boreholes in East Siberia” at the Melnikov Permafrost Institute SB RAS (Yakutsk). Once the temperature data had been systematized, the existing boreholes were to be found in the field. Prior to the field season, 16 boreholes were selected which we expected to return to operation. In practice only nine of them were discovered and only five were suitable for monitoring (one in Anadyr).

We learned from the gained experience that search for 20 to 50 years old boreholes without a guide who would know where they may be had little chance to be successful. Thus it was decided to deploy a new network of stations instead of looking for old logging holes and repairing them. The new stations were installed in boreholes remaining after geological surveys and mineral exploration, first in the Omsukchan district of the Mogadan region, in 2011.

The geothermal facilities were HOBO U12 Outdoor/ Industrial 4 External Channels, recommended by IPA for monitoring permafrost responses to climate change, mounted in five suitable boreholes: two in the vicinity of Magadan, two in the Matrosov mine area, and one in the outskirts of Anadyr (Fig. 1).

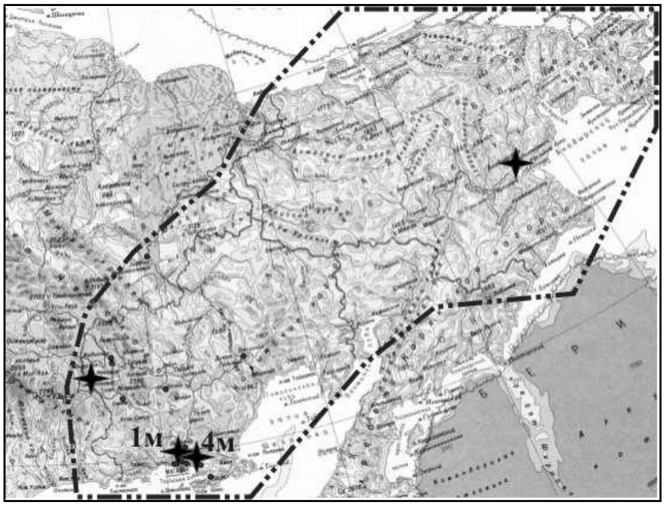

Fig. 1. Area where permafrost monitoring has been resumed since 2007. Stars mark boreholes where new logging stations were installed.

Inasmuch as the logged boreholes exist in markedly different climate conditions, additional measurements began in 2008 using automated iButton Data Logger probes (iBDL-L) for snow thickness and density, air temperatures at 2 m above the surface and ground temperatures under the snow.

In order to protect the instruments, ground was poured over the tubes and loggers placed in water- and heat-tight containers. Nobody can retrieve thus buried stations but the people who personally participated in the camouflage work or those who know the exact GPS coordinates. The safety of the instruments obviously pays off the time-consuming earthing work.

Results

Temperature logging in 2007 through 2011 in geothermal boreholes used for the same purpose 18-20 years ago revealed notable permafrost warming. It was, for instance, 0.28 °C on average at a depth of 20 m in the Okhotsk Sea coast (Ola and Khabla passes). A marked temperature rise occurred within shorter time spans as well (Fig. 2).

Warming of permafrost was also reported from elsewhere: e.g., Sharkhuu & Sharkhuu [*2011*] recorded an up to 0.8 °C increase at depths 15-20 m over 40 years of observations in Mongolia (MAGT).

The ground temperature rise evidently correlates with warming at the zero annual amplitude depth and with increase in mean annual air temperatures. The latter rose from -4.1 in 1960 to -3.5 °C in 1990 at the Nagaevo weather station in Magadan and from -11.9 to -11.0 °C in Seimchan Village, respectively, according to Climate Reference Books. Our data collected at the Northeastern Research Permafrost Station, Magadan (SVNIMS) show a mean air temperature of – 2.6 °C by the end of 2010. The mean annual warming cannot be unequivocally attributed to the rise of seasonal means (winter and summer) as it was suggested in [*Gavrilova 2008*] and [*Skachkov 2009*] for Yakutia.

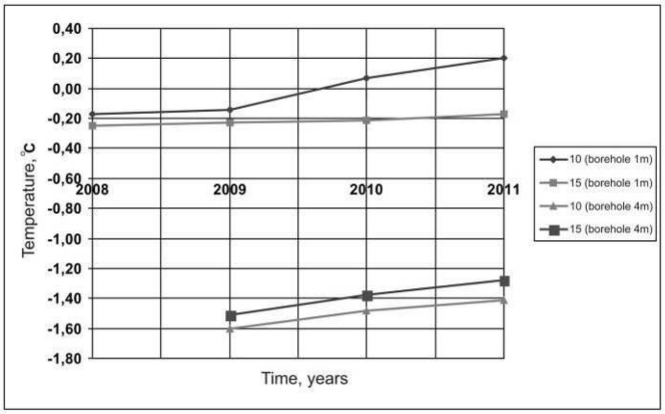

Fig. 2. Mean annual ground temperature (°C) at depths 10 and 15 m in two boreholes, Magadan area, for past four years of observations.

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Cryostratigraphy and Ice Content of the Near-Surface Permafrost in Lower Adventdalen, Svalbard

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The understanding of permafrost processes and thus periglacial landscape response to climatic changes requires knowledge on thermal and physical characteristics of the permafrost. The thermal state has been monitored in several periglacial landforms in the Adventdalen area on Svalbard since 2008 [*Christiansen et al., 2010*]. Detailed knowledge of the near-surface cryostratigraphy is, however, still very limited. Here, we present the first data on cryostratigraphy and ice content of five top permafrost cores obtained from two different Late Holocene ice-wedge polygon sites in the Adventdalen valley. The Adventdalen valley is centrally located in Svalbard at 78°12´N and 15°50´E. The mean annual air temperature during the last decade ranged between -1.5° and -5°C at sea level, and the permafrost is continuous [*Christiansen et al., submitted*]. Arctic desert conditions cause periglacial landforms to prevail. These landforms are related to terrestrial conditions that have only been present since the regression of the sea from the lower valley bottom in the Early Holocene [*Lønne & Nemec, 2004*].

Geomorphology and sites

In the lower Adventdalen valley bottom, the Adventelva braided-river fills a 1 km wide river plain, which drains alluvial fans coming from tributary valleys. The river erodes itself into the surrounding landforms, forming a 0.5 to 4 m high cliff. Deflation of fines from the freeze-dried river plain mainly in autumn leads to persistent loess accumulation adjacent to the river-plain where active syngenetic ice-wedge polygons are widespread [*Christiansen, 2005*].

Site A is located on a well-drained and sparsely vegetated ridge, composed of 2 to 3 m silty loess deposits overlying a unit of alternating peat and loess. The ridge has insignificant orthogonal polygons up to 40 m in diameter, underlain by 1 m wide and supposedly dormant ice-wedges [*Härtel 2011*].

Site B is located on the outermost part of an alluvial fan and composed of 2 m silty loess deposits, overlying alluvial deposits. Therein well-developed low-centered, 10 to 20 m large polygons have formed with ice-wedges up to 3 m wide at the top [*Härtel 2011*]. A deep and wet, an intermediate, and a shallow and dry polygon were investigated.

Methods

Six active-layer pits (A1-A3, B1-B3) were dug and sampled in the centre of the ice-wedge polygons. OSL-dating was performed on A2 and B2. From the base of the pits, permafrost cores were obtained down to depths of 2.75 m below the ground surface. The cryostratigraphy of core A3 and B3 was studied and sedimentological analyses were performed [*Härtel, 2011*]. The gravimetric water and ice content of the active layer and all permafrost cores (except core B1) was determined after drying at 60° C.

Results and Discussion

Transition active layer to top of the permafrost

Ice contents at the top of the permafrost are generally stepwise increased by 41 to 106 % compared to the water content in the active layer directly above. The distinct inter-site variability in gravimetric water content in the active layer, ranging from means of 9.2 % at A3 to 52.9 % at B1, applies less for the ice-content in the near-surface permafrost (Table 1 and Fig. 1).

Table 1. Site location and water and ice content characteristics.*

Site Sub site	Location (UTM) Drainage	ALT cm	MWC$_{AL}$ %	MIC$_{UPF}$ %	MIC$_{LPF}$ %
A	33X519065	8680980			
A1	well-drained	90	19.0	43.8	182.5
A2	well-drained	95	12.3	42.3	-
A3	well-drained	95	9.3	40.3	109.0
B	33X521109	8679280			
B1	poorly-drained	50	52.5	-	-
B2	intermediate	47	31.1	72.9	98.3
B3	well-drained	65	30.2	50.5	74.2

*Drainage conditions, active-layer thickness (ALT), mean gravimetric water (MWC) and ice (MIC) content in the active layer ($_{AL}$), upper- ($_{UPF}$) and lower permafrost ($_{LPF}$).

Permafrost cryostratigraphy and gravimetric ice content

The near-surface permafrost can be subdivided into an upper moderately ice-rich and a lower, ice-rich zone. The division between the two zones corresponds approximately to the lithological division of loess/peat-loess alternation at site A, and the loess/composite loess-alluvial deposit limit at site B.

Micro-lenticular cryostructures dominate the upper permafrost, extending from the top of the permafrost down to 1.95 m at A3 and to 1.75 m at B3 (Fig. 1). Ice-lenses are rarely thicker than 0.1 to 1 mm and occur rather evenly distributed and parallel to the horizontal loess layer. Only occasionally they alternate with sections of pore ice. Moderate gravimetric ice contents prevail in this upper permafrost zone ranging from

32.7 % to 58.0 % at site A and, slightly higher, from 35.4 % to 73.9 % at site B.

The lower permafrost cores are dominated by layered (A3) and lenticular-layered (B3) cryostructures. They are composed of larger and more variable, 0.2 to 8 mm thick ice-lenses. A downward increase in the visible ice-content is concurrent with an increase in the frequency and thickness of organic layers at A3, and an increase in the proportion of gravels in its silty matrix at B3. Meanwhile, the mean grain size of the <1 mm fraction of the loess deposit gently decreases with depth [*Härtel 2011*]. Only at the base of both cores the visible ice-contents slightly decline again.

The gravimetric ice content in the lower permafrost zone approximates and exceeds super-saturation with mean ice contents near or above 100 % (Table 1). Interestingly, the highest gravimetric ice contents of 200 % (A3) and 364 % (A1) occur at the presently well-drained site A. At site B, which is presently poorly-drained, ice-contents of up to 138 % were approached. However, high water contents at site A also account for a high proportion of low-density organic material present at depth, relevant when determining gravimetric water content.

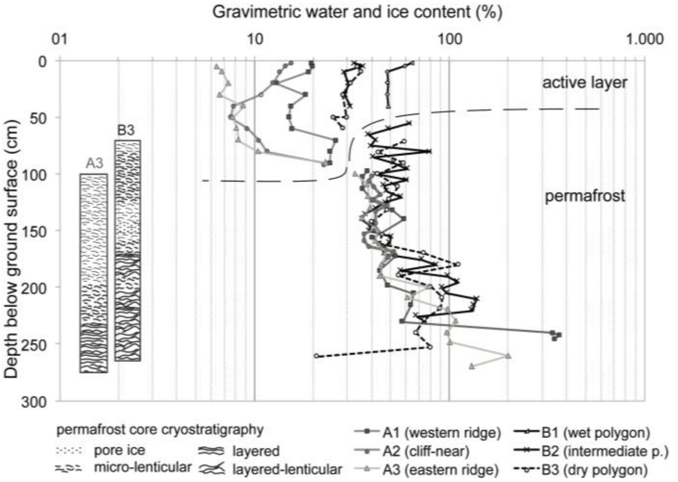

Figure 1. Active layer gravimetric water content, permafrost cryostratigraphy and gravimetric ice content (beneath the dashed line).

Implications for periglacial activity and frozen ground history

Micro-lenticular to layered-lenticular cryostructures are indicative of syngenetic permafrost formation and reflect steady loess deposition with gradually aggrading permafrost during the Late Holocene at both sites.

The described thickening of ice-lenses at the transition from the upper to lower permafrost zone may account for previously wetter conditions when the surface was located lower in the landscape. Or, it is related to the slightly finer lithology and accordingly higher frost-susceptibility of the ground, and the sedimentation rate. OSL-dates obtained from the active layer at 0.9 m in A2 and at 0.5 m in B2 show high sedimentation rates during the last millennium with 1 m ka^{-1} and 0.52 m ka^{-1}, respectively, with higher rates during the Little Ice Age (LIA), and considerably lower rates today [*Härtel 2011*]. Radiocarbon-dated peat obtained from site A at a depth of 2.2 m yields an age of 2770-2950 modeled cal yr BP and suggests lower sedimentation rates prior to the LIA, in particular when subtracting the large volume of ground ice. Considering the effect of sedimentation rate on permafrost aggradation, disregarding changes in ground thermal regime, a lower sedimentation rate also slows down the rise of the permafrost table, and thereby enhances the potential for ice-accumulation at the (former) transient layer.

Härtel [*2011*] questioned the significance of these findings as a regional palaeoenvironmental signal. Regarding sedimentation rate changes, it needs to be taken into account that sustained thermo-fluvial undercutting by the river gradually reduces the distance between the depositional area (where the cores where obtained) and the riverbed source area. Today, the thickness of the loess cover quickly decreases at site B within a distance of 200 m to the cliff, suggesting a considerable reduction in sedimentation rate with increasing distance to the cliff. The significantly lower sedimentation rate at B2, mentioned above, can be explained by its location about 50 m further away from the cliff than A2. This indicates the importance of taking the range of local geomorphological processes into account when interpreting cryolithostratigraphic records.

Conclusion

Lower Adventdalen valley is characterised by ice-rich near-surface permafrost composed of aggrading frost-susceptible sediments with micro-lenticular to layered cryostructures, and a dense network of ice-wedges. Even presently dry and well-drained areas are underlain by ice-supersaturated permafrost at depths of less than 3 m and ice-wedges at the top of the permafrost. Degradation of ice-wedges could initiate considerable thaw settlement of these surfaces.

Acknowledgements

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The Interaction between Remote Sensing Product Producers and the User Communities in ESA DUE PERMAFROST (Circumpolar Remote Sensing Service for Permafrost)

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Introduction

The main purpose of the ESA Data User Element DUE Permafrost project is to define, demonstrate, and validate a permafrost monitoring information service based on operational satellite data that are processed for the pan-peramfrost region North of 55° N. The service is supposed to support the GCOS implementation plan with systematic satellite-based Earth Observations of global permafrost extent, change and related products. It should further support permafrost monitoring activities of national and intergovernmental bodies and scientific groups involved in climate change research.

Permafrost is a subsurface phenomenon, i.e. frozen ground below 0°C for at least two consecutive years (International Permafrost Association, IPA). DUE PERMAFROST uses a suite of indicative remote sensing-derived parameters: ‘Land Surface Temperature’ (LST), ‘Surface Soil Moisture’ (SSM), ‘Surface Frozen/Thawed State’ (Freeze/Thaw), ‘Elevation’, ‘Land Cover’ (LC), and ‘Surface Waters’. The remote sensing data products are provided from local to large spatial scales. An operational monitoring service for Snow Extent and Snow Water Equivalent is currently being set up within the ESA DUE project GlobSnow. The GlobSnow products will be integrated in the DUE PERMAFROST service.

The DUE PERMAFROST consortium is led by the Vienna University of Technology, Austria. Vienna University of Technology is responsible for all parameters based on microwave remote-sensing technology (active and passive microwave sensors): Surface Soil Moisture (SSM) with weekly to monthly averages from 2007 to 2010, Freeze/Thaw and Surface Waters. The University of Waterloo (Canada) provides Land Surface Temperature Services (LST) from MODIS and ENVISAT-AATSR with weekly to monthly averages from 2007 to 2010. The Friedrich Schiller University (Germany) is responsible for the circum-Arctic/ boreal Land Cover products. Gamma Remote Sensing (GAMMA, Switzerland) has evaluated the newly released (2009) Global ASTER GDEM for high-latitudes and found frequent data voids and noises due to cloud coverage. Therefore, GAMMA has assembled national DEM data-sets and build-up the first circum-arctic DEM dataset with a 100 m pixel resolution north of 55° N. The Alfred Wegener Institute for Polar and Marine Research (AWI, Germany) organizes the exchange between the scientific stakeholders of the permafrost community and the project consortium, including the managing of the ground data and the adaptation of remote sensing products into the modelling.

User Interaction

ESA held an expert consultation workshop at the Alfred Wegener Institute of Polar and Marine Research, Potsdam, Germany in February 2008 in order

to define permafrost indicators which are observable from space, describe opportunities for trend analyses from data archives (Earth observation and in situ), generate a strategy for present Earth observation capabilities, and develop recommendations for a future permafrost monitoring programme. The project itself started in June 2009. The first phase comprised the collection of User requirements, the definition of a monitoring strategy, the service design engineering and system development. Researchers from permafrost monitoring and from modelling groups (permafrost, climate) provided feedback to a survey based on questionnaires in 2009.

As a concept within the ESA DUE programs, user workshops are an important tool for the interaction between the scientific user’s community and the remote sensing experts. The first DUE Permafrost User Workshop was held from in May 2010 in Vienna as an official side-event of the EGU. The observation strategy for all products and regions was presented by the project team and reviewed with the participants.

The service has been demonstrated and validated within the second phase. The first version of the full dataset has been released in the beginning of 2011. All data are available via a data portal which will be maintained for two more years after the completion of the project.

The 2nd DUE Permafrost User Workshop has been financially supported by the International Arctic Research Centre, IARC, Fairbanks (US) and took place from 2nd to 4th March 2011 in Fairbanks, Alaska. More than 30 scientists from scientific and governmental institutions participated. The workshop offered assessments of the DUE Permafrost products via tutorials (using the freely available software packages ESA BEAM-VISAT and Quantum-GIS). During in-depth sessions the participants discussed remote sensing products in context to modelling and permafrost monitoring.

The third and final Permafrost User Workshop took place at AWI Potsdam (DE) from the 15th to 17th February 2012 together with the final ESA ALANIS User Workshop. The Workshop focused on discussion sessions on remote sensing products as drivers and boundary parameters for permafrost and climate modelling and remote-sensing applications for permafrost monitoring. Participants presented their applications in talks and on posters.

User Requirements for Permafrost Monitoring

Researchers involved in permafrost monitoring are interested in the highest possible spatial and temporal resolution of all parameters. High spatial resolution of geomorphologic information has been explicitly claimed by a wide range of Researchers and by the International Permafrost Association IPA as a must for Permafrost Observations. Remotely sensed data shall provide information on relief, and vertical and horizontal change detection where the disturbances are mainly due to subsidence and erosion processes. The rate of subsidence phenomena in permafrost regions is on the order of centimeters per year (or less) and can exhibit a great spatial variability and therefore high vertical and horizontal accuracy and resolution is required.

Users inform that numerous types of permafrost landscapes are covered by small to medium-sized water bodies: ponds and lakes. The area percentage of water bodies in the coarser-scale remote sensing pixel needs to be known to understand the physical and bio-physical properties of products.

High-spatial resolution data is needed for the upscaling and evaluation/validation processes.

User Requirements for Permafrost Modelling

Table 1. Summary 2009 of model requirements

spatial coverage	largest possible coverage: panarctic
classes of required spatial resolution	< 1 km information for upscaling 10 km, 25 km, 0.1°
required driving forces	required, highest priority: **near-surface air temperature** *seasonal range of air temperature variations, monthly near-surface air temperature, mean annual air temperature* required for initialisation and validation: **soil moisture** *moisture content at different depths* *freeze/thaw-degree days, solid-liquid ratio* and **snow water equivalent, snow coverage**
classes of boundary parameters	[fixed] **land cover:** *vegetation physiognomy / bare soils / water body/ sand / peatland / moss /* *area percentage of water body* *area percentage of vegetation physiognomy, area percentage of bare soil* [fixed] **elevation** and **topography** (*variance and aspect*) [variable] **albedo** (i.e. no snow, no leaf condition) [variable, e.g. monthly] **leaf area index LAI** or another *volumetric index of total vegetation or an index of height of vegetation cover*

The following modeling groups provided feedback:

Geophysical Institute Permafrost Lab Model GIPL (Fairbanks, USA)

Lund-Potsdam-Jena Dynamic Global Vegetation Model LPJ (Jena, Germany)

Minimal Advanced Treatments of Surface Interaction and Runoff Model MATSIRO (Fairbanks, USA)

All models require near-surface air temperature that is the forcing parameter in all models. Partly, a very high temporal resolution is needed. E.g., to calculate the land only case, MATSIRO needs hourly data. However, the pseudo intra-monthly variations can be calculated. For atmosphere-coupled calculations monthly averages are required.

The required parameter accuracy of the temperature product is high around the freezing point: ~0,1°C, and 1°C when far from the freezing point.

Soil moisture, the snow water equivalent, and optionally the water body ratio within a grid point are used for initialization and validation. Since soil moisture is a prognostic value in the model, moisture related values are important in terms of model performance validations. Parameter accuracy for ‘soil moisture’ should be 5 to 10 % of the volumetric water content.

Land Cover, LAI (or an equivalent measure for biovolumina or height of vegetation cover), topography and snow coverage provide the boundary conditions.

Outlook

Further experimental applications of the DUE Permafrost products are experimentally developed by the DUE Permafrost team and modelling groups (permafrost and climate). Two modelling groups joined this experiment: the climate modelling groups of AWI with the

HIRHAM4 - regional climate model (RCM) for the Arctic

and the HZG Helmholtz Research Centre Geesthacht, Germany with the

regional climate model COSMO-CLM (climate version of the COSMO numerical weather prediction model)

Within the EU project “Changing permafrost in the Arctic and its Global Effects in the 21st Century" PAGE21, that has started in 2011, more modeling groups are being actively involved (*www.page21.eu*).

The Experiments carried out will range from (i) the evaluation of external data of the models, with modifying or providing new external data (e.g. tundra land cover, surface water ratio for permafrost regions, soil distribution), to (ii) new drivers for regional models derived from remote sensing (e.g., Land Surface Temperature), to (iii) the evaluation of the output data from the modelling (e.g. spatial patterns of moisture and temperature).

Seasonal Surface and Soil Water Storage Dynamics in Wet Polygonal Tundra, Lena River Delta, Northern Siberia

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Introduction

Wet polygonal tundra is characterised by a mosaic of different landscape units with complex microtopographies. A shallow active layer restricts hydrological processes to the upper soil layers in these environments and mainly controls hydrological connectivity between the landscape units. Soil thaw during summer therefore plays a crucial role for seasonal water storage dynamics of low-gradient catchments and drives redistribution of water storage within a catchment [*Woo & Guan 2006*]. The objectives of our study are (i) to identify landscape units with distinct water budgets and (ii) to explain major hydrological processes contributing to the high spatial variability of water storage conditions within a small polygonal tundra catchment.

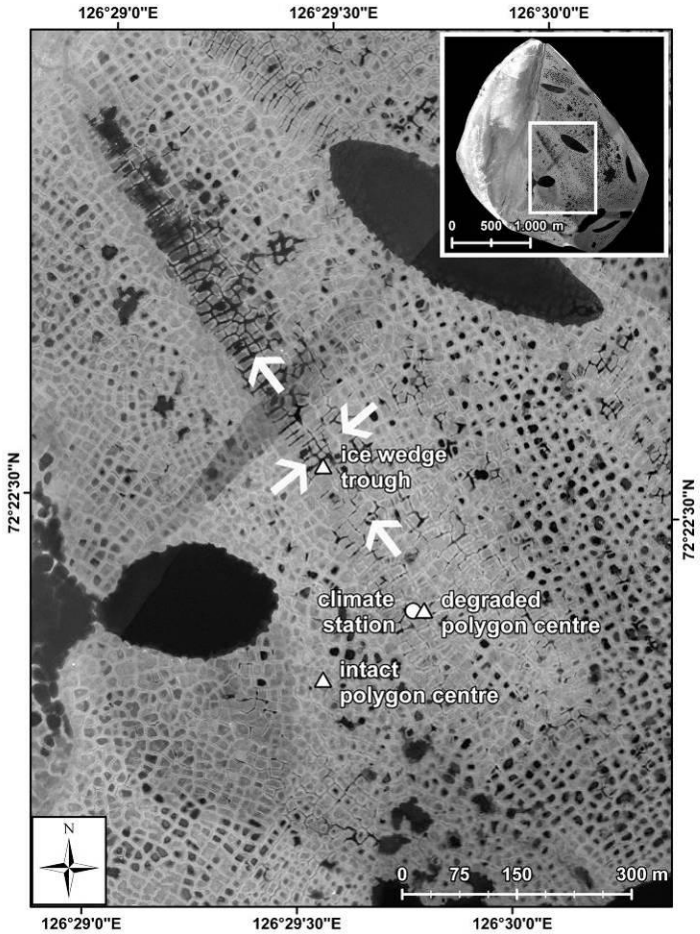

Figure 1. Location of study sites in the catchment, and its location on the island (aerial picture from Muster et al. in press). White arrows indicate the direction of flow within the catchment.

Study area

The study area is a small catchment (~ 0.3 km^2) underlain by continuous permafrost situated on Samoylov Island (~ 5 km^2) in the Lena River Delta, Northern Siberia (72°22’ N, 126°30’ E). Low slope gradients (< 0.2 %) are dominant in the catchment. The landscape is characterised by wet polygonal tundra typical for the circumpolar lowland tundra. Water-saturated depressed polygon centres, raised surrounding intact and degraded rims underlain by ice wedges, water-filled troughs above degrading ice wedges, as well as thermokarst ponds and lakes shape the landscape (Fig. 1). The climate at the study site is arctic-continental, and snow melt typically recharges catchment water storage to its maximum in the beginning of June. The maximum active layer depth is usually reached in early September with depths ranging between 30 cm and 100 cm.

Methods

During the study period 4 June to 21 August 2011, water level was measured continuously in the centre of a polygon with intact rims, in the centre of a polygon with degraded rims, and in a water-filled trough above a degraded ice wedge. Precipitation was measured for the same period at a climate station situated within the catchment. An eddy covariance system was installed at the climate station consisting of a sonic anemometer and an open path infrared CO_2/H_2O gas analyser (Fig. 1). Latent heat flux (*LE*) calculations during low turbulence, rain, and fog were removed from the data set. Small data gaps (< 2 consecutive hours) were filled using linear interpolation. For larger gaps, a multi-linear regression on the quality-controlled *LE* data was used as an empirical gap-filling model ($R^2 = 0.94$, $RMSE = 14.8$ W m^{-2}). Input variables were vapour pressure deficit, wind speed at 2 m, net radiation, soil temperature gradient between 2 cm and 5 cm depth below the soil surface, and volumetric water content at a rim.

The water budget for these sites was assessed for 30 min intervals as follows:

$$P - ET - RO = \Delta S \qquad (1)$$

where P is precipitation (mm), ET is evapotranspiration (mm), RO is net runoff (mm), and ΔS is the change in surface and soil water storage (mm). For water table fluctuations above the ground surface ΔS is the observed change in water table height. Specific yield ($S_y = 0.7$) is to be considered when the water table drops below the surface.

Results & Discussion

P from the beginning of the measurement period until the end of June was low and amounted only to 22 mm. Frequent rain events accounted for 46 mm in July. In August *P* was dominated by two heavy rain events on 1-2 August (total 39 mm) and on 20-21 August (total 14 mm). Total *P* for the study period was 122 mm.

ET exceeded *P* by more than 100 % in June and was approximately equal to *P* in July. In August *ET* amounted to only half of P. Overall, the climatic water budget was almost balanced at the end of the study period. It is to be mentioned that site-specific *ET* was assumed to be represented by landscape *ET* measured based on the eddy covariance approach. However, this assumption may not always be valid, and more research is needed to account for possible effects of small scale heterogeneity of *ET* on runoff estimates.

Significant *RO* led to a distinct depletion of S at the intact polygon (-61 mm) and at the trough above a degraded ice wedge (-40 mm) at the end of August. No net runoff was observed at the degraded polygon site, and only minor variations of *RO* between different months were observed. The intact polygon was characterised by limited *RO* in June. Here, more than 50% of total *RO* was released in July. At the ice wedge trough most of *RO* was produced in June. A net inflow at the ice wedge trough was observed in late summer coinciding with high *P* events. These events led to no noticeable net inflow at the intact polygon (Tab. 1).

Table 1. Monthly summer water budget term estimates in mm for the study catchment (P, ET) and different landscape units (RO, ΔS) (04 June to 21 August 2011). Negative net runoff represents net inflow to the site.

	June	July	August	total
P	+22.5	+46.3	+52.9	+121.7
ET	+46.4	+50.7	+26.6	+123.7
intact polygon				
RO	+24.3	+33.6	+1.5	+59.4
ΔS	-48.2	-38.0	+24.8	-61.4
degraded polygon				
RO	+2.8	+6.0	-8.8	0.0
ΔS	-26.7	-10.4	+35.1	-2.0
ice wedge trough				
RO	+45.9	+11.7	-19.6	+38.0
ΔS	-69.8	-16.1	+45.9	-40.0

Clear differences exist between water budgets of intact polygons with continuous ridges and degraded polygons with troughs connecting the polygons to the ice wedge trough network. The enhanced runoff early in summer at the water-filled ice wedge trough site was followed by attenuated runoff by the middle of June. This runoff was very likely the remnant of a snowmelt runoff event which took place in the end of May. By the middle of June, equilibrium was approached and inflow and outflow were almost balanced. At the same time, storage in intact polygons steadily decreased due to net runoff which was very likely enhanced by the deepening of the active layer and the hydraulic gradient between polygon centre and ice wedge trough [*Young & Abnizova 2011*]. Ice-cemented frozen ground blocked runoff early in summer. This barrier gradually thawed, and subsurface outflow to the ice wedge trough occurred at the lowest position of the frozen ground surface in the soils of the rim at a specific time. Centres of degraded polygons were connected to the ice wedge trough early in the season due to the lower rim and were less influenced by temporal changes in drainage rates. The implication is that with faster thaw rates intact polygons move more quickly towards drier conditions, whereas lower parts of the catchment gain water from these areas and feature a more balanced water budget.

An understanding of the thaw dynamics on the microscale is, therefore, crucial for understanding hydrological processes of polygonal tundra. These dynamics are characterised by several feedback mechanisms which render difficult accurate predictions of future active layer development. For instance, the presence of surface water or wet soil conditions enhances ground thaw rates itself [*Guan et al. 2010*]. Jorgenson et al. [*2010*] found in this regard water temperatures near the sediment surface of shallow lakes (< 1.5 m) to be ~10 °C warmer than mean annual air temperature in central Alaska. That implies that increased runoff from a polygon causes a negative feedback mechanism on ground thaw due to the drying of the polygon centre. At the same time, lateral export of water transfers latent heat and causes a positive feedback on the thaw dynamics within the outflow trough of the polygon rim [*Guan et al. 2010*].

Conclusion

Different landscape units of polygonal tundra show distinct differences in their hydrological behaviour during the summer season. Intact polygons feature a greater loss in water storage due to subsurface runoff caused by an increased thaw depth compared with degraded polygons and water-filled troughs above degraded ice wedges. A main driver of these seasonal dynamics is, thus, very likely the development of the active layer controlling the redistribution of storage water within a catchment.

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Next-Generation Ecosystem Experiment (NGEE Arctic): A New Project Focused on Improved Climate Prediction

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The Arctic may be the most climatically sensitive region on Earth. High latitudes have experienced the greatest regional warming in recent decades and are projected to warm twice as much as the rest of the globe by the end of the twenty-first century. These areas are uniquely characterized by the presence of permafrost, defined as ground that has been continuously frozen for two or more years. Recent observations suggest that rapid permafrost degradation is increasingly common in the Arctic and is linked to warmer temperatures [*Jorgenson et al. 2006*]. Permafrost degradation is expected to drive changes in climate forcing through biogeochemical and biophysical feedbacks. Biogeochemical feedbacks are dominated by the potential to release a large amount of currently stored carbon back into the atmosphere as CO_2 and CH_4 [*Schuur et al. 2009*], whereas biophysical feedbacks include terrestrial energy budgets that are changing in response to warming in high-latitude ecosystems [*Chapin et al. 2005*]. These biogeochemical and biophysical processes will take place in an environment undergoing dramatic geomorphic change and landscape reorganization [*Rowland et al. 2010*]. Thawing of ice-rich permafrost can lead to subsidence and deformation of land surfaces that range from localized depressions to deep and extensive thermokarst events. These landscape features, along with thermal erosion, gully formation, and drainage network expansion, are dramatically changing topography, surface and subsurface hydrology, and vegetation structure in the Arctic on time scales of years to decades.

Identifying Critical Ecosystem-Climate Feedbacks

The mechanisms responsible for biogeochemical and biophysical change in the Arctic have been unpredictable and difficult to isolate due to a large number of interactions among individual components of the system. The U.S Department of Energy through their Biological and Environmental Research (BER) program have sponsored a new Next-Generation Ecosystem Experiments (NGEE Arctic) project. The goals of this project are to improve model prediction of climate by quantifying the complex physical, chemical, and biological behavior of terrestrial ecosystems in Alaska. The project will focus on interactions that drive ecosystem-climate feedbacks through greenhouse gas fluxes and changes in surface energy balance associated with thawing permafrost and threshold-dominated permafrost degradation and thermokarst formation, and the many processes that arise as a result of these landscape dynamics. The ultimate deliverable of the NGEE Arctic project is a high-resolution terrestrial system model that is able to simulate coupled thermal, hydrological, geomorphic, biogeochemical, and vegetation processes as needed to predict the evolution of a warming Arctic landscape and its feedback to the global climate system. This vision includes field observations; laboratory experiments; modeling of critical and interrelated water, nitrogen, carbon, energy dynamics; and important interactions from the molecular to the landscape scale that drive feedbacks to the climate system.

The NGEE Arctic project will use observations and models to quantify the response of physical, ecological, and biogeochemical processes to climatic change across molecular to landscape scales. Our approach addresses how permafrost degradation in a warming Arctic, and the associated changes in landscape evolution, hydrology, soil biogeochemical processes, and plant community succession, will affect feedbacks to the climate system. Field and lab research will focus on interactions that drive ecosystem-climate feedbacks through greenhouse gas fluxes and changes in surface energy balance. These feedbacks will arise due to gradual thawing of permafrost and thickening of the seasonal active layer. Feedbacks will also occur as a result of the threshold-dominated processes of permafrost degradation and thermokarst formation and through the many processes that are influenced as a result of these landscape-scale dynamics. Our approach will consider how components of complex systems are linked and the interplay in space and time that determines system behavior. Fundamental knowledge gained in these investigations will be used to improve representation of ecosystem dynamics, subsurface biogeochemistry, and land-atmosphere processes in regional and global models, and will reduce uncertainty and improve prediction of climate change in high-latitude ecosystems.

Phase 1 – Implementing Our Approach on the North Slope

The research scope of NGEE Arctic Phase 1 is designed to address our overarching science question through a series of integrated field observations, laboratory experiments, and modeling activities. Permafrost degradation and its impact on water, nitrogen, carbon, and energy-related processes will be investigated across a hierarchy of scales, including the pore/core, plot, and landscape scales. Field research will be conducted in Alaska initially on the North Slope (Barrow) but in other important regions as they become identified. Modeling efforts will focus on application of existing models to evaluate their predictive capability across a range of spatial scales, from single-column to plot to landscape scales. Model results will be compared with laboratory experiments and field observations. We will simulate permafrost degradation in a warming Arctic using the land surface component of a major climate prediction model as well as several high-resolution process-resolving models of subsurface physical and biological dynamics. These efforts will (1) quantify how surface and subsurface processes interact to influence permafrost degradation and hydrology, (2) resolve biogeochemical mechanisms that control rates of CO_2 and CH_4 flux, (3) characterize the role of nitrogen availability in shrub expansion and plant productivity, (4) identify mechanisms underlying changes in ecosystem net energy budgets due to vegetation dynamics, and (5) quantify prediction skill for existing models.

Phase 2 – Expanding to Other Regions of the Arctic

Insights gained in Phase 1 will be used to address the challenge of extrapolating or scaling process studies to larger grid scales of climate models and to sharpen our focus on physical, chemical, and biological processes that shape the structure and function of Arctic ecosystems. Phase 2 will expand to include process-level studies at plot to landscape scales in other regions of Alaska and with collaboration with international partners throughout the Arctic. Modeling efforts will focus on design and implementation of a new Arctic process-resolving land simulator for inclusion in regional and global climate models, building on strengths and improving on the weaknesses of existing models as identified in Phase 1. Our ultimate goal throughout the NGEE project will be to develop a high-resolution, process-rich land model, extending from the bedrock to the top of the vegetative canopy, with which the evolution of the structure and function of the Arctic landscape and its ecosystems in a changing climate can be simulated on the scale of an Earth System Model (30x30km) grid cell.

Understanding the Importance of Spatial and Temporal Scales

The research scope of the NGEE project is designed to characterize critical ecosystem-climate feedbacks and incorporate process knowledge into models that, in turn, can simulate impacts of climate change in high-latitude systems. Permafrost degradation and its impact on water, nitrogen, carbon, and energy-related processes will be investigated across the pore/core, plot, and landscape scale (Figure 1). Although the characteristic lengths and interrogation approach will vary depending on the process being studied, some generalities about these three scales of investigation can be made. Pore/core-scale investigations will focus on processes that operate at the micron to tens of centimeter length scales, typically using homogeneous soil samples and controlled lab conditions. At this scale, biogeochemical processes are determined more by sediment characteristics, such as grain size and porosity; thus intact cores will be studied. Investigations at the plot-scale allow us to interrogate those processes in the presence of natural heterogeneity, including spatial and temporal variations in thermokarst, snow and active layer thickness, and soil texture, which will in turn impact moisture distribution, vertical and lateral flow, and solute (including electron) transport affecting subsurface biogeochemical reaction, vegetation, and energy balance. Representative length scales for plot investigations range from meters to tens of meters. Landscape-scale investigations, operating at representative length scales of kilometers, allow us to consider the impact of factors such as topography, geomorphology, and large-scale drainage on carbon, nitrogen, and energy partitioning and to explore the how processes occurring over smaller length scales contribute to the integrated GHG flux signature as is needed to inform climate models. Research conducted across these scales will ensure quantification of fundamental process coupling while developing insights on scale transitions and macroscopic rules that govern terrestrial Arctic system behavior.

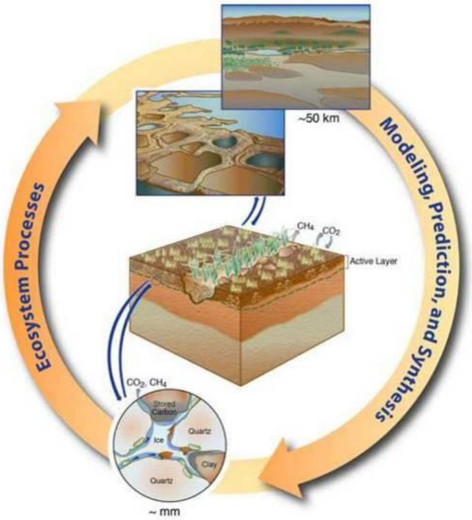

Figure 1. Multi-scale approach of the NGEE Arctic project.

Acknowledgement

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Organic Matter Composition and Dynamics in Permafrost Soils of the Siberian Polygonal Tundra

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Northern permafrost soils contain approximately 50% of the global belowground carbon [*Tarnocai et al., 2009*]. Increasing global temperatures are assumed to enhance the decomposition of the soil organic matter (SOM), which will increase carbon emissions released to the atmosphere [*Khvorostyanov et al., 2008*]. Microbial metabolic activity is a key factor in the mineralization of SOM and the active layer thawing during summer is the main place for SOM decomposition within the permafrost. At the same time the active layer is the interface between atmosphere and permafrost concerning temperature regime, carbon dioxide and methane exchange. The identification of temperature sensitive carbon pools and their microbial availability is complicated by the very heterogeneous composition of SOM. Numerous approaches have been used to partition SOM into functional pools with different turnover rates, which are determined by their chemical properties and bioavailability [*Lützow et al., 2007*, *Trumbore, 2009*].

The aim of our study was to characterize the active layer's SOM composition, to determine where less bioavailable organic carbon components are located within differently stabilized SOM compartments and to what degree soil microbial communities are metabolizing these presumably more stable components. We investigated depth intervals of the active layer of two characteristic cryogenic structures of polygons (rim and centre) in the tundra of the Lena-Delta in Siberia (Russia). To evaluate the distribution and quality of the SOM, we used elemental, molecular and ^{14}C analysis as well as physical soil fractionation.

SOM content in the active layer showed considerable differences between the water saturated polygon centre and the relatively dry rim. Total organic carbon (TOC) contents were higher in the centre (10.3 to 2.4 mg/g) consisting of peaty, little decomposed plant material compared to the rim (3.4 to 2.0 mg/g) and decreased strongly with depth. SOM of the polygon rim showed a higher degree of decomposition by its lower TOC content and C/N ratios.

Low radiocarbon ages of bulk SOM in the polygon centre (0 to 43 cm depth: modern to 300 yrs BP) imply an increased accumulation of fresh organic matter. Decreasing ^{14}C ages of bulk SOM in the polygon rim with depth (0 to >25 cm depth: 866 to 3000 yrs BP) reflected the accumulation of 'old'/refractory material with depth. Whether 'old' SOM compounds are stabilized by the association with mineral compounds or by other mechanisms will be answered by radiocarbon dating of physical SOM fractions.

Microbial metabolic activities have been identified by the analysis of their membrane lipids in combination with ^{14}C dating of these compounds [*Rethemeyer et al., 2005*]. Radiocarbon ages of individual phospholipid fatty acids (membrane lipids of living microbial cells) were always higher compared to the ^{14}C ages of the bulk SOM in the same depth interval indicating that the living microbial biomass feeds mainly on 'younger'/labile carbon pools. This suggests that either old carbon pools are not in favor of microbial decomposition or are not bioavailable.

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Permafrost Extents in China during the Last Glaciation Maximum (LGM)

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Inactive ice wedges in Wuma (52º50' N, 120º45' E, 350 m) in the northern Da Xing'anling Mountains was formed and active during the Last Glaciation Maximum (LGM) in the Late Pleistocene on the basis of C^{14}-dating results (14,475 ±300 a B.P.) at the depth of 2.1m of the host material (Fig. 1). It was surrounded by ice-rich gravelly silt. It was inferred, from the sedimentary analysis of the host materials, that the mean annual air temperatures (MAAT) would be approximately -9 ~ -10 ºC for the ice wedge formation. Based on the pollen records in the Sanjiang plain (47º ~ 48º N), the MAATs of -5 ~ -6ºC in the late period of Late Pleistocene was inferred (Li, 1991). Comparison of the two MAATs at the same period, the elapse rate of MAAT with northern latitude was about 1ºC/ºN. Consequently, it is likely that the 0ºC isotherm of MAAT in Northeast China was in the Songliao Plain (42ºN) slightly north of Shenyang (41º51'N). It is known that the mean annual ground surface temperature (MAGST) of 0ºC is essential for the occurrence of permafrost. Generally, the difference between MAGSTs and MAATs is about 1.5~2.0ºC. As a result, the 0ºC isotherm of MAGST probably paralleled along the 43ºN in the vicinity of the Horqin Left (East) Wing Rear Banner and Changtu, with a present MAAT isotherm at 7~8ºC. However, influenced by other environmental factors, such as topography and elevations more than 500~600 m, the southern limit of permafrost (SLP) might not linearly extend in the east-west direction, but might protrude southwestwards along the Qianshan Mountains in Eastern Liaoning Peninsula with the southern most part at 41ºN.

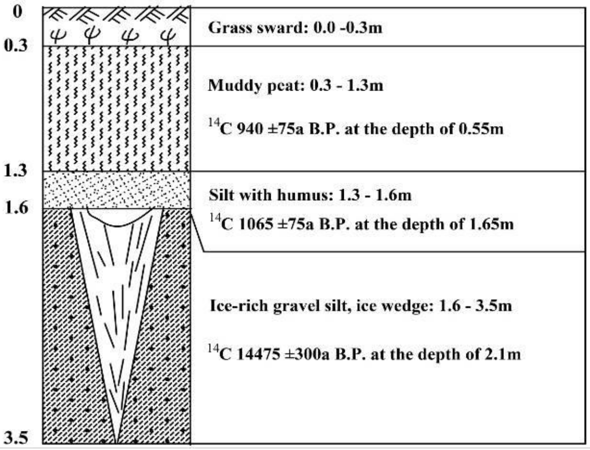

Fig. 1 Ice wedge diagram in Wuma in the north of Da Xing'an Ling Mountains

The SLP in Northeastern and Northern China was delineated on the basis of the fact that the 0ºC isotherm of MAGST in the Late Pleistocene coincides with the present 8~9ºC isotherm of MAAT (Fig. 2). The SLP starts in the south of the Water Divide of the Song and Liao Rivers (42ºN) in Northeastern China, protrudes southwestwards into the Eastern Inner Mongolia and Northern Shaanxi Provinces, extends west along the southern edge of the Inner Monglia Plateau, and finally intersects with the lower limits of permafrost (LLP) in the mountains in the Western China and on the Northeastern Qinghai-Tibet Plateau at elevations of 2200~2300 m. It is about 1º to 2º south of the locations where many sand or soil wedges were identified, such as Datong in Shanxi Province and Erdos (Dongsheng) and the Aohan Banner in the Inner Mongolia [*Yang et al, 1983; Cui et al, 2004*]; and 4º to 7º north of those locations with numerous excavations of fossils of mammoth (*Mammuthus primigenius*) and wooly rhinoceros (*Coelodonta tologoijensis*) [*Sun, 2007*]. This delineation in the SLP agrees well with those at similar latitudes in other adjacent and other regions in the world [*Xu et al, 1983*].

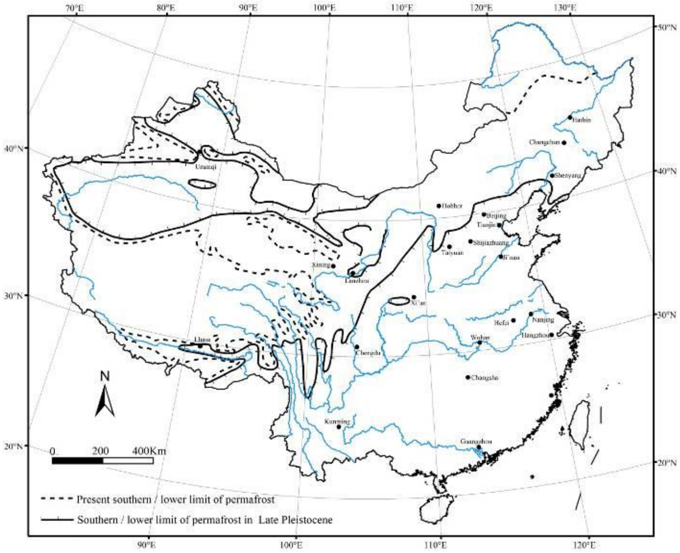

Fig. 2 Permafrost extent in China during the Last Glaciation Maximum (LGM)

In addition, soil wedges formed in the Late Pleistocene have been found in Nachitai and Cold Lake with longitudes ranging from 93º to 94º30'E and latitudes ranging from 36º to 38º50'N on the Northern Qinghai-Tibet Plateau. Inferred from the presence of these soil wedges, the LLP of the LGM was at 2600~2700 m in Nachitai, but 2150~2200 m in Cold Lake, with elevational differences of 450~500 m. It agrees well with the fact that the LLP descends with latitudes on the Qinghai-Tibet Plateau at present. For example, the LLP ascend at rates of about 150 ~200 m per 1º decline in northern latitudes [*Zhou 1982*]. Therefore, the LLP of the LGM on the Eastern and Southeastern Qinghai-Tibet Plateau, and in the Qilian Mountains, Tianshan Mountains and Altai Mountains can be delineated as follows:

The LGM LLP is estimated to be at 1950~2100 m in Yumen and Jiayu Passes (40ºN) in the northern piedmont of the Western Qilian Mountains, but 2200~2300 m in the Lenglongling (37º~38ºN) in the Eastern Qilian Mountains. It was extended to the southern and northern fringes of the Tarim Basin North and Northwest of the Qinghai-Tibet Plateau in the Late Pleistocene. For example, on the northern slopes of the West Kunlun Mountains, it varied from about 2800~2900 m in the western part (37ºN) to 2400~2500 m in the eastern part (39ºN). On the southern slopes of the Tianshan Mountains, the LGM LLP was at 2100~2200 m, whereas 1900~2000 m on the northern slopes of the Tianshan Mountains. Further northwards, it was about at 1400~1500 m on the southern slopes of the Altai Mountains.

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Svalbard Permafrost in a Long Time Perspective

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Detailed reconstructions of Arctic temperature developments during the Tertiary are still preclusive. It is clear, however, that the persistent cooling which ultimately leads to the Quaternary glaciations did not set in until around 33 Ma BP in Oligocene times. The steady northward drift of Europe, Asia and North America most likely contributed to the longer history of cooling recorded in these land areas. In addition, the gradual tectonic closing of the connection between the Pacific and the North Polar Ocean reduced the previous efficient ocean heat transport from equatorial regions toward the North Pole.

Other geological mechanisms leading to extensive land surface altitude changes may have been instrumental in the gradual cooling of the northern hemisphere climate. One important event may be attributed to the emplacement of magma from the Iceland plume in and below the crust, while later isostacy associated with Quaternary glaciations is believed to have been important in an second uplift event.

North Polar climate at the Pliocene-Pleistocene transition

The closure of present-day Panama isthmus about 3-4 Ma BP presumably was significant for this overall cooling. By shutting down the flow of water between the Atlantic and Pacific oceans, the Panama isthmus re-routed ocean currents in both the Atlantic and Pacific Oceans. Atlantic currents were forced northward into the present Gulf Stream. Warm Caribbean waters with high salinity thus began flowing into the northeast Atlantic, by which the climate of NW Europe and Svalbard became considerably warmer. The European Arctic also grew moister, and large glaciers formed in adjoining land areas, changing the planetary albedo towards lower values. The onset of northern hemisphere glaciation presumably began in the Late Miocene with build-up of ice in southern Greenland. However, progressive intensification of glaciation did not seem to have begun until 3.5-3 Ma BP, when the Greenland ice sheet expanded to include northern Greenland. The closure of the Panama isthmus thereby enhanced the already ongoing global cooling. Due to polar amplification the cooling may have been pronounced in many parts of the Arctic, leading to widespread growth of permafrost from about 3 Ma BP.

Palaeoclimatic reconstructions from the present Arctic North Atlantic for the following Pliocene-Pleistocene transition have revealed a number of apparent discrepancies. Around 2.6 Ma BP Major parts of Fennoscandia, Iceland and Greenland were characterized by cold climate and covered by large ice masses. At the same time NE Greenland and Svalbard presumably were without any major ice cover [*Funder et al. 1985*]. Late Cenozoic changes in the Barents Sea region may explain this apparent paradox. Today the Barents Sea receives about 40-50% of the warm water flowing into the Norwegian Sea, while the remaining warm water masses continue north along the west coast of Svalbard, into the Arctic Ocean or towards NE Greenland. It has long been recognised that the Barents Sea was subaerially exposed during pre-Quaternary times, and at that time all Atlantic water flowed directly into the Arctic ocean or towards NE Greenland. The following transition of the Barents Sea from a continental region to an epicontinental shelf sea may therefore have been an important driver for major changes in the Polar North Atlantic, by reducing the warm inflow to the Arctic Ocean and thereby increasing the extent of sea ice. This development may also explain the apparent paradox of the forested High Arctic [*Funder et al. 1985*]. A pronounced W-E temperature gradient presumably then existed across Svalbard, in contrast to now, where the main gradient is SW-NE. Thus, it is likely that the initial Svalbard permafrost mainly formed in the easternmost islands, and that permafrost formed later in the western regions.

Pleistocene (2.6 Ma-11.7 ka BP) Arctic climate

The global cooling that began during the Tertiary culminated in a series of step-like, sudden, changes in climatic conditions over the last 2.6 Ma as climate began a series of recurrent shifts between glacial and interglacial conditions. From ocean cores and long sequences of loess, it is apparent that no less than 25-30 and maybe more than 50 glacial cycles have affected the Earth's surface during the Quaternary.

The last 800 ka have been characterized by long glacial periods (90-100 ka) of cold climates interspersed with shorter interglacial periods (ca. 10 ka) of warmer interglacial conditions. Geological evidence suggests that more than 90% of these 800 ka in the Arctic was much colder than today. Very thick permafrost (1-1.5 km) in parts of Siberia presumably grew during most of the Quaternary, and especially since 800 ka BP. By its thickness it signals mean annual surface temperatures below –30°C for prolonged periods in these regions.

Early Holocene (c. 11.7-5 ka BP) Svalbard climate

The warming at the end of the Younger Dryas period 11.7 ka ago was abrupt. In central Greenland air temperatures increased by 7°C or more within only 10-30 years. Evidence from NW Spitsbergen suggests glaciers by 11.7 ka BP to have retreated behind their modern limits.

In the Northern Hemisphere, summer insolation peaked about 9 ka years ago when the last remnants of the large ice sheets in the northern hemisphere retreated rapidly. At that time the incoming solar radiation was approximately 8% greater than present. This may have been especially important for high latitude summer active layer thawing with daylight for 24 hours. Later the Northern Hemisphere summers have seen decreasing incoming solar radiation.

The early Holocene sea surface temperature record for the eastern Nordic Seas show a warming trend interrupted only by the short Preboreal oscillation at 9.8 ^{14}C ka BP. A major change of climatic conditions occurred over the Greenland and Norwegian seas as the insolation reached its maximum around 9 ka BP, when the sea ice cover and the oceanic fronts retreated to a northwesterly position along NE Greenland, and the ocean temperatures rose. Sea surface and air temperatures in the Svalbard region reached their Holocene maxima at 9–7.5

^{14}C ka BP and remained higher than present temperatures until c. 5 ka BP. From lacustrine evidence a warm early Holocene climate has been demonstrated, followed by a period of renewed glacier growth from 4-5 ka BP.

Late Holocene (c. 5 ka BP-2011 AD) Svalbard climate

In much of the Nordic Seas the mid Holocene period 6–4 ka BP encompasses a transition to reduced Atlantic Water influence and lower sea surface temperatures. The late Holocene period from ca 4 ka BP to the present is characterized by sea-surface cooling caused by decreased Atlantic Water influence in the surface waters of the Nordic Seas, including coastal Svalbard. Atlantic Water inflows to the Arctic Ocean may also have been affected by bathymetric changes elsewhere in the Arctic. The opening of Bering Strait c. 11 ^{14}C ka BP might be especially important as it introduces relatively fresh Pacific waters into the Arctic Basin. This may have strengthened the meridional Atlantic Water circulation through the Fram Strait, at the expense of Barents Sea inflow. On the East Greenland Shelf evidence for late Holocene cooling from 4.7 ka BP has been found, associated with southward expansion of the Arctic sea ice and increased polar water influence. A general shift towards cooling and return to the present tundra environments at many Eurasian arctic and subarctic sites apparently started around 4.5 ka BP.

In Svalbard permafrost was reforming near sea level shortly before 3 ka BP [*Humlum et al., 2003*], and there are evidence for a late Holocene glacier advance reaching maximum size around 2.3 ka BP and during the Little Ice Age (LIA; c. 1300-1920 AD). In western Spitsbergen, sediments from the proglacial lake Linnévatnet indicate that a nearby presently ice-free cirque was glaciated for the first time during the Holocene. In central Spitsbergen *in situ* vegetation found below the 5 km long glacier Longyearbreen demonstrates a net glacier advance of about 2 km since 1.1 ka BP. Most likely, also Svalbard permafrost grew to its present extension and thickness during the LIA.

A major ion series developed by sampling from the GISP2 ice core from central Greenland have enabled a mapping of the shifting strength and position of the Icelandic Low and the Siberian High in the past. Around 1400 AD a marked change suggests more stormy and wet conditions in the North Atlantic Arctic sector, presumably caused by a stronger Siberian High and a deeper Icelandic Low. Another prominent change occurred between 1920 and 1927. Apparently the Icelandic low reached maximum intensity and a relatively northerly position just prior to the major atmospheric warming registered in many Arctic regions at that time, after which the Icelandic low weakened and shifted southwards. This coincides with the onset of a prolonged weakened state in the Siberian High, leading to relatively dry conditions in Svalbard since about 1920, as shown by meteorological measurements.

A prominent feature of the meteorological Svalbard temperature record is a marked warming 1917-1922, which changed MAAT at sea level from about -12.2°C to -4.9°C. Following this temperature rise the record is characterized by a warm period lasting until around 1955, a cold period lasting to about 1990, and a new warming lasting until at least 2006 [*Humlum et al. 2012*]. A number of decadal-scale variations apparently are superimposed on this overall pattern of change. MAAT variations are mainly derived from variations in winter temperature, and the summer temperature shows small variations only. Since about 1990 the Svalbard MAAT has increased about 3-4°C, but it is not possible to determine if this temperature increase is the leading edge of a more permanent increase as suggested by most climate models, or merely represents a typical decadal-scale oscillation. Indeed, decreasing MAAT since 2006 suggests an oscillation [*Humlum et al. 2012*]. The post-LIA warm period since around 1920 has resulted in generally increasing Svalbard permafrost temperatures. However, the low precipitation and the derived shallow post LIA winter snow cover may to some degree have protected Svalbard permafrost towards recording the full thermal effect of the higher air temperatures during the 20th century.

Near future (2012-2100 AD) Svalbard climate

For Svalbard novel downscaled climate models assuming dominance of atmospheric CO_2 suggest a future warming rate up to year 2100 three times stronger than observed during the latest 100 years [*Førland et al. 2012*]. The average winter temperature in central Svalbard at the end of this century is projected to increase with about 10 °C, or about 1.1 °C per decade. These changes would adversely affect Svalbard permafrost towards higher temperature and partly thawing at low altitudes.

In contrast to this warming scenario, two alternative, independent climate models assuming dominance of natural variations [*Humlum et al. 2012; Solheim et al. 2012*] suggest variable and not increasing future temperatures for the Svalbard region until at least 2035. The next decade might even be characterized by cooler conditions, which would end the recent permafrost warming. Svalbard is considered having a climatic sensitive location, and the next 5-10 years will show which of these three different modeling attempts is most correct.

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Behaviour Of Experimental Permafrost Submitted To Warming Conditions: Lithology & Ice Content Impact

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Introduction

Today, permafrost remains about one quarter of the landmass of the northern hemisphere [*Zhang et al., 2000*]. In these regions, the consequences of global warming are felt with a melting permafrost in the order of 0.1 m / year up to the surface and 0.09 m / year at their base [*Osterkamp 2007*].

Understanding of the evolution of continental surfaces subjected to periglacial climate changes requires a wide knowledge of the behaviour of permafrost. This work shows that experimental data help to better constrain the impact of warming on permafrost.

Our methodology is based on physical modeling in cold-room. This methodology permits understanding of the controlling factors on permafrost evolution as, for example, lithology, water-content and ice-content. Physical modeling brings also interesting data on (i) the surface evolution (thaw-settlement), (ii) the thermal evolution (monitoring of the freezing-thawing front) and (iii) changes in active layer thickness.

These experiments are a preliminary work and models are not to scale. Consequently the results are not directly applicable to field analogy.

Methodology

Physical modeling in periglacial conditions implies specific cold-rooms available in the UMR CNRS 6143 - M2C (Caen, France).

Experimental permafrost was reconstituted according to field data. The lithology of the material is a mixture of fine sand and loess. The ice-content is between 30 and 80%.

A set of 25 experiments was set up to test the different controlling factors on permafrost evolution.

Permafrost blocks have dimensions of 0.37x0.57x0.25 m. They are thermally insulated so that the fronts of freezing and thawing are produced only by the surface of the block. Infrared rays are used to produce warming of the air and the ground surface. The temperature measurement is registered by 12 thermal sensors located at different depths.

Topographic data are collected every day, before and after the thawing period.

Results

Experiments have generated a large amount of data useful to show what might be the effects of warming on experimental permafrost taking into account 6 major parameters: lithology, ice-content, occurrence of massive ice-layer, water-content, thawing temperature, number of freeze-thaw cycles. In this abstract are only considered the first 3 parameters.

Lithology impact

In the experiments, two types of sediments were used. A mixing of loess-dominated sediments (2/3 loess + 1/3 fine sand) and a sand-dominated sediments (1/3 loess + 2/3 fine sand).

Lithology has a major role on the topography evolution and the structure of the active layer. The thaw-settlement of the ground-surface by thawing of the ice, leads to a rearrangement of particles which is control by the nature and the size of the sediment particles. The lithological control can be enhanced or decrease by the amount of ice.

In the first case, with a 30% ice-content, the thaw-settlement of the surface and the thickening of the active layer are clearly favored by a sand-dominated lithology (Fig. 1 - A1, A2). Changes are the most important in sandy sediments.

With a 50% ice-content, the thaw-settlement and the thicknesses of the active layer are similar for the loess- and the sand-dominated models (Fig. 1 - A1, A2).

With a 80% ice-content, the thaw-settlement strongly increases for the loess-dominated models (Fig. 1 - A1). The thickness of the active layer remains constant with respect to other models (Fig. 1 - A2).

Ice-content impact

In the experiments, 3 ice-contents are tested 30, 50 and 80%. As shown by previous models, the ice-content has an important role in the thaw-settlement of the permafrost surface and therefore on the evolution of the topography.

For loess-dominated models, one can note significant changes in ground-surface thaw-settlement. For an increasing ice-content, the final thaw-settlement evolves from 5, 10 to 30 mm (Fig. 1 - A1). The value of the thickness of the active layer remains about 20 mm (Fig. 1 - A2).

For sand-dominated models, the thaw-settlement reaches the same max-value for the 3 models (Fig. 1 - A1). The max-value of the active layer thickness is obtained for the less ice-rich model (30%). Then, active layer thickness decreases when ice-content increases (50% and 80% ice-content models, (Fig. 1 - A2).

Massive ice-layer impact

In some models, a massive ice-layer is interbedded near surface. This ice-layer could represent segregation-ice or buried-ice. Thickness of the massive ice-layer tested is 20 mm. Models with a massive-ice layer are sand-dominated and moderate ice-rich (50% ice-content).

The thaw-settlement with massive ice-layer is the most important in our range of data (35 mm after 15 cycles). Its evolution is not linear as a consequence of a period of quick ice-layer melting (Fig. 1 - B). For comparison the same models without ice-layer show a surface thaw-settlement restricted to 15 mm.

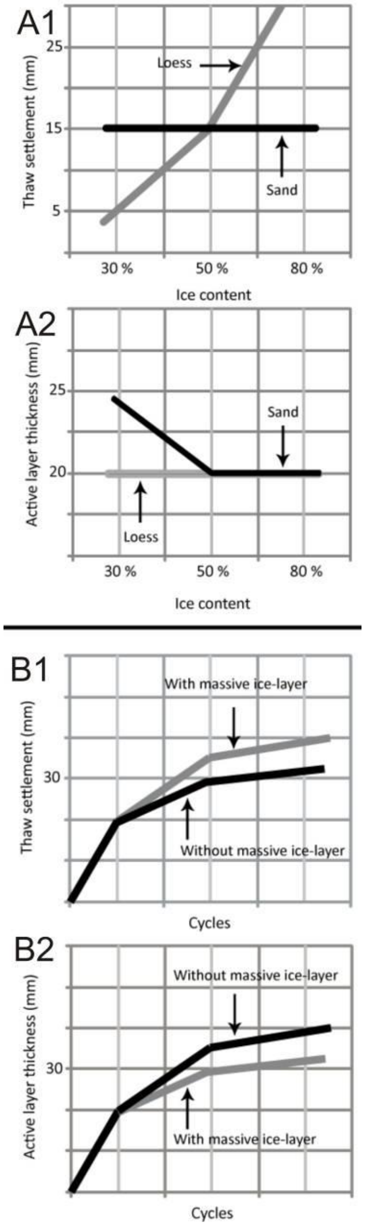

Figure 1: Trends for ground surface thaw-settlement and active layer thickness obtained during physical modeling on experimental permafrost submitted to warming.

Conclusions

This work contributes to the development of new experimental techniques applied to permafrost. It also contributes to the enrichment of databases related to physical modeling on permafrost.

According to our results it is already possible to identify some major trends (Fig. 1):

(1) for poor ice-rich permafrost (<50% ice-content) thaw-settlement is higher for a sandy sediment (A1);

(2) for a loess-dominated permafrost, thaw-settlement increases with the percentage of ice (A1);

(3) for a sandy sediment, thaw-settlement is not dependent on ice-content (A1);

(4) for a loess-dominated permafrost, the thickness of the active layer is not dependent on the percentage of ice (A2);

(5) for a sandy sediment, the thickness of the active layer seems anti-correlated with the ice-content (for ice-content > 50%, A2);

(6) the thaw-settlement increases strongly when a massive ice-layer starts to melt (B1);

(7) the presence of a massive ice-layer in sub-surface slightly decreases the thickness of the active layer (B2). This point can be correlated with the amount of heat needed to melt the massive ice-layer.

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Spatial Variability of Ground Temperatures and Active Layer Thickness in the Central Tian Shan

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Introduction

Climate change actually leads to an accelerated ablation and retreat of high mountain glaciers in most parts of the world, and to a runoff increase of the related rivers in the short to middle term. Whereas this is a well-known fact, the additional runoff supplied by slowly melting ground-ice and perennial snow fields is almost unknown. However, this periglacial contribution is significant in extremely arid mountain areas as e.g. the Central Tian Shan. Here, the water of the rivers form the vital source for the economic development of the Taklamakan basin, rich in natural resources, and strongly suffering from water shortage. With a contribution of more than 70 % to the total runoff of the Tarim river, the Aksu has by far the largest impact on the water resources and the future development of this region under climate change conditions.

The availability of basic data (e.g. mean air temperature) is very scarce in the whole region. Main scientific tasks of our subproject hence include an improvement of knowledge on permafrost distribution and the variability of ground temperatures and active layer thickness. These results are fundamental to better understand the contribution of permafrost to the water discharge in the Aksu catchment and the Central Tian Shan.

Study area

The Tian Shan, located in Central Asia, stretches some 2,500 km from east to west. It is one of the highest mountain ranges in the world and can be divided into a Western, Inner, Northern, Central and Eastern Tian Shan. Maximum altitudes range from more than 7,000 m a.s.l. in the Central Tian Shan to about 6,000 m a.s.l. in the Inner and 5,000 m a.s.l. in the other parts of the Tian Shan, respectively. The highest mountains, Pik Pobedy (7,439 m a.s.l.) and Khan Tengri (7,010 m a.s.l.), are also the most northerly peaks over 7,000 m a.s.l. in the world. Apart from the southwest, where it is bordering the Pamir Mountains, the Tian Shan is surrounded by (semi-) arid lowlands. The climate can be described as highly continental, with decreasing precipitation from northwest to southeast. Therefore the average annual precipitation in the Central Tian Shan is very low, even in high altitudes. The altitudinal lower limits of continuous permafrost in the region have been identified at 3,500 m a.s.l. for the Northern and Eastern, 3,600 m a.s.l. for the Inner and 3,800 m a.s.l. for the Western Tian Shan [*Gorbunov et al., 1996*].

Our detailed field investigations in the ca. 130 km² Gukur catchment started in 2010. The catchment is a tributary of the Aksu river and is located in the vicinity of Tomur peak. Altitudes in the catchment range from about 2,000 m a.s.l. to nearly 6,000 m a.s.l..

Data and Methodology

Instruments

A dense network of 45 high resolution thermistor strings and mini temperature data loggers were installed in the Gukur catchment.

The commercial M-Log5W (GeoPrecision, www.geoprecision.com) wireless mini data loggers with inbuilt PT1000 sensors are used to measure the ground surface temperature (GST). They have a high memory capacity (2048 kB), low energy consumption and come in a small, but waterproof housing. The inbuilt PT1000 temperature sensor has a high resolution of 0.01 °C and an accuracy of ± 0.1 °C. These features minimize the maintenance to a minimum (battery change every 5 to 10 years, depending on temperature conditions) and are thus ideal for continuous temperature monitoring in remote areas. Furthermore, the wireless interface with an operating range of up to 100 m (433 MHz) allows reading-out data remotely by laptop and a USB-dongle.

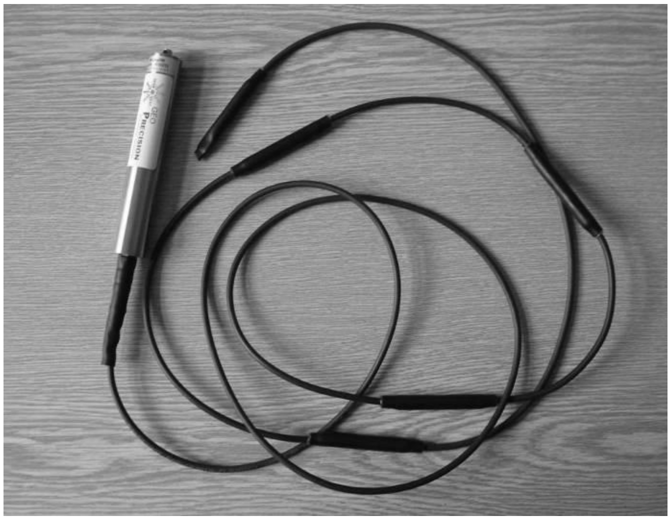

Figure 1. M-Log5W data logger (www.GeoPrecission.com) and attached thermistor string.

For the temperature measurements at multiple depths in the active layer, the same M-Log5W wireless mini data loggers are used. But, instead of an inbuilt temperature sensor, they can be attached to thermistor strings (Figure 1). For maximum cost benefits, the thermistor strings were designed and manufactured at the Institute for Physics at the University of Giessen with the help of GeoPrecision. The chosen DALLAS DS1820 temperature sensor has a lower resolution (0.065 °C) and accuracy (± 0.25 °C) in the expected temperature range, but is cheap and easy to handle. The unique 64-Bit serial code allows multiple DS1820 sensors to function on the same 1-Wire bus and can therefore be controlled with an M-Log5W. For each string, five DS1820 sensors were used with intervals of 20 cm, 20 cm, 30 cm and 50 cm, adding up to a total length of 120 cm. Some extra cable ensures that the attached M-Log5W can be safely buried and hidden from human and animal disturbances. The temperature strings are waterproof and resistant to tensile stress.

Experiment design

In order to identify the factors having the largest influence on GST and active layer depth, the 45 locations were carefully chosen to represent the local conditions in terms altitude, topography, substrate and ground cover as well as snow thickness and distribution.

While altitudes range from about 3,400 m to 4,130 m a.s.l., the substrate and ground cover can be grouped in three classes: (1) very fine grained and grass covered deposits at valley and lee positions, (2) coarse blocky material at talus slopes and young moraine deposits and (3) a mixture of coarse and fine grained material with very little grass cover at older moraine deposits. As there is no direct information on snow cover, the intensity of the daily temperature amplitude can be used to identify the presence and duration of snow cover. Additionally, topographic parameters in combination with wind exposure are taken as a proxy for snow depth. The re-distribution of snow, common in cold and dry environments, results in thicker snow covers on gentle slopes in lee positions due to drift snow.

Depending on substrate, the depths of the deepest sensor of the thermistor strings ranges from 72 cm to 125 cm below surface. To best represent the GST, the upper most sensor of the string as well as the M-Log5W with inbuilt sensor are at a depth of 2 cm below the surface, with only few exceptions at 5 cm. Temperatures are recorded at an hourly interval.

First results and outlook

Data quality

The instruments proved to be highly reliable and easy to handle. Time consuming recovery of the data loggers and therefore loss of logger and data is not applicable due to the wireless data interface.

Analysis of the zero curtain periods also indicates a higher accuracy of the DALLAS DS1820 temperature sensor in the relevant temperature spectrum than the 0.25 °C stated before.

Spatial variability of GST

First results indicate that the depth of the active layer and the propagation of the diurnal temperature signal depend - besides altitude, slope and aspect - largely on substratum and snow distribution. Especially, a cover of large blocky debris material favors the occurrence of permafrost, as cold air can circulate freely between the large blocks. Furthermore, with less than -3 °C, wind exposed ridges show the lowest mean annual ground surface temperatures (MAGST) of the observed sites. Relatively large daily temperature amplitudes at these wind exposed spots indicate a very thin snow cover during winter time. Re-distribution of snow by wind significantly influences the snow distribution in the very cold and dry climate of the Central Tian Shan. Without the insulation effect of a thick snow pack, cold temperatures can penetrate deep into the ground. Besides snow thickness, onset and duration of snow fall is of great importance for the GST [*Bartlett et al., 2004*]. In addition, snow has a high albedo and in late spring, snow cover can cool the ground considerably. These findings clearly underline the significance of snow cover and drift snow for permafrost distribution in the Central Tian Shan.

The detailed identification of parameters determining the active layer thickness and thaw dynamics is fundamental for the large scale modelling of the state of the permafrost in the Central Tian Shan. Furthermore, the field studies will contribute to a better understanding of the thermal effects of substantial debris cover of subsurface ice-rich material or ground-ice, and of the temperature regime of rock glaciers and ice-cored moraines. These features store large amounts of ice in a permafrost environment over long time periods.

Acknowledgments

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An Optimization Algorithm For Interpreting Thermal Parameters For Frozen Soils With Significant Unfrozen Water Content

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Motivation

The thermal conductivity and heat capacity of soil and rock are important parameters in modeling the ground thermal regime. In permafrost science, these parameters have typically been estimated from time series of ground temperature measurements, as part of the model optimization or from laboratory measurements on samples (calorimetric or thermal methods).

Over the past decades, simple heat pulse sensors have become available that allow calculation of thermal conductivity and heat capacity based on heat pulse propagation in the material in question [*Campbell 1991*]. The sensor generates a heat pulse with a heater in one pin, and measures the temperature development some short distance away, using a thermistor in another pin. The sensor device is small and can be installed either in the field for in-situ measurements or in samples in the laboratory.

Typical analysis of data from such sensors is based on the assumption that no phase change takes place in the course of the measurement. However, when the method is applied to the study of fine grained materials at sub-zero temperatures where changes in unfrozen water content may be significant, the interpreted results are erroneous due to the effect of latent heat.

In this study, we are attempting to establish an optimization algorithm for interpreting the thermal soil parameters from measurements with needle pin sensors by taking into account the temperature variation in unfrozen water content.

Theoretical background

Forward modeling framework

Our modeling framework is based on a description of the sensors heater as an infinite line source. We therefore use a finite difference approach to solving the heat conduction equation in cylindrical coordinates, centered on the heater pin:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\lambda_e\frac{\partial T}{\partial r}\right) = \left(C_e - L\frac{\partial \Theta_u}{\partial T}\right)\frac{\partial T}{\partial t} \tag{1}$$

In eq. 1, the radial distance from the heater is r [m], T is the temperature [K], t is the time [s], L = 333.2 MJ/m^3 is the volumetric heat of fusion of ice (expressed per m^3 of water), and Θ_u is the temperature dependent volumetric unfrozen water content [m$^3_{water}$/m$^3_{soil}$]. The soil is considered as a large homogeneous continuum, where λ_e and C_e are the temperature dependent effective thermal conductivity [W/m·K] and heat capacity [J/m^{3}K], based on weighing the respective properties of the soil in frozen and unfrozen states relative to the fraction of ice and unfrozen water in the pores. According to Nicolsky et al. [*2007*] they can be taken to be:

$$C_e = C_f\,(1-\phi) + C_t\phi \tag{2}$$

$$\lambda_e = \lambda_f^{(1-\phi)}\lambda_t^{\phi} \tag{3}$$

where subscript f and t denote frozen and thawed states respectively, and ϕ is the fraction of the unfrozen pore water.

The initial condition is a constant temperature throughout the model domain corresponding to the soil temperature before the measurement, and we apply a Neumann (flux-type) boundary condition at r = 0. The flux is non-zero during heat pulse generation, and zero at all other times. At the outer boundary, far from the domain of interest, we use a Dirichlet boundary condition with constant temperature (equal to the initial domain temperature).

The temperature variation of the unfrozen water content of the soil is parameterized as:

$$\Theta_u = a\,|T - T_f|^{-b} \tag{4}$$

where a and b are empirically determined constants, and T_f [K] is related to the freezing point depression of the soil.

Measurement setup

The specific sensor in use is available commercially, and has a 3 cm long resistive wire heater enclosed in a metal pin, and a thermistor in a second pin oriented parallel to and 6 mm from the heater. A heat pulse is generated during typically 4 seconds, and the resulting temperature rise and decay is logged for two minutes. The measurements are repeated at different discrete sample temperatures between -10 and +5 °C.

The temperature variation of the unfrozen water content is established independently by measuring the temperature variation of the permittivity of the soil by means of frequency domain reflectometry. The permittivity is translated into unfrozen water content using different calibration formula for different soil types.

Optimization algorithm

The thermal parameters, thermal conductivity and heat capacity in completely frozen and thawed states, are estimated using an iterative non-linear least squares optimization scheme. The cost function is based on the distance between the observed temperature time series – the temperature rise and decay measured during a 2 min time period counted from the beginning of a 4 s heating period – and corresponding synthetic time series calculated based on eq. 1. The optimization is conducted jointly using measurement time series for several initial temperatures.

At the moment, the parameters of the unfrozen water content relationship are included as fixed prior knowledge, which could be obtained by Time or Frequency Domain Reflectometry, as described above.

Results

A synthetic example

A synthetic dataset was created by solving the forward problem using literature values for parameters of a typical fine grained soil (see table 1). Synthetic data were generated for measurements at T = -10, -5, -2.5, -1 and 1°C. The synthetic data thus obtained were truncated to 2 decimals and fed as observed data to the optimization routine. Different initial parameter guesses were used in the optimization which converged to the right solution in all cases (see fig. 1).

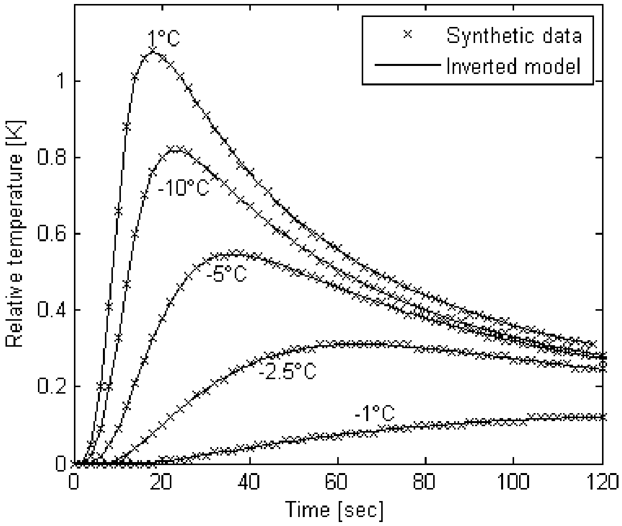

Figure 1. Synthetic data (crosses) and optimized model (solid lines) for heat pulse measurements at initial temperatures -10, -5, -2.5, -1 and 1°C. The significant change in amplitude and width of the peak is caused by the effect of latent heat.

Table 1. True parameters, example of initial guesses, and optimization results for the synthetic example, as well as optimization results using the standard analytical approach for -10 and 1°C.

Parameter	True	Guess	FD	Ana
λ_f [W/m·K	1.60	2.00	1.60	1.40
λ_t [W/m·K	1.40	1.00	1.39	1.42
C_f [J/m^3·K]	1.60	2.00	1.60	2.85
C_t [J/m^3·K]	2.10	1.70	2.10	2.07
Porosity	0.35	0.35*	-	-
a	0.21	0.21*	-	-
b	0.19	0.19*	-	-
T_f [°C]	0.0	0.0*	-	-

* Indicates parameter fixed in optimization.

Table 1 also includes estimates of the frozen and thawed thermal parameters based on optimization of the -10 and +1°C data sets independently using the standard analytical approach. As expected, the parameters in the thawed state are well estimated, since no phase change affects the measurements. The results show that with the parameterization chosen, even at -10°C the heat consumed during phase change significantly affects the estimated heat capacity and thermal conductivity, when using the standard analytical optimization approach. On the other hand, the FD approach does resolve the parameters well, even at freezing temperatures.

Application with real sample

We have measured a real permafrost drill core sample of frozen clay and silt using the described setup. The heat pulse data show similar change in amplitude and peak dispersion as observed in the synthetic data. However, the estimated thermal parameters of the sample in the thawed state were unrealistically low. We attribute this to problems determining the unfrozen water content parameters from the FDR and heat pulse measurements, possibly due to sublimation and drainage effects during the measurement cycle. We are targeting these problems in the further development of the laboratory setup, as well as enhancing the code to include also the unfrozen water content parameters directly in the optimization. Furthermore, we have installed the sensors at a field site in Sisimiut, West Greenland, where drainage is believed to be a minor issue. The installations will measure during the spring thaw, and should provide a useful data set for validating the approach.

Conclusion

We are developing an optimization algorithm for interpreting thermal parameters for frozen soils with significant unfrozen water content using a dual needle heat pulse technique. At sub-zero temperatures such measurements are significantly affected by latent heat effects due to changes in unfrozen water content caused by the transmission of the heat pulse. By including a parameterization of the unfrozen water content in the heat transport model and effective thermal conductivity and heat capacity, we account for these effects and improve the estimation of the thermal properties of the frozen sample.

The optimization method was proven to converge when applied on synthetic data. Data have been collected in the laboratory on a drill core sample, but due to sublimation and drainage effects during measurement, attempts at interpreting these data have thus far yielded unrealistic results. Further development of the optimization algorithm to handle also parameters of the unfrozen water content are presently undertaken, and in-situ field measurements are being collected for validation of the method.

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Ground State and Determination of the Strength and Compressibility Characteristics of Plastic Frozen Soils with the help of the Static Probing Method

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Introduction

Determination of the ground state and of the strength and compressibility characteristics of plastic frozen grounds is one of the principal issues being solved in the course of engineering and geocryological research. Traditionally it is solved as a result of: drilling of engineering and geological boreholes, selection of monoliths, their transportation (usually over long distances) to the sites of geocryologic laboratories equipped with refrigerating chambers and with the necessary facilities for laboratory testing of grounds.

The research carried out by foreign experts and the experts of our country (including NIIOSP) showed that it is possible to determine the properties of these grounds even in conditions of their natural occurrence by using the static probing method. Using probing in combination with traditional methods of geotechnical site investigations carried out in lower volumes allows us to considerably reduce their overall duration, cost and labor intensity.

In conditions of permafrost, a tensometric probe with a cone and a friction clutch, additionally equipped with a temperature sensor that is installed in the probe cap cone is used (fig.1). According to the international classification, such tests should be called the Cone Penetration Test with Temperature Measurement (CPTT).

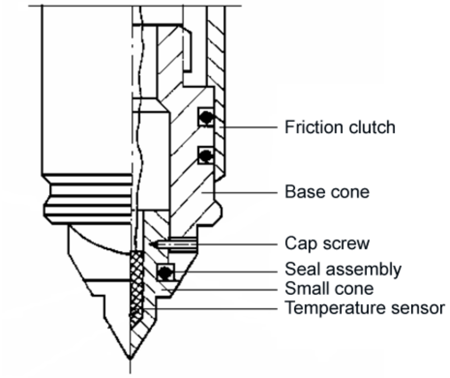

Figure 1. The tensometric probe with a temperature sensor (CPTT)

Determining the ground state based on the results of the probe temperature measurement results

Measuring the probe temperature during the process of its penetration

When the probe penetrates the thawed ground, a frictional interaction occurs between the ground and the cap. It is accompanied by a temperature rise of the cone and of the friction clutch. Their warm-up degree that at times reaches 10°C is proportional to the ground strength, coarse particles amount and probing speed.

The situation is not so clear when probing frozen ground. At the boundary of the "probe-frozen ground" system a complex thermo-physical interaction takes place. It depends on many geocryologial and technological factors. Seemingly abnormal thermo-physical effect was discovered and later studied during the experimental works.

While in low-temperature grounds, as well as in thawed grounds, the probe heated up (usually less than 1°C), in plastic frozen grounds (within high-temperature range close to the phase transitions zone) it often cooled down by 0.1…0.5°C.

The results of theoretical research made it possible to develop a model of the thermo-physical interaction of "probe-frozen ground" system. It explains the observed "pseudo-abnormal probe cooling" effect. It is based on the assumption that there are two mutually contrasting thermal processes that occur at the boundary of the "moving probe-frozen ground" system. The first process is caused by the heat flow absorbed by the probe. This flow is formed as a result of the probe friction against the ground. The second process is caused by the heat flow emitted by the probe as a result of ice melting temperature decrease during the pressure increase. Depending on the correlation of these flows, the probe temperature can increase or decrease.

The "pseudo-abnormal probe cooling" effect always indicates that the ground that has a negative temperature is in the frozen state.

Measuring the probe temperature during its shut-off and testing in the relaxation-creeping mode

Data analysis of the change in temperature of the shut-off and tested in the relaxation-creeping mode probe showed that temperature curves and corresponding thermal processes vary considerably in thawed and frozen grounds.

The experiments showed that after the probe shut-off in thawed grounds, the temperature curve, in general, is sufficiently described by a known relation from the solution for the problem that deals with the cooling of a one-dimensional body put into the environment with the constant initial temperature. Using this relation, at the initial section of a curve it is possible to determine the thawed ground original temperature.

However, the curves were of a complex character in frozen grounds and were adequately described using this relation only some time after the probe shut-off. This allowed us to draw a conclusion that it is impossible to use this relation to determine the ground original temperature.

Comparison of the probe temperature curves with measurements in the thermometric wells made it possible to develop a technique for determining frozen ground original temperature. It is based on the analysis of the probe cone temperature change in time. The probe freezing-in into the ground can be considered complete if the speed of the probe temperature change reduces to 0.01°C/min.

Determining the ground state based on the measurements of grounds resistance to probing

As is shown above, the probe equipped with a temperature sensor makes it possible to determine the ground original temperature that to a considerable degree characterizes its state.

This is often not enough for the exact evaluation of the ground state. It is also necessary to know its initial freezing temperature that depends on the lithology, salinity, peat content of the ground and so on. Therefore, this approach is not always convenient and reliable.

The research showed that when tests with the probe "stabilization" are performed, it is possible to identify the ground state with the accuracy that is sufficient for practical purposes, even without a temperature sensor.

As a result of field studies, it was revealed that the coefficient of the resistance stabilization of the ground underneath the probe cone (R_{vs} = q_{cv}/q_{cs}) is considerably different in thawed and frozen grounds. While in thawed grounds the coefficient value R_{vs} was 1.4 on average, in frozen grounds it was considerably higher - 3. However, this criterion does not work in all cases. Within the interval of R_{cvs} = 1.5…3.0, the histograms of thawed and frozen grounds are superimposed on each other creating an uncertainty zone.

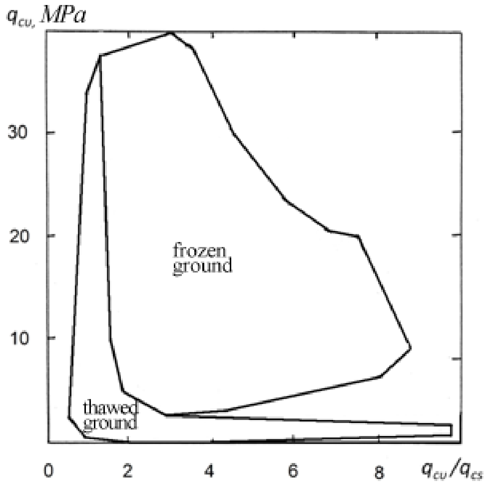

Figure 2. The diagram of determining the ground state based on the static probing data: q_{cv} and q_{cs} are resistances of the ground underneath the probe cone that are registered respectively during its penetration with the velocity of V_c = 0.5 m/min and in t_s=5 min after the start of relaxation-creep testing mode

Other signs based on the analysis of ground resistance to probing may help in ground state determination. Among them we can single out the following: sharp increase (decrease) in "velocity" resistance of the ground underneath the probe cone q_{cv} during its penetration within one engineering and geological element; the presence (absence) of initial increase of "stabilized" resistance of the ground along the friction clutch f_{ss}, that is caused by the process of the probe intensive freezing-in into the ground, and so on.

Due to that, a two-parameter criterion for ground state assessment was suggested (Fig.2). It turned out to be possible to divide the grounds according to their state more precisely, simultaneously using the coefficient of resistance stabilization of the ground underneath the probe cone R_{vs} and the «velocity» resistance q_{cv}.

Determination of mechanical properties' characteristics of plastic frozen grounds.

As a result of comparative field tests of plastic frozen clayey grounds by using the static probing method as well as in laboratory conditions (using the method of ball-stamp and compression tests), we obtained correlation dependencies making it possible to estimate the marginal duration value of equivalent cohesion C_{eq} and of deformation modulus E_f of the ground based on «velocity» q_{rv} or «stabilized» q_{rs} ground resistances under the probe cone.

In engineering geocryology the ratio C_{eq} = 0,5R_c is widely applied to frozen grounds. It enables the determination of the marginal duration value of the ground resistance to linear compression R_c based on the C_{eq} value.

To determine the specified values of C_{eq}, R_c and E_f in conditions of their natural occurrence, Table 1 or Table 2 can be used, depending on the probing mode. Forecast grounds' temperature correction (for the operating period of the designed object) may be done in two ways.

The first way is to correct the measured ground resistances to probing based on their dependences on the temperature before using the proposed Tables. The second way is to correct the values of characteristics of mechanical properties corresponding to the natural temperature of ground, based on their dependencies on the temperature.

Table 1. Determination of characteristics of strength (c_{eq} and R_c) and deformation (E_f,) properties of plastic frozen grounds based on "velocity" ground resistances to probing.

q_{rv}, kPa	5 000	10 000	15 000	20 000
c_{eq} , kPa	34	96	170	260
R_c , kPa	68	198	340	520
E_f , MPa	16	23	28	32

q_{rv} is the ground resistance under the probe cone, registered during its penetration with the velocity of V_c = 0,5 m/min

Table 2. Determination of characteristics of strength properties (c_{eq} and R_c) of plastic frozen grounds based on "stabilized" ground resistances to probing.

q_{rs}, kPa	3 000	5 000	10 000	15 000
c_{eq} , kPa	58	110	240	390
R_c , kPa	116	220	480	780

q_{rs} is the resistance of the ground under the probe cone, registered in 5 minutes after the start of the relaxation-creep mode of the test.

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Comparison of Development of Repeated Ice Wedges and Glaciers under the Conditions of Harsh Continental Climate: Exemplified by the Kodar Range and Charskaya Depression

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Abstract

The author assumes that comparison of the development of two essentially different products of cryogenesis will help to present a sufficiently clear picture of climate changes in the area of the Charskaya depression and the Kodar Range, and to determine the role of cryogenesis for this territory at present.

Keywords: climate change; cryogenesis; cryosphere; glacier; moraine; repeated-ice wedges.

Introduction

Mountainous areas under continental climate conditions are characterized by the presence of the cryosphere and, accordingly, cryogenesis, i.e. a total of physical, chemical, biochemical and other processes that occur within the cryosphere and are accompanied by ice formation. More precisely, these are the processes of change and transformation, to some extent, of mineral, organic, aquatic, and atmospheric substances that make up the geographical envelope in connection with the ice formation at subzero temperatures.

The resulting ice is also a rock with its characteristic properties. Formation of special objects of various kinds proceeds with the participation of ice.

Researchers from the V.B. Sochava Institute of Geography (including the author) as well as from Lomonosov Moscow State University, the Institute of Natural Resources, Ecology and Cryology, SB RAS, and the Limnological Institute, SB RAS, carried out scientific investigations of the Kodar glacial area by joint efforts and were helped by the international program "INTAS", during the period 2008-2010. The following were studied: the central area of glaciation of the Kodar, namely, Glaciers No. 20 (Azarova's), 18, 11, 12, and 14. according to the Catalogue of glaciers of the USSR [*1972*], as well as the Chara River valley, along the coastal cliffs of which there occur repeated ice wedges.. The present study attempts to compare the development of these homotopically related objects in order to reconstruct climate events of the past.

Objectives and results

The Kodar Range (56°45' to 57°15' N and 117° to118° E) is an uttermost northeast range of the Stanovoe Upland, situated in the watershed of the Vitim and Chara Rivers. It is predominantly northeast trending. The area of glaciation covers the highest central part. It rises above 2300 m; many summits reach 2700 - 2800 m and some are higher than 3000 m.

<u>Glacier No. 20 (Azarova's)</u>. It is a valley glacier of northern exposure, situated in the upper reach of the right-hand source of the Sredniy Sakukan River. The length of the open part of the glacier is 1540 m; the maximum width is 500 m. It is situated at an altitude of 2100-2425 m above sea level. On the foreslope of the moraine the fluvioglacial stream flows into the lake, where the right source of the Sredniy Sakukan River has its origin (the author's research, 2008). The firn line has it slowest point at lowest at 2192 m and the highest point is 2360 m.

<u>*Glacier No. 18*</u>. The slope of the kar glacier has a northeastern exposure. The area is 0.1 km^2. The largest length is 400m. It is located at altitudes of 2240-2380 m, at the beginning of the left source of the Sredniy Sakukan River. The lower edge of the glacier has retreated slightly. Its lowest point is located at an altitude of 2270 m.

On the largest Azarova's glacier, the end moraine of the glacier is a massive formation about 100 m high with traces of thermokarst. The ice core in its structure is about 80%. The moraine is composed of fragments of rocks with a diameter of 30-50 cm; however, pieces of up to 7 m in diameter are not uncommon. On their surface there are no signs of biological activity.

Behind the frontal moraine of the Azarova's glacier there is a complex of older moraines, separated by intermorainal lakes. It stretches over more than 1.5 km to the north.

A peculiar feature of the glacier No. 18 is that its moraine deposits exceed at least 10 times the area of the glacier. Moreover, the zone of accumulation is approximately twice as large as the area of ablation. Characteristic of a vast zone of moraine deposits are large subrounded boulders, ubiquitous thermokarst, and almost no initial growth of lichens is observed.

On the other glaciers similar moraine complexes are observed. This is suggestive of significant glaciation, which took place during the Little Ice Age.

The Charskaya depression is adjacent to the Kodar Range in the south. The bottom of the depression covers an area within the altitudes of 630 - 1100 m.

Outcrops of polygonal-vein structures occur often on both banks of the Chara River. During the 2009 expedition, a section of the river from the confluence of the Sangiyakh tributary to the ravine slightly downstream from the settlement Chapo-Ologo was investigated.

Pronounced outcrops of polygonal-vein structures were found twice at the site from the Sangiyakh River to the area near the Chapo-Ologo settlement. The most prominent is the outcrop "Belyi Klyuch" on the first terrace above the floodplain, described by Vasilchuk et al. [*2010*]. Here, thick syngenetic repeated-ice wedges, that originated 7500 to 10,000 years ago, are observed.

At the outcrops of the repeated ice wedges their sizes were registered; sampling of soil horizons and supposedly ancient organic residues preserved in the permafrost was carried out.

Visually, it is clearly seen that the repeated ice wedges are fairly stable. The processes of melting and washing by the river water are underway, but the pace of these processes is not catastrophic for the existence of these structures.

It is not entirely correct to compare glaciers and polygonal-vein structures due to the fact that they possess different properties; however, when viewed from the standpoint of their origin and the influence of the major factors, cryogenesis in this area is one such major factors.

It is known that during the Quaternary glaciation the altitude of the Kodar and Udokan Ranges contributed to the development of glaciers, reaching a length of 60-120 km with the thickness of ice amounting to 500-700 m [*Kovalenko 2008*]. Glaciers have transformed many valleys of the region into the typical troughs with a characteristic U-shaped transverse profile and left numerous traces in the form of terminal moraines, sheep-shaped rocks, fields of ice-scoured rocks, and smoothed rocky spurs. Apparently, during this period in the Kodar above the snow line the formation of acute-angled ridges and peaks was developing under the effect of denudation processes. In the Charskaya depression thick masses of loose material were accumulating and outwash landscapes were developing.

The glaciers of the Kodar glacial region are characterized by a tendency to respond to the observed climate changes, are not reduced much in area which is typical of the majority of glaciers in the world. but they are losing mass and thickness. This directly points to the dependence on the existence of these glaciers to a greater degree on the properties of the underlying surface than on the amount of precipitation in the territory.

With regard to the tendency of such response to the climate change for the repeated ice wedges of the Chara River, it is not characterized so rapidly by the rate of degradation, which would be expected given the recent positive changes in mean annual temperature.

The present author can agree with the V.S. Sheinkman’s view [*2008*] about the huge reserve of cold beneath the entire area of this region that had accumulated during the glaciation and that maintains such structures in a relatively stable condition.

Climatic conditions in the region are still extremely harsh to date. For some indices they are even more severe than in the Far North. For example, in Chara region the number of days with a mean daily temperature below minus 25°C is 94, whereas for Igarka and Magadan it is 84 and 36, respectively.

Conclusions

Thus, low temperatures and low moisture allow glacial objects to be in a relatively stable state. In our view, the development of natural ice of the Kodar Range and the Charskaya depression reflects the trend of global positive change of temperature with intrinsic characteristics of these territories. Externally, the ice structures are subjected to the warming impact of climate, while on the inside the cooling effect of permafrost zone still has a very strong influence. It can be said that ice formations of frost and glacial genesis, which are usually perceived as the antagonists, in this case are able to complement each other.

In the future, it is planned to trace the formation and existence of various glacial forms against the background of a severe climate.

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Promising Material for Thermal Stabilization of Grounds

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Negative cryogenic impact on the foundations of engineering structures in conditions of permafrost and heaving grounds requires specific construction measures. One of them is thermostabilization of foundation grounds with the use of thermal insulation materials. Until recently the ability of most of the conventional thermal insulation materials to accumulate moisture limited their usage for grounds thermal protection.

Foam glass is an efficient insulant that is able to save its thermal insulation properties in the ground. It is hardened glass foam with closed pores (material porosity reaches 97%), which prevents it from accumulating moisture. With the density of 140 kg/m^3, foam glass thermal conductivity is 0.045 W/(m·K), while the destructive load reaches 50 t/m^2 (0.5 MPa) [*Goryaynov & Goryaynova 1982*]. Incombustibility, chemical stability and durability make this material unique. However, due to the difficult and energy-intensive technique, foam glass is the most expensive non-organic thermal insulation material. This severely limits its use for thermal stabilization of foundation grounds.

The author solved the problem of obtaining foam silicate that is a cheap insulating material with properties similar to those of foam glass, based on cheap mineral raw materials (siliceous rocks - diatomite and tripoli) and alkaline additives. The idea of obtaining foam silicate is based on the process of leaching amorphous SiO_2 from siliceous rocks with the help of alkaline solution with soluble alkali silicates formation. When heated, they produce fusible eutectics and facilitate the mixture's transition into piroplastic state with the temperature lower than 700 °C [*Iler 1979*], and crystallization water that is released from clayey minerals of siliceous rocks foams the mixture. Thus, the mixture of siliceous rock and alkali may be subject to thermal treatment directly after leaching. This significantly simplifies this technology and significantly reduces its cost. Energy-intensive operations of quenched cullet preparation and its crushing into fine powder are eliminated.

The research was carried out with the use of diatomite from the Kamyshlov field in Sverdlovsk region, with amorphous SiO_2 content of 42.5 wt %. Diatomite was mixed with the 40% NaOH solution (the mass ratio of 2.3:1.0) with the addition of water until a homogeneous mass was obtained, and with the subsequent heating at the temperature of 20 and 95 °C. SiO_2 release (of the weight of dry diatomite) after leaching was determined by the method described in the work by Sokolovich [*1963*].

With the help of a plate granulator, grains with the diameter of 5-8 mm were produced from the mixture. Dried to constant weight at 100 °C, grains were subject to thermal treatment in open metal moulds, using the scheme: heating rate of 25 °C/min, soaking at 775 °C for 2 min and cooling with the furnace (~1 °C/min). During the thermal treatment, the grains foamed and became caked together, forming a continuous mass of foam silicate. Samples (cubes with an edge of 30 mm) were cut from it.

It was determined in the research that raising the temperature up to 95 °C significantly accelerates the process of leaching amorphous SiO_2. As early as 30 min after soaking at 95 °C its release is by 3.3 times higher than for the same time period at 20 °C, and makes up 43% against 13%, and experiences almost no increase thereafter. Samples density and strength change from 580 to 290 kg/m^3 and from 7.8 to 1.7 MPa with the change of SiO_2 release from 13 to 43 %, correspondingly.

Volumetric water absorption of all samples does not exceed 2 % (the ratio of absorbed water volume to material volume). Thermal conductivity of samples with the density of 290 and 580 kg/m^3 is 0.08 and 0.14 W/(m·K). The samples have a homogeneous structure that consists of closed cells the average diameter of which is 1.5 mm. Cells surface is well vitrified and its color varies from light gray to gray-green.

Given that foam silicate is on average by three times cheaper than foam glass, there is probably a possibility of full or partial replacement of sodium alkali with waste of different industries with various alkali content.

Foamed silicate will help minimize negative cryogenic impact, playing the role of a thermal insulator as well as the role of a hydrobonder, preventing moisture movement to the hazardous zones of foundation grounds.

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Cryogenic Processes and Phenomena in the Polar Urals

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Introduction

Polar regions relief clearly captures the development history of the area in the Pleistocene-Holocene period in its morphology. This enables the reconstruction of its formation conditions. Modern exogenic, mostly cryogenic, processes significantly contribute to the polar landscapes transformation, forming various landforms. In harsh geocryological conditions of the Polar Ural Mountains, they create a wide range of cryogenic phenomena. Cryogenic phenomena in the Urals were actively studied during the expeditions of the 2nd International Polar Year (1932-1933) [*Aleshkov 1935*] and in the middle of the 20th century [*Aleksandrov 1948, Boch & Krasnov 1943*]. Modern climate changes lead to the glacier shrinkage [*Ivanov 2009*], to the vegetation advance to the north and up the slopes [*Shiyatov 2009*], and to cryogenic conditions change.

Study methods and study area

During the summer field works of 2010 modern cryogenic processes and phenomena in the central part of the Polar Urals were studied. Analysis of climatic and cryogenic conditions was performed.

The Polar Urals stretch from southwest to northeast, from Mount Kolokolnya to Mount Konstantinov kamen. The southern part width is about 20 km. The ridge broadens to 70 km to the north of the Sob River. Western macroslope relief is of alpine type. The level difference is from 200 to 1300 m. This creates contrast compared to the flattened eastern macroslope. Middle mountains predominate there. According to A.I. Popov [*Popov 1967*], composing rocks are represented by rather dislocated Paleozoic metamorphic and effusive rocks. Loose sediments are thin and are represented by rubbly clayey silty moraine, gravitational coarse and deluvial soliflual clayey silt-sandy material on the slopes and by alluvial coarse and oozy-peaty material in the valleys. Thickness of permafrost strata is measured in tens and hundreds of meters (up to 400-500 m in the north). Permafrost temperature varies greatly, depending on hydrogeological conditions [*Panova et al. 2003*].

Climatic conditions of the central part of the Polar Urals are most fully studied based on the data from B.Khadata meteorological station that operated in 1957-1981 at the Institute of Geography USSR AS. A close correlation (0.9) of meteorological elements measured at this station with those of Vorkuta and Salekhard meteorological stations, located respectively 80 and 100 km from B. Khadata station, was established. At all three stations, air temperature variation is synchronous. The gradient is maintained. It is colder in winter and hotter in summer in Salekhard and on the eastern macroslope of the Polar Urals. As a result of mountains barrier effect, there is twice as much precipitation in the Polar Urals' central part as in Salekhard. Precipitation was measured more reliably and regularly in Salekhard, as compared with Vorkuta. According to the weather stations data, from 1946 to 2011, snow accumulation period lasts from October to May; average winter air temperature is –13ºC; average temperature in February that is the coldest month reaches –21ºC; the absolute minimum of air temperature in the northeast (Khalmeryu) is –49.6ºC; average summer temperature is +9ºC; temperature gradient is 0.6ºC/100 m. According to Salekhard weather station data, from 1891 to 2011, an average of 220 mm (up to 440 according to B. Khadata station) of solid precipitation falls during the winter.

Results and discussion

The special character of relief and climate creates conditions for existence of permafrost and about 90 cirque and slope glaciers in the Polar Urals [*Troitskiy et al. 1966*]. Due to the increased snow cover concentration in the western and central parts of the ridge, seasonal freezing depth and permafrost thickness are less (up to 100-150 m) than on the eastern macroslope with little snow, in the conditions of lower temperatures (up to 250-300 m.) Permafrost thickness on bedrock slopes of the mountains is insufficiently studied. However, most glaciers are located exactly on the western side of the Urals, due to the abundant snow accumulation in the erosional landforms. Vertical zonality is caused by the temperature gradient and is clearly distinguished by vegetation on the mountain slopes. Apart from that, cryogenic processes and phenomena vary on the slopes of different exposure and form certain sectors. In subarctic conditions, northern slopes get almost no sunlight. Vegetation is less developed there, which leads to cryogenic processes intensification.

Boulder streams, solifluction, landslides and creep are the most common of cryogenic slope processes. Solifluction terraces, streams and swells are especially well developed on the slopes of southern exposure due to higher-temperature grounds (Fig. 1d). Boulder streams, reaching tens of meters in width, creep and cryogenic deserption are better developed on the slopes of northern exposure. Forms of polygonal and heaving relief are indistinctly expressed in mountain valleys and are mostly confined to foothills. A number of mounds with the height of up to 2 m were described in the area of Lake B.Khadatinskoe and in the upper reaches of the B.Lagorta River [*Surova et al. 1975*], on the eastern spur of the Ray-Iz Massif [*Koshkarova et al. 1999, Troitskiy et al. 1966, Jankovska et al. 2006*] and in the area of Chernaya gorka at 2 km to the north from Polyarny village [*Jankovska et al. 2006*].

Forms of cryostructural relief are widely presented at the peak surfaces. They are formed during the frost sorting of materials. They have the forms of stone rings and polygons, (Fig. 1b), stone strips, reaching the length of 20 m and spot-medallions, (Fig. 1c). Meltwaters from snow patches and slope glaciers play a significant role in the stone strips formation (Fig. 1a). Cryogenic frost weathering plays a leading role in the development of nival landforms - kars, cirques, niches, ledges and golets terraces. The dimensions of these landforms indicate that their formation lasted for a long period that exceeds hundreds of thousands of years. Forms of thermokarst relief – basins, padings, flat bottom steppe depressions, subsidences, lakes and hollows – are developed in the central part of the mountains, mainly in the areas of ancient moraine deposits. Forms of cryoerosion relief (gullies, hollows and dales) are insignificantly developed.

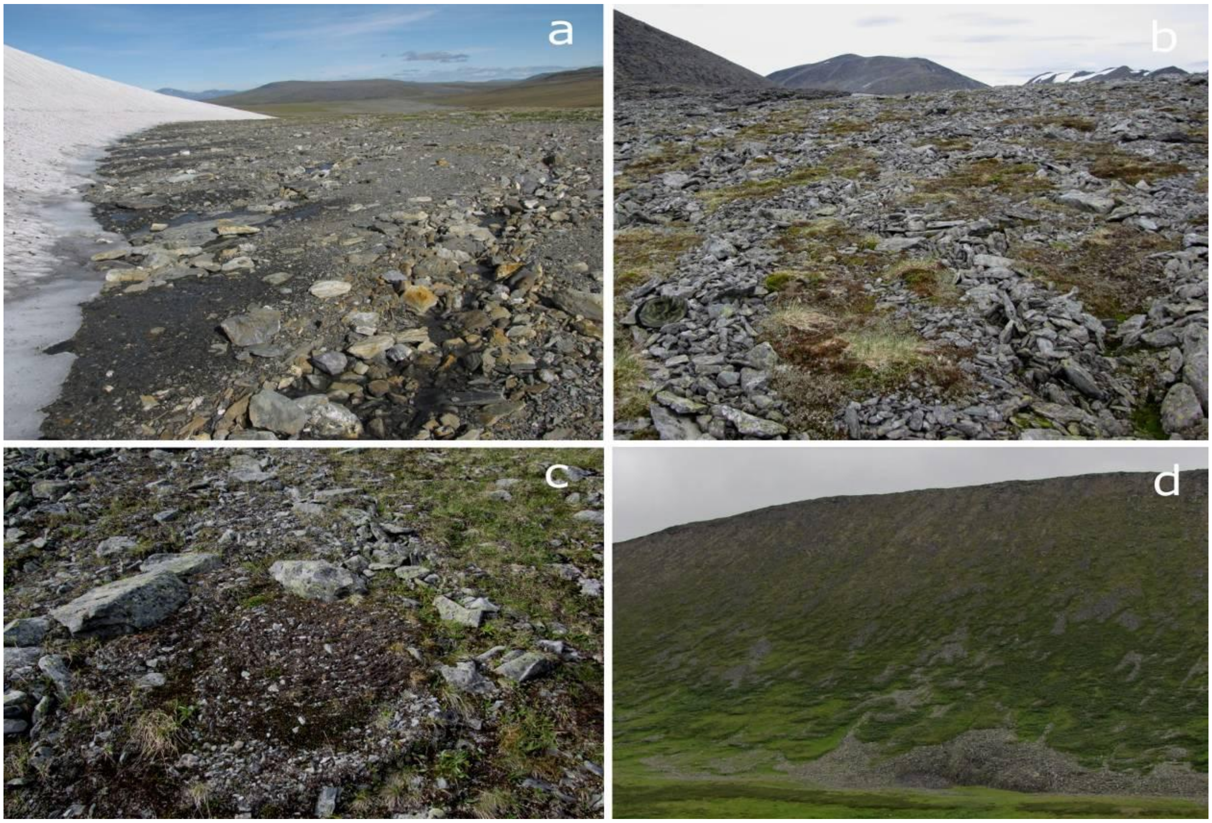

Figure 1. a – stone strips that are formed near the edge of thawing glacier № 138, b – stone polygons on the elevated plain of subaerial denudation to the east from glacier 22, c – spot-medallion in the valley of Lake B. Khadata, d – forms of solifluctional relief in the upper reaches of the B.Usa River. Photos by M.N. Ivanov, 2010.

Conclusions

Due to favorable cryogenic conditions, a whole range of cryogenic landforms is developed in the Polar Urals: from large (plains of subaerial denudation, cirques, kars, trough valleys, horn-peaks and golets terraces) and medium (rock glaciers, stone-fields, moraine lines, frost heaves) to small (solifluction terraces, earthflows, spot-medallions etc.). A stable cryonival complex of landforms was shaped by glaciers, processes of frost weathering, solifluction, erosion caused by meltwater, cryogenic sorting and other processes. In spite of climatic changes of the recent years, the intensification of cryogenic processes in the mountains is practically not observed and is manifested mainly in the seasonal thawing depth increase.

Acknowledgments

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Paleoclimate Reconstruction Based on Group Palynospectra

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Abstract

A method of paleoclimate reconstruction based on the weight of the dominant palynospectrum group is suggested. It was established that its size and distribution on the surface is roughly the same as the dryness index. Formulas of the relationship between the dryness index and other elements of the modern climate were found. Knowing the depth distribution of the dominant and the age of host grounds, it is possible to reconstruct climates of the past using these formulas. The paper discusses the case of such reconstruction for the area of Salekhard.

Keywords: dryness index; paleoclimate; palynospectra; phytoproduction; phytosphere.

As a rule, full sets of floristic elements (reaching 40 and more taxons) in palynospectra are divided into three groups by their general composition: 1) pollen of wood species and shrubs d_1, 2) pollen of herbs and low shrubs d_2 (sometimes low shrubs are identified as a separate group), 3) spores d_3. They roughly reflect the share participation of the upper, middle and ground storeys of vegetation in the floristic complex. This participation, similarly to species diversity, depends on the climate. Each group is characterized by a certain share of the total palynospectrum weight equal to one. It was demonstrated [*Konovalov & Ivanov 2007*] that the interaction of the palynospectrum parts can be considered a dichotomy of the D dominant (groups with large weight in the shares from 1) and sub-dominant $D_5=1-D$ (sums of relative weights of the other groups). Climatic parameters correlate with the D value very well. Minimum $D=0$ corresponds to the condition of impossibility of vegetation existence when all three d are equal to 0. This condition is fulfilled in the zone of perpetual cold, where the average temperature of the warmest month does not go higher than 0°C, and also in hot deserts, where the soil moisture content tends toward 0. Maximum $D=1$ is observed in the case of equal shares of warmth and moisture content. According to the nature of the distribution on the surface and to the value, D is roughly the same as the dryness index J. In the first approximation we can assume that $D \approx J$. Value $J \approx 1$ divides the phytosphere into moist phytosphere (cold) – pluviophytosphere, and dry phytosphere – xerophytosphere. Maximum D and J, equal to 1, are found in sub-taiga zone that represents an area of symmetry. The formulas of relationship J and, by means of it, D with the main climate elements and phytoproduction Pr were obtained. The supplemented Figure shows a schematic map that reflects these relationships in Tyumen-Omsk region.

Another method of identifying the relationship between D and the climate is presenting its components, similarly to palynospectra, in the form of a dichotomy of dimensionless components d_1 and d_2 that characterize warm and cold periods of the year and whose sum equals 1, for example: $d_1=d_{t1}=-t_1/2A$ and $d_2=d_{t7}=t_7/2A$, where $A=(t_7-t_1)/2$ amplitude; t_7 and t_1 – mean temperatures of the warmest and the coldest months. We can also present the duration and precipitation of the warmest and the coldest months of the year in the form of a dichotomy of dimensionless components d_1 and d_2 that characterize the aforementioned warmest and coldest months. In terms of quality these relative climatic oppositions behave similarly and correlate with each other very well. If we assume, according to the principle of actualism, that the relationship type of the dominant of surface and fossil palynospectra with climate elements is identical, then, knowing the depth distribution of value D and the age of host grounds, we can reconstruct the climates of the past using schematic maps (see Figure) and the formulas of the interaction of the modern climate elements, for example according to [*Konovalov & Ivanov 2007*]. An example of such reconstruction for the area of Salekhard is shown in the Table.

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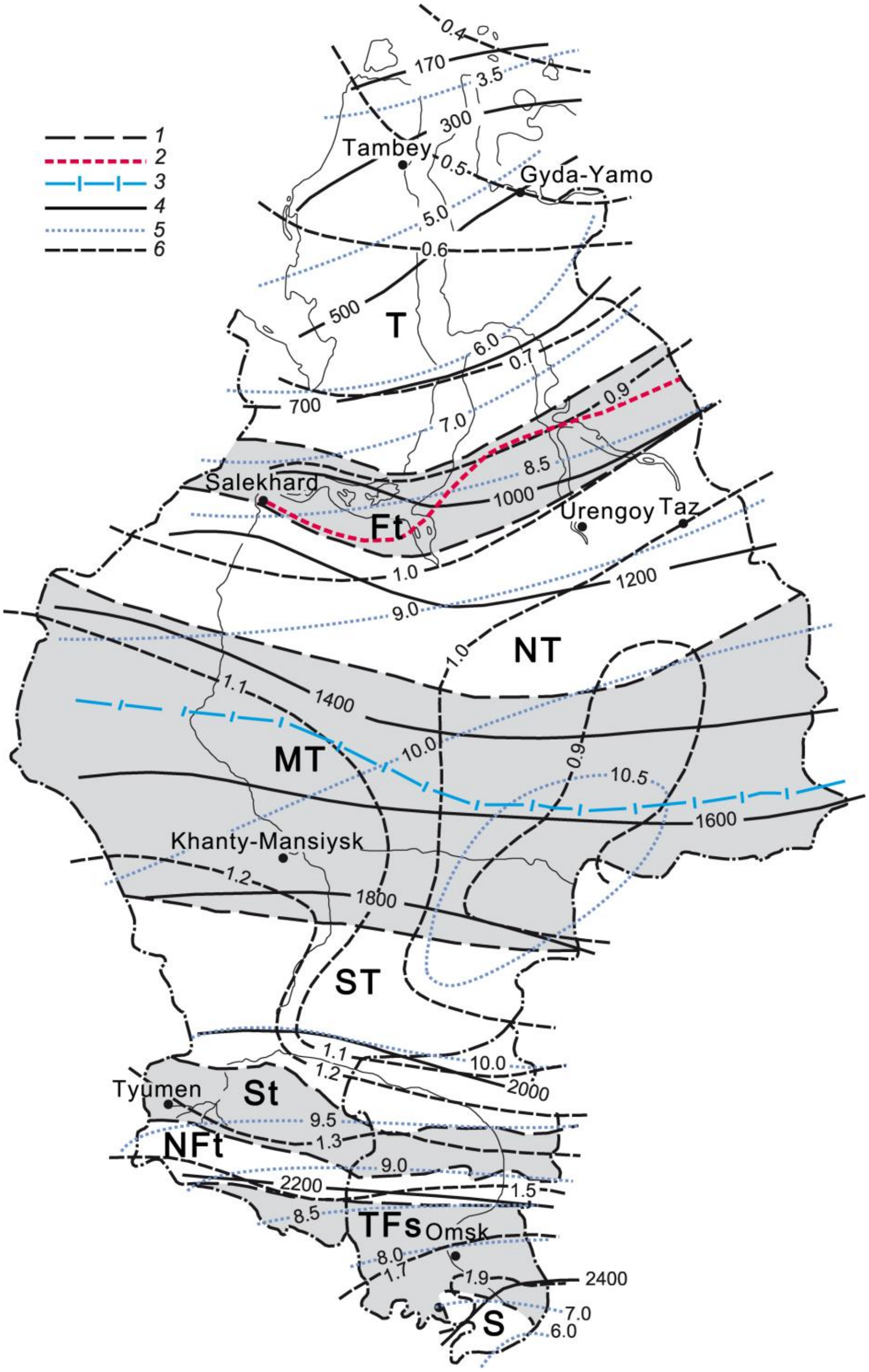
Table.
Determination of the elements of paleoclimate and phytoproduction in the area of Salekhard.

h, m	*τ, years ago*	d_1	d_2	d_3	d_{t1}	$-t_1$	t_7	U	Pr
0.025	197	0.18	**0.60**	0.22	0.7	26.3	11.6	314	9.4
0.125	987	**0.40**	0.33	0.27	0.8	30.3	8.0	266	7.2
0.225	1777	0.22	**0.46**	0.32	0.77	29.1	9.1	281	7.9
0.325	2567	0.28	0.35	**0.37**	0.82	31.1	7.3	259	6.8
0.425	3035	0.24	**0.44**	0.32	0.78	29.5	8.7	276	7.6
0.525	4146	0.10	**0.80**	0.10	0.6	22.2	15.1	362	11.1
0.625	4936	0.09	**0.46**	0.45	0.77	29.1	9.1	281	7.9
0.725	5726	0.025	0.16	**0.83**	0.59	21.8	15.5	369	11.3
0.775	6310	0.06	0.35	**0.60**	0.70	26.3	11.6	314	9.4

Notation: *h* – sample collecting depth; τ - deposits age; *d1…d3* – groups weights (D is given in bold); t_1 and t_7 – mean air temperatures in January and July, °C;. U – annual precipitation rate, mm; Pr – phytoproduction, (t/ha . year)



Schematic map of the geobotanic zoning of Tyumen-Omsk region.

1– zones and sub-zones borders (T – tundra, Ft – forest-tunda, NT– northern taiga, MT– middle taiga, ST – southern taiga, St – subtaiga, NFs – northern forest steppe, TFs – typical forest steppe, S – steppe); 2 – southern boundary of continuous permafrost; 3 – southern permafrost boundary; 4 – sums of temperatures above 5°C; 5 – phytoproduction Pr, t/ha* year, 6 –dryness index

Investigation of permafrost on the summit area of Mt. Fuji

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Introduction

Perennially frozen ground in the mountains of Japan represents some of the southernmost distribution of permafrost in the Northern Hemisphere. The occurrence of permafrost in Japan was reported for the first time on the summit area of Mt. Fuji in the early 1970s [*e.g., Higuchi & Fujii 1971*] and has since been observed in the Daisetsu Mountains, northern Japan [*e.g., Sone 1992; Iwahana 2008*]. Permafrost existence by definition, however, has not yet been confirmed on Mt. Fuji. In view of recent climate change, public attention has been given to possible changes in permafrost, which affect surface and underground conditions on mountains in Japan, especially on Mt. Fuji.

After an interval of more than 30 years, intensive investigation of permafrost on Mt. Fuji launched again in 2008. The aim of our study is to grasp permafrost distribution and to reveal the history of its formation on Mt. Fuji as a base for long-term studies of climate and ecological change on high mountains. We report the ground temperature profile of two 3-m boreholes, micrometeorological measurements on the summit during 2008-2010, and preliminary results from an analysis of 9.7m-borehole newly installed in 2010 summer.

Study site and methods

The study site is on the summit area of Mt. Fuji, the highest mountain in Japan (3,776 m asl). The last eruption of this stratovolcano was about 300 years ago. Two 3-m bore holes were dug at wind-swept (Site K) and leeward (Site T) sites in August 2008, for measurement of ground temperature profiles. An automatic micrometeorological measurement system was installed at Site K. Another, deeper borehole (9.7 m) was installed in August 2010 at a peak of the outer rim of the crater (Site H). Ground surface at these sites consists mainly of scoriae.

Shallow ground temperatures down to maximum of 1.15 m were also monitored at 15 sites with relative height intervals (from 2800 m asl) of 100 m on the northern flank and 200 m on the southern flank, and at 4 points on the summit area.

Air, snow, and ground temperatures were measured with calibrated thermistor and Pt100 sensors. Surface soil moisture was measured by TDR method. Other meteorological components were measured with a Weather Transmitter (WXT520, Vaisala). All measurements were processed and stored every 10 min. in a data logger (CR1000, Campbell) at Site K. Ground temperatures at other sites were measured and logged every hour.

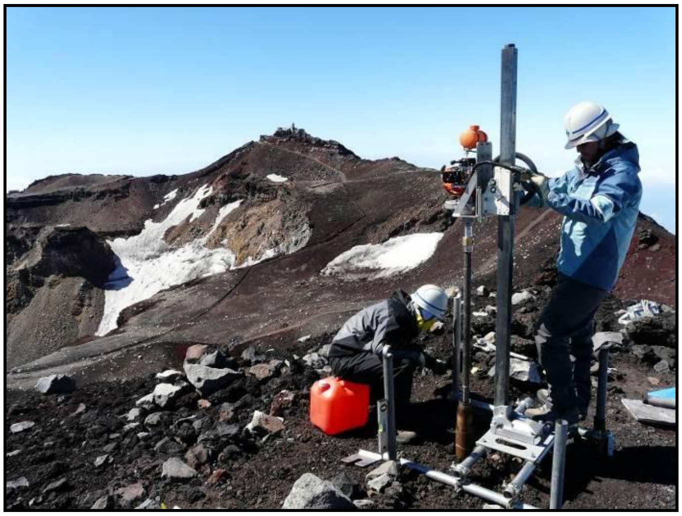

Figure 1 Core boring on the top of Mt. Fuji

Water from the 9.7-m borehole (Site H) soil samples was extracted using centrifuge and stored for measuring oxygen and hydrogen stable isotopic ratios. Geological features of the soil samples were recorded, and the volume of the cores was determined approximately in situ. Soil water content was determined in the laboratory after oven-drying the samples.

Results and discussion

Air temperature and summer precipitation on the summit

The 30-year average air temperature at a meteorological station on the summit was -6.4ºC. The average freezing and thawing indexes from 2006 to 2010 were 2613 and 566 ºC-days, respectively. Judging from these air-temperature indicators, our study site is classified as continuous permafrost; see the diagram of Harris [*1992*], for example.

Monthly precipitation varied from 291 to 582 mm during the rainy seasons of our study period. This large amount of rainfall is a prominent climatic feature on Mt. Fuji, compared to other mountains with reported permafrost.

3-m boreholes

Over two years beginning in 2008, we have not confirmed the occurrence of permafrost on the summit of Mt. Fuji, based on our two ground temperature profiles down to 3 m. At Site K, we observed seasonal frost reaching more than 3 m deep. However, rain events every summer triggered large increases in ground temperature, and heavy rains during the autumn rainy season rapidly thawed the frozen layer deeper than 2–3 m. The seasonal change in ground temperature cannot be explained only by heat conduction, but there was also apparent temperature increase due to heat advection by 3-dimensionally percolated rainwater.

At Site T, the insulating effect of snow cover weakened frost penetration into the ground, and heating by rain infiltration kept the ground temperature relatively high throughout the monitored period. The ground temperature regime varies greatly between years, and the thermal status of frozen ground is unstable on the summit of Mt. Fuji.

Possible distribution of permafrost on Mt. Fuji

We examined the ground freeze-thaw patterns above the tree line of Mt. Fuji based on recent year-round records of temperatures at shallow depths at 22 sites. The mean annual temperatures at the ground surface on the south-facing slope were 1.5 to 3°C higher than those on the north-facing slope at the same altitude.

Considering the annual changes in ground temperature, we roughly estimate permafrost presence probable only at the north- to west-facing windy sites, above 3500 m asl., although studies in the 1970s suggested a lower boundary around 3000 m asl. on both the north- and south-facing slopes. However, in the 1970s, the estimation of the permafrost distribution on Mt. Fuji might have been based on the thaw depths in the middle of the thawing period.

9.7-m borehole

Ground temperature data is limited due to logger breakdown by lightning strike. However, obtained temperature shows -3.3ºC at 9.7-m depth as a minimum, gradually increasing toward the surface to -2.0ºC at 4.0-m depth, and thaw depth was about 1.0 m on 10 Oct 2010. This ground temperature profile at the end of the thawing season strongly indicates occurrence of permafrost at Site H; however, measurement of more than two years is required to confirm permafrost by definition.

Gravimetric soil water content at site H swung largely along the depth. The profile showed that there were at least three mutual ice-rich and dry layers down to 9.7-m depth. The maximum amplitude of gravimetric water content was more than 0.6. The large difference of water content in the wet and dry layers should have been reflected by the stratified structure of low-permeable and porous high-permeable layers, which support the effect of advection on ground temperature change at Site K.

The profile of $\delta^{18}O$ values showed an increase from 1-m to 6-m depths with several waves and retained the value range down to 9.7 m. The low value at around 1 m was -14.5‰ and around -10‰ at 6m. It is curious that values increase toward the range of summer rain (around -9‰) as depth increases. This profile could be created by rapid formation of permafrost after the cease of volcanic activity about 300 years ago.

Summary

Two-year measurements of 3-m ground temperature profiles did not confirm the occurrence of permafrost at the summit area of Mt. Fuji. Despite air temperature and snow condition supporting permafrost occurrence, 3-dimensional heat advection of percolating water during rainy season has a greater role in driving ground temperatures to entirely melt winter frost at the end of the thawing season.

Permafrost on Mt. Fuji seems to exist in limited part near the summit area and will be confirmed by definition in the near future from the temperature measurements of our 9.7-m borehole.

It is difficult to evaluate the influence of recent climate change on the underground conditions on the summit area of Mt. Fuji using information available at this moment. Evaluation of long-term changes in the ground-temperature regime and the status of frozen ground should be based on multipoint and long-term monitoring of the ground to a deeper extent, together with surface micrometeorological observations.

Acknowledgements

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Numerical Modeling of the Permafrost Temperatures Sensitivity to Climate Change in Alaska During the 21st Century

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Sensitivity of permafrost to climate change can be addressed via studying thermal properties of mineral and organic soils, volumetric soil moisture content and snow thermal properties. Global Climate Models project increase in amount of snowfall and mean annual air temperature (MAAT) in Alaska during 21st century. Warming climate has a direct effect on soil moisture balance, vegetation and frozen ground thermal state. The frequency of forest fires as results of dry and hot summers can increase the overall warming effect of changing climate on permafrost.

To assess possible changes in the permafrost thermal state and active layer thickness, we implemented the GIPL2-MPI transient numerical model for the entire Alaska permafrost domain. Input parameters to the model are spatial datasets of mean monthly air temperature and precipitation, prescribed thermal properties of the multilayered soil column, and water content which are specific for each soil class and geographical location. As a climate forcing we used the composite of five IPCC Global Circulation Models that has been downscaled to 2 by 2 km spatial resolution by Scenarios Network for Alaska Planning group.

We calibrate the model according to the annual borehole temperature measurements for the State of Alaska and performed more detailed calibration for fifteen shallow borehole stations where high quality data are available. To validate the model performance we compared simulated active layer thicknesses with observed data from the Circumpolar Acrtive Layer Monitoring (CALM) project research stations. Calibrated model was used to address possible ground temperature changes during the 21st century.

Our sensitivity analysis indicates the significance of the appropriate organic layer presence in the model in order to achieve measured ground temperatures after 30 years simulation run. This organic layer provides permafrost with necessary resilience within the ecosystem-protected permafrost zone. The severity of permafrost degradation depends on the corresponding ecosystem type. The effect of the upper organic layer, soil water saturation, and soil thermal properties play a significant role and provide necessary resilience for permafrost to sustain even when MAATs are close or slightly above 0°C. According to the modeling results average areal decadal permafrost degradation at 20 m depth can be pursued with 2.4% rate per decade (Fig 1), which concludes that for the next 90 years Alaska could lose about 22% of its currently frozen ground.

To better quantify the ecosystem effect further sensitivity analysis including the impact of each of the influencing factors as well as the combination of several factors based on specific geographic location and climatic zone is necessary. Future modeling results will include the impact of forest wildfires using higher (1 by 1 km) spatial resolution.

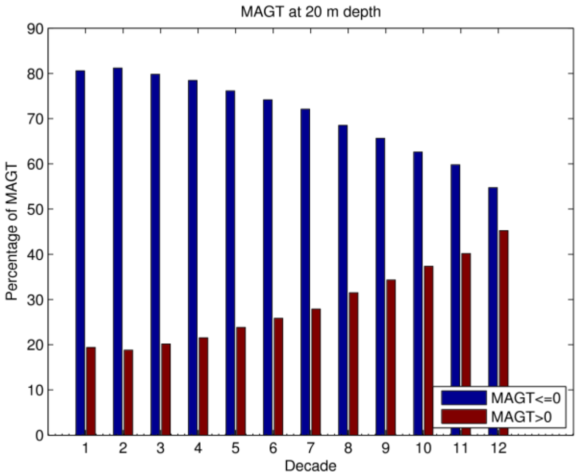

Figure 1. The percentage of overall area in Alaska occupied by colder and warmer than 0°C mean annual ground temperatures (MAGT) averaged over ten years time intervals from 1980 to 2099 at 20m ground depths.

Decadal Changes of Vegetation Phenology over the Arctic as Detected by Satellites

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Introduction

Arctic tundra ecosystems are very sensitive to temperature shifts and play an important role in ecosystems feedbacks to global climate [*Levis et al 1999*]. Phenology represents the seasonal dynamics of vegetation, and changes in phenology are likely indicators of local and global climate change. A linear response of vegetation phenology to global warming has been demonstrated.

The key question behind this study is: in the warmth limited northern biome, what will happen to the phenological patterns of tundra vegetation as the global climate warms and seasonality of air temperature, sea ice, and snow cover shift? To answer the question we examined the onset of vegetation greenness, senescence of greenness, length of growing season, and dates of peak greenness along Arctic bioclimate gradients (subzones) to see how they change over years.

Methods

Here, we combine multi-scale sub-pixel analysis and remote sensing time-series analysis to investigate recent decadal changes in vegetation phenology along spatial gradients of summer temperature and vegetation in the Arctic. The datasets used here are AVHRR 15-day 8 km time series, AVHRR 8-day 1 km dataset, MODIS 8-day 500m collection 5 NDVI dataset, and CAVM vegetation classification. Fractional vegetation cover was analyzed in order to select homogenously vegetated areas of tundra and autoregression analysis was performed on time series of those homogenous pixels.

To better understand most recent changes in phenological parameters over the Arctic region, we further examined inter-annual variations of the average SOS, EOS, and LOS during 2000-2010 based on the Terra MODIS time series from 2000-2010.

Results

There were detectable changes in phenological pattern over tundra biome in past three decades. Increases of vegetation greenness were observed in most of the summer periods in low arctic and mid-summer in high arctic. Peak greenness appeared earlier in high arctic and declined slower after peak in low arctic. Generally, tundra plants were having longer and stronger photosynthesis activities, and therefore increased annual vegetation productivities. Field studies have observed early growth and enhanced peak growth of many deciduous shrub species in tundra plant communities.

These changes in seasonality are very likely to alter surface albedo and heat budget, modify plant photosynthesis/respiration and soil microbial activities, and even change hydrological patterns in the arctic. Based on these results, data fusing and assimilation of multi-sensor remote sensing data time series with process models will be applied to create a comparable vegetation phenological dataset to improve our understanding on shifting seasonality patterns over Arctic tundra biome.

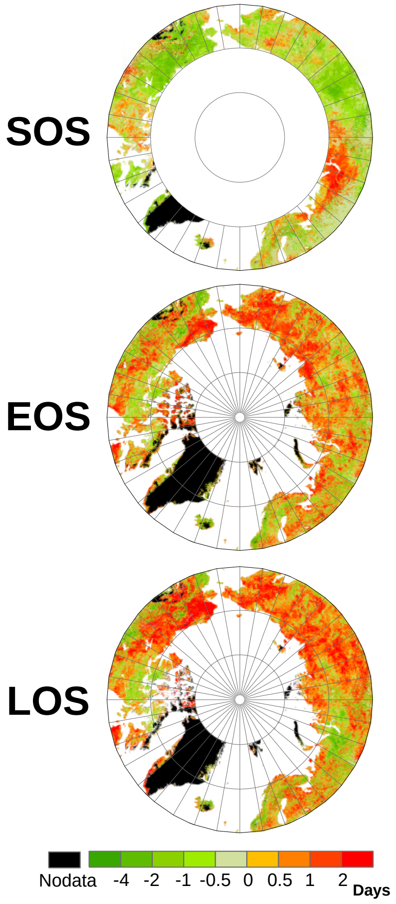

Figure 1 Spatial patterns of the linear trends in SOS, EOS and LOS from 2000 to 2010 based on MODIS data. Positive values (warm colors) indicate later onset (SOS), later finish (EOS) and longer duration (LOS) of the growing season (Zeng et al, 2011)

During this period, SOS advanced and LOS significantly lengthened over most of the high-latitude region. Positive EOS and LOS anomalies indicated delayed senescence and a longer growing season since 2000. There was generally a more rapid green-up in spring (about 15.2 days), a significant later EOS in autumn (about 13.6 days) and a significantly greater MaxNDVI (about 0.2) over Eurasia than North America. Both North America and Eurasia experienced their earliest SOS in 2010, based on MODIS data from 2000-2010. NDVI reached its peak earlier in Eurasia since 2000, while there were fewer shifts in North America.

There were obvious differences between North America and Eurasia in terms of magnitudes of decadal phenology changes. In Northern America, SOS advanced by 11.46 days per decade, and EOS was delayed by 2.18 days per decade. In Eurasia, SOS advanced by 2.11 days per decade, and EOS was delayed by 3.52 days per decade. SOS has likely advanced due to the warming Arctic during April and May. In recent decades the longer vegetation growing seasons can be attributed to more advanced SOS rather than delayed EOS.

The lengthening of the growing season was largely attributed to climate warming in recent decades at global and regional scales. The correlation coefficients between phenology parameters and temperature in preseason months were strong over many areas. Higher temperatures in May and September likely contributed to recently advanced SOS and delayed EOS, respectively. Meanwhile, phenological shifts also may feed back to the warming in varies ways.

Discussions

Over the last two decades of the twentieth century, responses of vegetation growth to climate change seem straightforward, with increasing temperatures causing increased NDVI, earlier SOS, and delayed EOS. Recently, however, new studies indicate more complex trends of vegetation productivity due to increases in disturbances partly exacerbated by climate change, such as insect defoliation and fires.

One of the key changes in arctic seasonality is related to retreat/accumulate dates of sea ice and length of ice free period over several case areas (e.g. nearshore ice), to melt/accumulate dates of snow cover and length of snow free period over bioclimate gradients, and to phenology of tundra biome, i.e., onset of vegetation greenness, senescence of greenness, length of growing season, and dates of peak greenness. Interannual changes of key phenological indices such as onset of greenness, length of growing season are very critical to vegetation-climate interactions.

Complex changes in different areas are likely due to different climate regimes and disturbances. Clearly, a better understanding of decadal phenological changes of the northern high latitudes vegetation can only be achieved by integration of various reliable spatial datasets. These changes in seasonality are very likely to alter surface albedo and heat budget, modify plant photosynthesis/respiration and soil microbial activities, and even change hydrological patterns in the arctic.

So far all we have learnt about the earlier onset of greenness and longer growing season over tundra biome are that AVHRR and MODIS derived NDVI signal reached detectable minima (~0.09) earlier and in some cases ended later. Some literatures demonstrated with either satellite data or field camera data that snow melts earlier in spring, while others found that the blossom of several tundra plant species got earlier. In subsequent research we may have to answer questions like: 1) is there a trend of earlier snow melt and/or reduced snow cover? 2) Do vegetation (especially deciduous) start to grow even before complete snow melt if snow gets thinner? 3) How can we unmix signals of snow and vegetation in satellite data pixels to better capture vegetation signals in early growing season?

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The comparison of the surface energy budget between the permafrost region and the seasonally frozen ground region over the Tibetan Plateau

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Permafrost has different water-thermal properties and physical processes from seasonally frozen ground. The comparison of the surface energy budget between the permafrost region and the seasonally frozen ground region over the Tibetan Plateau is important to the research of the land surface model and ecology environment variations [*Tanaka, et al., 2001; Yao, et al., 2008*].

The research sites are respectively TGLMS site and BJ site. TGLMS site is located on the permafrost region (91°56′E, 33°04′N, with an elevation of 5100 m a.s.l.), and the maximum thawing depth of the active layer is about 3.4 m. BJ site is located on the seasonally frozen ground region (91°54′E, 31°22′N, with an elevation of 4509 m a.s.l.), and the maximum freezing depth of the soil is about 1.5 m. The instruments include the eddy covariance system and AWS. Some corrections were done for the eddy covariance data [*Webb, et al., 1980*]. The research period is from January 1st 2007 year to December 31st 2008 year for TGLMS site, and is the whole 2008 year for BJ site. And the research results show:

1. The variation process of surface energy budget over the permafrost region: the net radiation was small during January to February, which led to small sensible heat flux and small latent heat flux, and the net radiation was mostly converted into the sensible heat flux, that is, the sensible heat flux was higher than the latent heat flux during the period. In March the net radiation increased and led to the increasing sensible heat flux, but the latent heat flux had little change, and the sensible heat flux were much higher than the latent heat flux. During April to May the latent heat flux increased significantly but the sensible heat flux tended to reduce, and then the sensible heat flux and the latent heat flux were almost equivalent by the end of April to the beginning of May. After May the latent heat flux increased more rapidly but the sensible heat flux continued to reduce; the latent heat flux was very high during June to August. At the end of September the sensible heat flux started to increase again but the latent heat flux started to reduce, and at about the beginning of October the sensible heat flux and the latent heat flux were equivalent again. After that, the sensible heat flux was higher than the latent heat flux again.

2. The variation process of surface energy budget over the seasonally frozen ground region: same as the permafrost region, the sensible heat flux and the latent heat flux were both small during January to February. In March the sensible heat flux increased, but the latent heat flux had little change, and the sensible heat flux was much higher than the latent heat flux, too. However, after May, the latent heat flux began to increase, and the sensible heat flux began to decrease. This phenomenon is different from the permafrost region. During June to August, the sensible heat flux was lower, but the latent heat flux was higher. Such situation was last to the end of September. After that, the sensible heat flux began to increase and the latent heat flux began to decrease. The net radiation was mostly converted into the sensible heat flux again.

3. The variations of the sensible heat flux and the latent heat flux were taken on alternation characteristics with seasons at both sites. Besides the influence of the net radiation, the main reasons are the monsoon and the freezing-thawing process of the soil. For the permafrost region, the thawing process of the active layer began at the end of April, and the thawed water contributed to the latent heat flux. And it led to the latent heat flux increase and the sensible heat flux decrease. After May, the precipitation was concentrated in summer by the monsoon, and it led to the significant increase of the surface soil moisture content. This is an important reason why the latent heat flux increased rapidly after May and was much higher than the sensible heat flux in summer. The active layer reached the maximum thawing depth in the middle of September. At the end of September the latent heat flux began to decrease. The time of the active layer change and the time of the latent heat flux change were almost concurrent. Besides, the rainy season brought by the monsoon was over at the end of September, and it is another reason for the decreasing of the latent heat flux. For the seasonally frozen ground region, the influences by the thawing process on the surface energy budget were not great. The turbulent fluxes began to greatly change after May, and it was mainly influenced by the monsoon. The time of the rainy season and the time of the latent heat flux change were concurrent. To some degree, the influence by the freezing-thawing process on the surface energy budget is smaller over the seasonally frozen ground region than the permafrost region.

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The Effect of Permafrost Thaw on Methane Emissions in a Western Alaska Peatland Chronosequence

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Introduction

Permafrost soils store ~50% of the world's soil carbon, largely at high latitudes where rates of warming are greatest [*Tarnocai et al., 2009*]. Decomposition of carbon upon permafrost thaw in a warming climate may drive positive feedbacksto atmospheric warming, with an uncertain but important component from methane (CH_4) emissions [*Schuur et al., 2008; Grosse et al., 2011*]. Methane is responsible for about 20% of greenhouse gas forcing despite its relatively short lifetime (~10 y) and low concentration (1800 ppb) in the atmosphere. Northern peatlands contribute ~13% (15-50 Tg y^{-1}) of global CH_4emissions [*Frolking 2011; Roulet 2007*]. Understanding the relationship between permafrost thaw and CH4 flux in these environments is critical for understanding the climate system.

Methods

Fluxes of CH_4 and CO_2 were measured at sites along a~1000 year chronosequence of collapse scar features within the Innoko National Wildlife Refuge, southwest of Fairbanks, AK (63.58˚N, 157.72˚W). The sites included three field replicates of four landscape age-units: unthawed permafrost plateaus and ombrotrophic bogs at three stages of thaw ('young' ~100 years, 'intermediate' ~100-500 years, and 'old' ~500-1000 years). Distinction between landscape units was based on tree ring and radiocarbon analysis, as well as field observation of microtopography and plant community succession.

Seasonal and diurnal variation in CO_2 and CH_4 fluxes were evaluated during three field campaigns in the summer of 2011 using static chambers. A LI-COR LI-840A CO_2/H_2O analyzer was used to measure CO_2 flux in situ, and samples were collected for subsequent analysis of CH_4 concentration by gas chromatography, and flux calculations. Soil temperature, soil moisture, and water level were continuously recorded from September 2009 through October 2011.

Statistical analysis of CH_4 fluxes were performed using a permutation two-tailed T-test in R statistical software. We used a repeated measures analysis of variance and Tukey post hoc comparison of means tests to determine the effects of water table height, soil temperature, and water chemistry.

Results & Discussion

Methane fluxes across landscape units ranged from -1.5±1.5 mmol CH_4 –C m^{-2} hr^{-1} to +14.3 ± 6.9 mmol CH_4-C m^{-2} hr^{-1} (Table 1; negative values represent CH_4 consumption). Generally, CH_4 and CO_2fluxes were reduced at sites with cooler temperatures and/or lower water table height relative to the vegetation surface, while CH_4 and CO_2fluxes were consistently higher at intermediate age (~500 y since thaw) sites with both warmer soil temperatures and shallower water tables (Table 1, Fig. 1a). In intermediate bogs between spring and mid-summer, soil temperatures at 25cm gradually warmed to temperatures resembling those at 5 cm depth, and CH_4 efflux, CO_2 efflux (ecosystem respiration) and CO_2 uptake (net ecosystem exchange) all reached maximum levels (Fig.1b). As air temperatures declined between mid-summer and fall, fluxes also decreased (Fig. 1b).

Table 1. Total carbon stock and average flux rates across chronosequence type. Uncertainties are one standard error of the mean for n=3 sites.

Site	Total C stock (kg m^{-2})	Net CO_2 Flux(mmol $m^{-2}hr^{-1}$)	Net CH_4 Flux (mmol $m^{-2}hr^{-1}$)
Frozen Forested	53 ± 5	-4.9 ± 1.9	-1.5 ± 1.3
Young Bog	34 ± 18	-3.4 ± 1.7	-0.31 ± 0.13
Intermediate Bog	59 ± 33	-6.5 ± 1.5	14.3 ± 6.9
Old Bog	83 ± 31	-2.0 ± 0.6	1.3 ± 0.4

From September 2009 to October 2011, old and intermediate bogs were generally warmer than young bogs and frozen plateaus. During winter, the frozen plateaus were generally colder than the bog sites. Intermediate sites warmed up earliest in the spring and cooled down latest in the fall, and had consistently shallower water table heights. Active layer thickness from May to October 2011 reflected seasonal warming of features with lateral propagation of seasonal thaw throughout the summer at all thaw sites. Rates of active layer thickening varied with bog age; those in frozen and young sites (0-~100 y since thaw) thickened more slowly than those in intermediate and old sites (~500-1000 y). Our results suggest that thaw feature size/age and plant community structure influence both water table height and soil warming and cooling patterns, and hence lead to a long-term "pulse" in CH_4 fluxes.

Conclusions

Our results provide a 1000 year chronology of the relationship between CH_4 fluxes and seasonal temperature patterns as a function of time since thaw. Thaw of ice-rich peat leads to saturation, and lateral thaw propagation with time leads to warming of saturated soils and increasing CH_4 emissions. After ~1000 y, plant community succession stabilizes thaw boundaries through drying and cooling of thaw features, reducing CH_4 emissions. This long-term, slow-pulse response may occur with increasing areal frequency in vulnerable lowland locations as air temperatures continue to rise, potentially leading to dramatically increased CH_4 production from lowland settings in the future.

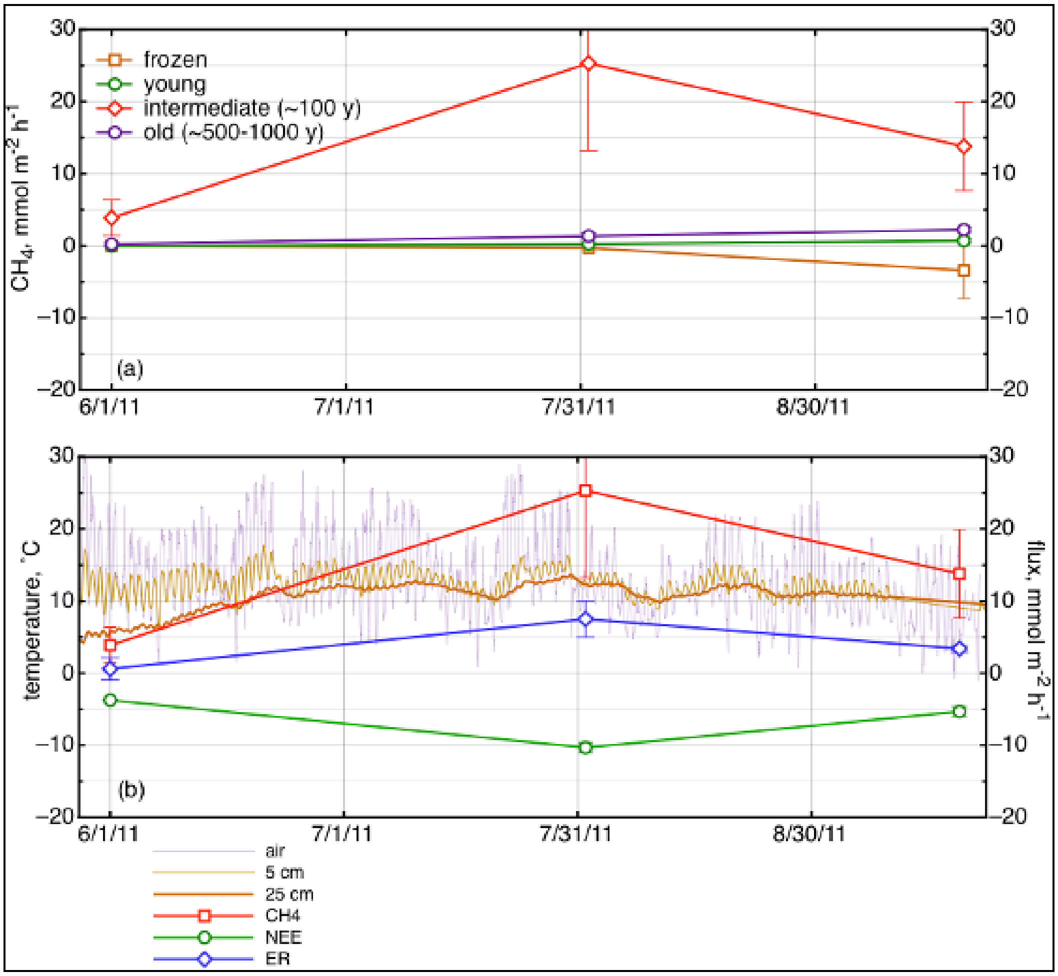

Figure 1.(a) Methane flux for each thaw feature (n=3) throughout the 2011 growing season; (b) seasonal variation in gas fluxes with air temperature, 5 cm soil temperature, and 25 cm soil temperature

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Assessment of Different Heat Drain Materials for Protection of Permafrost under Road and Airfield Embankments

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Introduction

The presence of permafrost is an important aspect to consider in civil engineering projects in arctic regions. The construction of engineering structures, such as roads and airfield embankments, changes the thermal regime of the ground, and may lead to permafrost degradation under or adjacent to such structures. This problem has in last decades been amplified by climate warming, which has been most evident in the arctic regions.

Through the years different mitigation techniques have been developed to avoid or at least minimize the damages caused by thaw settlements; reflective surfaces, air convection embankments, geosynthetic reinforcement, thermosyphons, berms, gentle slopes, air ducts etc. [*Esch, 1996; Beaulac et al., 2004*].

In this project two types of heat drain materials have been tested in small-scale embankments to determine their effectiveness. The materials tested are a geocomposite and a new tubular heat drain. The experimental setting is designed to represent the shoulder of a road embankment and was carried out in a size 25-50 % of a full-scale embankment.

The heat drain is an innovative system developed at Université Laval in order to protect the side-slopes of road and airfield embankments. The heat drain is a 25 mm-thick geocomposite drainage layer placed in the shoulder and connected to an air intake installed at the foot of the embankment and an air outlet installed at the top of the embankment to allow upwards circulation of the air during winter months. The main function of the drain is to extract heat from the embankment in order to raise the permafrost table in the ground at that critical location.

Methodology

In this project two materials were used in the laboratory tests; the conventional geocomposite and a tubular heat drain. The geocomposite is composed of a corrugated plastic core covered by geotextile layers with a total thickness of 25 mm, whereas the tubular heat drain consists of a series of perforated tubes placed between two layers of geotextile material. Tests were done with 4 tubes per meter and 8 tubes per meter configurations.

Cold air is allowed to penetrate into the embankments at the base, to allow an upward movement of air in the heat drain. This movement of air, also called the chimney effect, is a result of a lower density caused by the change in temperature. The heat initially flows toward the heat drain by conduction and is then expelled of the embankment by convection.

Laboratory testing

Previous laboratory and field studies of the heat drain technique have shown very positive results with the use of geocomposite [*Jørgensen, 2009; Jørgensen et al., 2008*]. However problems have occurred at a test-site On the Alaska Highway, in Yukon likely because the geocomposite layer was damaged during construction. In order to find a new type of heat drain material with a higher structural strength, the tubular heat drain has been tested to see if it can provide the sufficient cooling.

Material properties

The different embankments were all constructed of a granular material from a sand-pit located near Québec City, Québec, Canada (Table 1). The water content in the material was 3.0 %.

Table 1. Soil properties

Grain-size		
Gravel	> 2 mm	~ 19 %
Sand	63 μm - 2 mm	~ 79 %
Clay and silt	< 63 μm	~ 2 %
Soil gradation		
Coefficient of uniformity	(D_{60} / D_{10})	4.8
Average grain-size	(D_{50})	0.65 mm

Construction of embankment box

The box used for the laboratory tests includes two sections, thus two small-scale embankments (25-50 % of a full-scale road embankment) could be constructed, tested and compared at the same time. The box was insulated by covering the outside with 50 mm polystyrene layer and a 100 mm layer of polystyrene was placed between the two sections to avoid heat losses. Finally, a layer of 300 mm glass wool was placed on the side-slope of the embankments to recreate the insulating effect from a snow cover. At the bottom of the box the temperature was maintained constant at 0°C by a heating system.

Installation of the heat drain

The geocomposite was installed approximately 9 cm from the bottom of the embankment, while the tubular heat drain was installed approximately 14 cm from the bottom.

Data acquisition

Six thermistors were installed vertically in the test compartment in which the reference section and the section with geocomposite were tested. Seven thermistors were installed in the compartment where the tubular heat drains were tested. The thermistors allowed “continuous” monitoring of the thermal regime of the embankments. Measurements were made every 15 minutes and recorded using a DataTaker DT600.

Test conditions

The tests were carried out in a cold room, which maintained a constant air temperature at approximately -20°C (precision ±1°C). The refrigeration system was programmed to shut down every 10 h for deicing purposes. This process has slightly affected the temperature responses in the upper layers of the embankments.

Results

Comparison of temperature profiles

Temperature profiles at steady state conditions have been compared for the four investigated embankments; reference (without heat drain), geocomposite heat drain, tubular heat drain (8 tubes) and tubular heat drain (4 tubes). The results are shown in Figure 1.

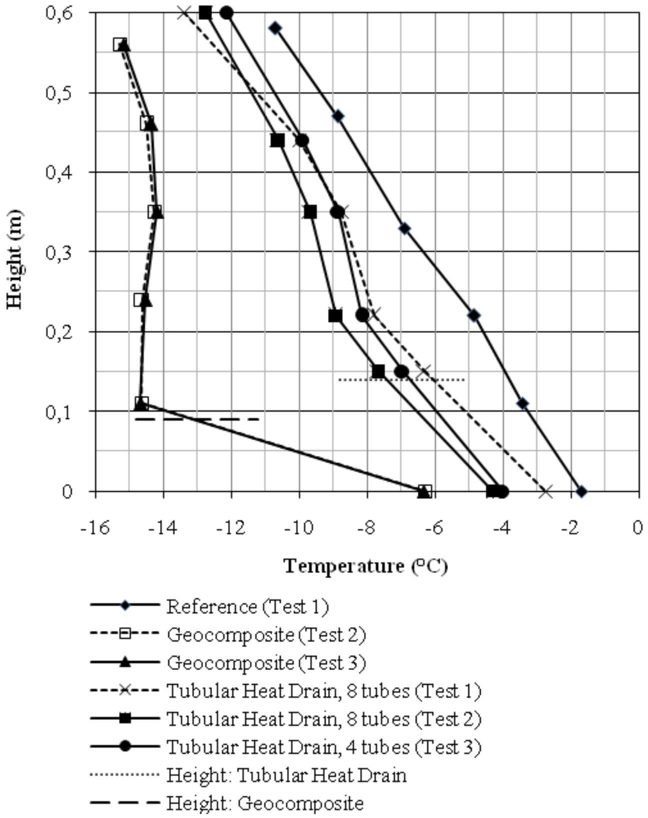

Figure 1. Thermal regime at steady state conditions for the four embankment types: reference, geocomposite heat drain, tubular heat drain with 8 tubes and tubular hear drain with 4 tubes.

It can be clearly seen that the different heat drain materials all have a significant effect on the thermal conditions and causes a decrease in temperatures compared to the conditions observed in the reference embankment. The geocomposite heat drain is almost three times as affective as the new tubular heat drain. It can also be observed that the benefit of doubling the number of tubes in the tubular drain is small..

Infra-red image analysis

At the end of each test the glass wool was removed and pictures were taken with an infra-red camera to observe the surface temperatures of the embankments. The results revealed a variation in surface temperature ranging from -6.0°C for the reference section down to -15.2°C for the embankment with geocomposite drainage layer.

It was also possible to measure the temperature difference between inlet and outlet for the different heat drain materials, approximately 3°C for both types. This indicates that the measured differences in the thermal regime of the embankments are caused by the smaller air circulation in the tubular heat drain, due to the volume difference compared with the geocomposite. The air intake surface for the tubular heat drain is approximately 20 cm^2/m, whereas it is approximately 130 cm^2/m for the geocomposite drainage layer.

Conclusion

The small-scale embankment tests of different types of heat drain material, geocomposite and tubular heat drain, have shown that placing these materials into the shoulder of a road embankment will lead to a significant decrease in temperatures, which will minimize the risk of permafrost degradation underneath the embankment and thereby avoid thaw settlements. The results showed that the tubular heat drain can be used as a heat drain material, but that its effectiveness is not as good as the geocomposite, due to a smaller area of air intake. Based on the results of the testing program, the geocomposite drainage layer is almost three times as affective as the tubular heat drain.

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Effects of Experimental Warming On Alpine Meadow Soil Respiration during the Growing Season on the Qinghai-Tibet Plateau

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As soil respiration (SR) is one of the largest gross fluxes in the annual C budget, small imbalances in photosynthesis and respiration can lead to significant interannual variation in atmospheric CO_2 levels [*Trumbore, 2006; Oberbauer et al., 2007*]. To our knowledge, few studies report the responses of SR of an alpine meadow ecosystem to ecosystem warming in situ on the Qinghai-Tibet Plateau. In order to understand the effects of global warming on biogeochemical circles of the alpine ecosystem on the Qinghai-Tibet Plateau, our study seeks to use open-top chambers (OTCs) to examine the effects of warming on SR in the alpine ecosystem characterized by undisturbed soils and thick organic layers. The alpine meadow is typical of more favorable locations with abundant soil nutrients and water regimes on the Qinghai-Tibet Plateau, and significant SR responses to increases in temperature are expected. This experiment tests the following hypotheses: (1) the high altitude and cold-climate alpine meadow ecosystem is mainly limited by low temperature; SRs will increase under warmer conditions; (2) stocks of labile soil C in the alpine meadow have high temperature sensitivity; the greater the temperature increments, the higher the carbon emission flux.

The experiment was undertaken in an alpine meadow ecosystem, which represents the most common (70% in area) vegetation type in the Beiluhe region (34° 49′ 25.8′, 92° 55′ 45.1″E) in the hinterland of the Qinghai-Tibet Plateau, China. The study site represents an area of 151.6 km^2, with an altitude of around 4600–4800 m. The alpine meadow ecosystem consists mainly of cold meso-perennial herbs which grow in conditions where a moderate amount of water is available. This primary vegetation consists of *Kobresia pygmaea* (C. B. Clarke), *K. humilis* (C. A. Meyer ex Trautvetter) Sergievskaja, *K. capillifolia* (Decaisne) (C. B. Clarke), *K. myosuroides* (Villars) Foiri, *K. graminifolia* (C. B. Clarke), *Carex atrofusca Schkuhr* subsp. (minor (Boott) T. Koyama), and *C. scabriostris* (Kukenthal) [*Zhou 2001*].

Experimental design

We followed the methods of the International Tundra Experiment for this study and used OTCs as a passive warming device to generate an artificially warmed environment [*Molau & Mølgaard 1996*). The experiment was conducted with a comparative trial design in the selected alpine meadow site with a vegetation coverage of above 70% (Fig. 1). To compare the warming effect of the OTCs, the air temperature 20 cm above the soil surface and the soil temperatures at depths of 5, 20, and 40 cm below the surface of the soil were taken with thermistor sensors, along with the soil moisture at depths of 5, 20, and 40 cm with soil moisture sensors (EC-5, Decagon USA).

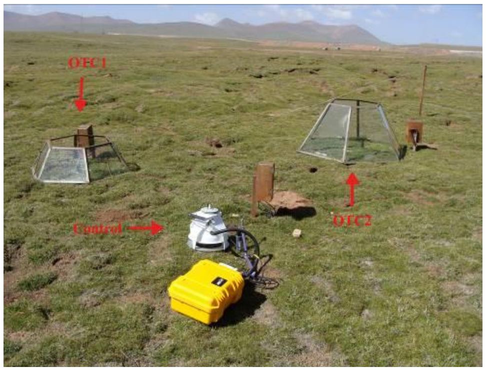

Fig. 1. Open-top chambers and associated control plot in an alpine site; a portable Li-8100A was used to measure soil CO_2 efflux.

Soil respiration measurements

Soil CO_2 efflux (microbial and root respiration) was measured with a portable LI-COR system (LI-8100A, Lincoln, NE, USA). Nine polyvinyl chloride (PVC) collars (20 cm internal diameter and 10 cm height) had been previously inserted at a depth of 8 cm into the soil with a chamber offset of 2 cm in the experimental plots. All living plants inside these soil collars were removed by hand at least one day prior to the measurements to exclude plant respiration from the above-ground parts.

Statistical analysis

Data from all plots were analyzed by ANalysis Of VAriance (ANOVA). Carbon dioxide flux data were naturally log-transformed to fulfill the assumption of normal distribution, and the significant difference between the plots with different warming levels was assessed by one-way ANOVA and Least Significance Difference (LSD) for each measurement of CO_2 flux.

Warming effects of OTCs on air temperature, soil temperature, and soil moisture

The air temperature (based on the mean daily temperature) increased by 2.59°C for OTC1 and by 5.16°C for OTC2 during the growing season (from May to September). A measurement of soil moisture at a depth of 5 cm showed its decrease with an increase in temperature, but these differences between the two treatments, and between the treatments and the control, were not significant ($F < 1.47$, $P > 0.26$). The soil moisture decreased by 11.8% in the OTC1 plots and significantly decreased by 20.5% in the OTC2 plots in contrast to the soil moisture in the control plots.

Effects of warming on soil respiration

At a 5% level of significance, soil efflux was significantly different both in the same month for different treatments and in different months for the same treatment (Table 1). The seasonal amplitude for soil efflux was highest at 6.661 μmol CO_2 m^{-2} s^{-1} for OTC2, followed by 4.029 and 2.827 μmol CO_2 m^{-2} s^{-1} for OTC1 and control, respectively. The coefficients of temporal variation (CV) for monthly CO_2 flux in the OTC2, OTC1, and control treatments were 35.01, 45.50, and 48.49%, respectively, from May to September. This shows that different temperature increments can result in spatial and temporal variations in soil CO_2 efflux.

Table 1. Seasonal variations in soil respiration due to different warming treatments

Treat-ment	Soil CO_2 flux (μmol CO_2 m^{-2} s^{-1})					
	May	Jun	Jul	Aug	Sep	Amplitude
OTC2	2.1±0.7	4.5±1.2	5.2±0.8	5.9±1.0	3.4±0.7	6.6
OTC1	0.8±0.3	1.9±0.3	3.6±0.5	3.5±0.4	2.5±0.5	4.1
Control	0.5±0.1	1.2±0.1	2.4±0.5	2.3±0.4	1.6±0.3	2.8

* Values are means (n = 3) ± SD

Warming effects

Distinctly different effects of experimental warming were observed on SR flux from the plots in which air temperatures were increased with the help of OTCs. In the alpine meadow ecosystem of our study site, CO_2 efflux by SR was found to be closely linked to soil temperature, showing instantaneous responses to experimental warming that were sustained over one growing season.

Temperature and moisture sensitivity of soil respiration. The effect of temperature on SR

Correlation analysis indicated that was a significant positive relationship between soil temperature and CO_2 flux among the different treatments during the growing season. Different warming treatments resulted in exponential increases in SR with increasing soil temperature at a depth of 5 cm. The increase in soil temperature at the depth of 5 cm explained 98.0, 97.0, and 98.0% of the seasonal variations in SR for control, OTC1, and OTC2, respectively. Based on the soil temperature at a depth of 5 cm, field-based Q_{10} values of SR for the control, OTC1, and OTC2 during the growing season were calculated to be 7.03, 6.29 and 2.23, respectively. The Q_{10} values exhibited strong seasonal variations for the three different warming treatments, which were negatively correlated to the seasonal variations in soil temperature. These results demonstrate that the alpine meadow ecosystem on the Qinghai-Tibet Plateau was very sensitive to increase in temperature, which was similar to the findings of the study by Chen in the eastern Qinghai-Tibet Plateau [*Chen et al. 2010*].

The effect of soil moisture on soil respiration

Correlation analysis indicated that there was a weak relationship between CO_2 flux and soil moisture content for any given treatment ($R^2 < 0.5$, $P < 0.05$), but a significant negative relationship between the different warming treatments. The change in soil moisture in this study probably did not reach either extreme, and was, therefore, not enough to affect the activities of microorganisms and roots, which resulted in the apparent lack of effect of soil moisture on SR. It can be concluded that long-term warming would not stimulate SR (*i.e*., lack of positive feedback) at all times in the alpine meadow on the Tibetan plateau, which may be due to the difference in the response levels and physiological mechanisms of soil microorganisms adapting to changes in the physicochemical environment of the alpine meadow and the arctic tundra.

Conclusions and prospective

Our results clearly show that experimental warming significantly affected SR in the alpine meadow ecosystem on the Qinghai-Tibet Plateau, and that the higher air temperatures inside the OTCs led to greater rates of soil CO_2 emission and drier soils. Although experimental warming led to soil dehydration, this drying seemed to have little influence on the rate of soil CO_2 efflux during short-term temperature increase (such as the growing season chosen for this study). Warming decreased Q_{10} values of SR, suggesting that warming may reduce the temperature sensitivity of SR. This indicated that future warming would not stimulate SR (*i.e*., lack of positive feedback) at all times in the alpine meadow on the Tibetan plateau, which may be due to the difference in the response levels and physiological mechanisms of soil microorganisms adapting to changes in the physicochemical environment of the alpine meadow and the arctic tundra.

Acknowledgments

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Swamping and Perennial Freezing of the Territory Composed of Coarse Grounds

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Abstract

It is assumed that swamping of the area is common in places where cover sediments are represented by clayey silts and silts or icy peatlands. It is also noted that in some areas bogs are intensively formed on the surface despite a small amount of rain over the summer period. The author conducted field studies, which showed that area swamping does not depend on the degree of sediments dispersion.

Keywords: coarse grounds; high ice content; peat; perennial freezing; sphagnum; swamping.

Perennial freezing of grounds in northern regions is connected with the change in conditions of the heat exchange on the surface. The most significant factor here is swamping of the territory and peatlands formation.

According to most researchers, who studied the problems of swamping of northern territories, the main requirement for bog formation is the presence of aquiclude in subsurface sediments. Clayey sediments or permafrost can serve as such aquiclude [*Reutt 1970*]. Apart from that, appearance of land subsidences in basins and depressions as well as on the slopes, in the areas of groundwater decrement, also facilitates swamping. According to the geobotanist G.A. Voronov [*1963*], swamping may occur as a result of succession when green hypnum moss is replaced with haircap moss and later with sphagnum moss.

In foreign publications it is noted that in the area of Fairbanks (Alaska) with continental climate and a moderate amount of precipitation, an abundance of areas subject to swamping is observed. The authors explain it by saying that "… spongy mat which consists of sedge, mosses and low shrubs, entraps surface waters and acts as a reservoir" [*Pewe, Paige 1974*].

The author of this report conducted field studies on the coast of the Sea of Okhotsk in the area of the Yana river mouth (Figures 1, 2).

The study was conducted in the lowland, which is a marine terrace, composed of pebbles and sand of various coarseness. There are no clayey sediments in the surface layer.

The coastal climate is monsoonal. During winter time cold air, which forms high pressure area, flows off the continent towards the sea. In spring the high pressure area above the continent disappears, and the frequency of western and southwestern winds increases. Humid air masses with low clouds and fogs are carried into the coastal area. Mean annual air temperature, as measured by the Nagaevo weather station (on the coast, within the limits of Magadan), is minus 4.1 ºC, absolute minimum is minus 48 ºC, absolute maximum is plus 25 ºC.

There is no vegetation directly on the coast (sea shore). Moving away from the coast to the north, in the direction of the mountain slope, the following can be observed. Directly adjacent to the beach is the surface overgrown with grass. After that, the grass cover is replaced with sparse solitary young dahurian larches and sparse groups of young dwarf pine. Further on, more mature larches appear in the landscape and groups of dwarf pine grow more thickly. The surface is covered with low vegetation, which consists of grass cover and mosses (Figure 3). Even further, the forest becomes thicker and more mature.

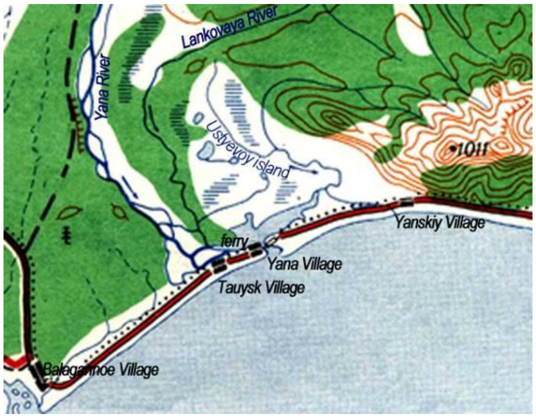

Figure 1. Field study region in the area of the Yana river mouth (schematic map)

Figure 2. General view of the field studies region in the area of the Yana river mouth

In Figure 2 the border between forested area and tundra with lakes on its surface in observed. In Figure 4 this border is shown from a closer distance. At the tundra border the larch forest is rather thick and mature. The understory is represented by groups of elfin wood with limited size and thick shrub with moss cover on the surface.

Figure 3. Sparse larch forest and groups of dwarf pine

Figure 4. The border of forest and tundra.

We carried out the study of the vegetation influence on the thermal regime of the upper grounds layer. One-time temperature measurements at the depth of up to 0.7 m were performed simultaneously during the period of maximum warm up of grounds (second half of August), within the following areas: point 1 – pebble marine cable; point 2 – overgrowing marine terrace (Figure 3); point 3 – the border between the forest and tundra (Figure 4); point 4 – in tundra, at the distance of approximately 100 m from the forest. Charts comparison (Figure 5) shows that vegetation communities change and swamping lead to perennial freezing and permafrost formation.

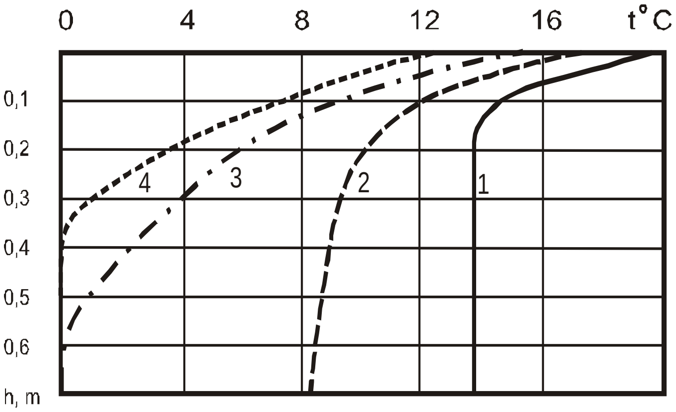

Figure 5.

The following conclusions can be made based on the observation:

1. Vegetation communities change leads to the change in the conditions of heat exchange on the surface. The appearance of sphagnum mosses may be considered the beginning of the surface swamping. Sphagnum mosses actively absorb moisture and peatlands, which appear as a result of mosses life activity, are a reservoir, which accumulates moisture.

2. The dispersion degree of grounds, which occur on the surface, has almost no effect on the conditions of swamping and permafrost formation, as a layer of peat serves as an aquiclude. Over time and under certain thermal conditions this layer freezes and facilitates the grounds saturation with ice.

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Leibnitzkopf Rock Glacier (Austrian Alps): Detection of a Fast Moving Rock Glacier and Subsequent Measurement of its Flow Velocity

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Introduction

Kinematics of rock glaciers

Rock glaciers are striking features of mountain permafrost. Knowing the kinematic state of a rock glacier is of great importance in several aspects: (1) it enables the classification into active/inactive rock glaciers, (2) it supports rheological modeling, (3) it contributes to climate change research, and (4) it makes hazard risk assessment possible. The kinematic state of a rock glacier or, in general, of any slope of the Earth's surface can be determined by various observation and measurement techniques, e.g., field investigations, geotechnical measurements, optical/radar spaceborne, airborne or terrestrial remote sensing, and geodetic measurements based on tacheometry or global positioning systems, for example GPS. Information about spatio-temporal change needed in the above applications can be obtained through proper (long-term) monitoring.

Objectives

This paper describes a simple method for detection and quantification of fast moving rock glaciers using high-resolution orthoimages of at least two different epochs provided by the geobrowsers Google Maps and Microsoft Bing Maps. A practical test was carried out for the western part of the Schober Mountains in the Austrian Alps and provided the basis for subsequent photogrammetric and geodetic measurements. The techniques applied and results obtained are also presented in this paper.

Image-based identification of fast moving rock glaciers

Study area

The eastern part of the Schober Mountains (46°58' N, 12°58' N) has been the focus of detailed rock glacier studies conducted by the universities of Graz and Innsbruck for at least two decades. Research in the western part has remained scarce [*Buchenauer 1990*] and has only recently been resumed with a main focus on fast moving rock glaciers.

Screening a large area for fast moving rock glaciers

Google Maps and Microsoft Bing Maps (formerly Microsoft Virtual Earth) were used for planning purposes. Both geobrowsers provide high resolution orthoimages (orthophotos) covering the area of interest (approx. 120 km²), but from different sources and acquisition dates. The latter fact was successfully utilized in identifying fast moving rock glaciers. Both geobrowsers were opened side-by-side and corresponding areas showing potential active rock glacier candidates were adjusted vertically. Possible geometric differences (disparities) of the orthoimages presented were detected directly through stereo fusion with the naked eye. Earth terrain movements (motion parallaxes) approximately parallel to the eye base will be observed as a virtual 3D landscape. Areas without any geometric differences show up as horizontal planes. Active rock glaciers with a main flow direction different to EW or WE can be tested in the same way as outlined before, but image data must be rotated appropriately in a digital or analog manner. Screenshots were made of all suspicious rock glaciers detected for further quantitative analysis. A total of 5 rock glaciers with large motion parallaxes were found (see Table 1).

Map projection, image scale, and acquisition date

The well-known Mercator map projection is used in both geobrowsers. Ground sampling distance (GSD) for the screenshots of the different zoom levels was determined using the respective scale bars. The zoom levels of both geobrowsers were identical: GSD 20 cm, 40 cm, 80 cm, etc. The recovery of the acquisition dates is difficult because Google and Microsoft provide only scarce information on the image data. In the present case, however, the copyright information given in the geobrowsers allowed the authors to retrieve the original image data source and the respective acquisition dates (see Table 1). In a later stage of the project this original image data (aerial photographs) was ordered for reasons of comparison.

Table 1. Orthophotos covering Leibnitzkopf rock glacier.

*	
	
http://maps.google.com/	http://www.bing.com/maps/
Date: 18 September, 2002	21 September, 2006
GSD: 20 cm, 40 cm, 80 cm	
Source: Province of Tyrol	BEV, Vienna

* Leibnitzkopf rock glacier (46°55'51" N, 12°42'43" E)

Precise change detection and metric quantification

Image matching

Precise co-registration of all available data sets (5 rock glaciers, different coverages according to GSD selected) was carried out using a Matlab-based toolbox. Corresponding points were measured applying area-based image matching techniques with sub-pixel precision. The normalized cross-correlation coefficient was selected as a similarity measure. A consistency check was performed by back matching (left to right, and back from right to left).

Computation of displacement vectors and flow velocity

Since the screenshots refer to local image coordinate systems, offset coordinates must be computed from stable points in the surroundings of the rock glaciers. The two frames are subsequently co-registered to a common coordinate system to enable geometric deformation analysis. In order to compute flow velocities (rate of change) metric displacements must be scaled by the time span, which in our example is 4 years. Figure 1 shows the result obtained for Leibnitzkopf rock glacier (see also Table 1). If the acquisition dates of the two frames to be compared are not known, we can only obtain relative values of change. Information about the geometric quality of the geobrowser orthophotos and our own subsequent co-registration can be deduced from the residual vectors of the stable points. The 40 cm image data of Leibnitzkopf rock glacier was co-registered with a precision of ±0.31 pixel in x and ±0.41 pixel in y-direction, which allows the computation of respective velocities with a precision of ±5.1 cm/year. The maximum flow velocity is 136.9 cm/year. Results for two other rock glaciers have already been published in Kaufmann [*2010*]. The high geometric quality of the results obtained has been confirmed by a comparative photogrammetric evaluation of the original image data (see next section).

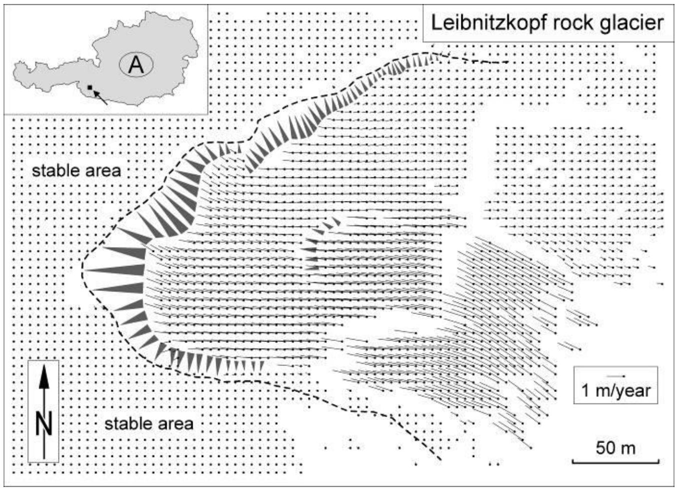

Figure 1. Displacement vectors of Leibnitzkopf rock glacier derived from image data of Google Maps (epoch 2002) and Microsoft Bing Maps (epoch 2006).

Rigorous photogrammetric measurement of the flow velocity field

Photogrammetric change detection

In order to facilitate the accuracy analysis of the simple method presented and to extend the 2D deformation analysis to 3D the original aerial photographs (stereopairs and stereotriplets) covering all 5 rock glaciers were ordered from the respective owners (Table 1). We furthermore augmented the time-series by image data from another epoch (2009), which was also provided by the Province of Tyrol. The photogrammetric processing chain followed the procedure outlined in Kaufmann & Ladstädter [*2003*]. The image matching of the quasi-orthophotos, however, was carried out with the Matlab-based toolbox mentioned earlier. Results are available for three rock glaciers, i.e., Leibnitzkopf, Ganot, and Tschadinhorn.

Analysis of Leibnitzkopf rock glacier

The analysis of the photogrammetric result (precision of velocities: ±2.9 cm/year at 25 cm GSD) with the simple geobrowser-based one (precision: ±5.1 cm/year for 40 cm GSD, ±4.2 cm/year for 20 cm GSD) confirmed the expected high quality of the latter. Independently, direct co-registration of orthophotos from the two different datasets showed that the geobrowser orthophotos are of very high geometric quality, irrespective of water marking and obvious data compression. This comparison confirmed once again that the geobrowsers use a Mercator map projection. It was also found that the scale of the geobrowser images was 2% smaller than the reference Gauss-Krüger map coordinate system. Furthermore, the mean flow velocity of 2006-2009 has increased slightly by approx. 5% compared to 2002-2006.

Low-cost GPS-based measurement of displacement vectors

A GPS-based observation network consisting of 19 stabilized points (4 of which are stable) was installed at Leibnitzkopf rock glacier in 2010. The measurement equipment (GPS module ASHTECH AC-12, data logger, Leica AS05 geodetic antenna, adapter) is low cost and also lightweight. A Virtual Reference Station (VRS) was used. Planimetric accuracy is ±1-2 cm, height accuracy is lower, i.e. ±7 cm. The measurements 2010-2011 revealed a strong increase in flow velocity by approx. 90%. The maximum flow velocity measured is 2.57 m/year.

Conclusions and outlook

Global climate change will have significant impact on rock glacier kinematics. The methods outlined in this paper have great potential to support permafrost and rock glacier research with high-quality numerical data on morphodynamics at relatively low cost.

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On the Frost Heaving Forces

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Ensuring of stability of engineering structures is associated with the solution to the problem of the impact that frost heaving of grounds has on foundations. In the existing regulatory documents [*SNiP 2.02.04-88. 1990*], the foundation stability under the influence of frost heaving forces is only designed for the layer of seasonal freezing - thawing. Conditions with thin permafrost are rather often encountered in the construction practice. Such conditions are often found on the right bank of the Yenisey North and in the southern zone of permafrost distribution.

When they are used as foundation grounds according to the 1st principle, the cooling effect of ventilated cellars leads to permafrost aggradation. The process is accompanied by intensive frost heaving that occurs due to moisture migration to the freezing front. In these particular cases, there arises a necessity to calculate the impact of frost heaving forces on foundations of buildings in the course of perennial freezing of grounds. Unfortunately, there is no required method in the regulatory documents so far; however, the construction is ongoing. The entire city of modern Norilsk was built in this way with no scientific rationale (Fig).

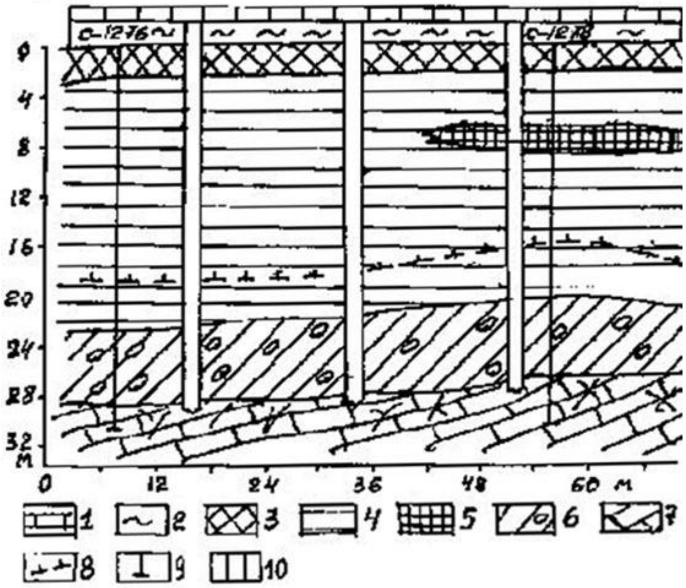

Figure. Geocryological section at the construction site in Norilsk. 1 – foundation frame; 2 – ventilated cellar; 3 – fill; 4 – varved clay; 5 – segregated massive ice; 6 – clayey silt with rubbles; 7 – limestone; 8 - permafrost boundary; 9 – exploratory hole; 10 – pile.

Frost heaving is understood primarily as movement of a particular ground layer perpendicular to the freezing front. Traditionally [*Tsitovich, Sumgin 1937*], the value of the tangential frost heaving force is determined by the long-term resistance to the displacement of the frozen layer of ground relative to the foundation, i.e. by adfreezing forces. However, regardless of how great its value is, the total adfreezing force cannot raise the foundation and does not cause deformations in structures. The lift force is provided only by the normal heaving force. Frost heaving pressure is entirely determined by crystallization pressure that develops and exists in the thin "ice - unfrozen water - mineral component" layer at the lower boundary of the deepest growing schlieren ice. Crystallization pressure is the greatest possible pressure of ice crystals on an obstacle under the given supercooling conditions [*Khaimov-Malkov 1959*]. This pressure is associated with the phase transition energy. In an open system, the pressure exerted by the weight of the upper ground layer and by the weight of the building is applied through a growing schlieren ice to the underlying layer of the mineral part of ground. Therefore, crystallization pressure is single-phase and is not applied to ground water. This fundamental conclusion about the external pressure redistribution between ground phases was initially drawn by K. Terzaghi as early as in 1920s [*Terzaghi, Peck 1948*]. Crystallization pressure is a thermodynamic parameter and is expressed in the following form:

$$\sigma = -L \cdot (T_o - T_s)/ T_o \nu_i$$

where σ – crystallization pressure, MPa;

L – the heat of phase transition of water, kJ/kg;

T_o – the melting point of ice at normal atmospheric pressure (101.3 kPa), K;

T_s – the temperature of phase equilibrium at the base of the growing schlieren ice, K;

ν_i – the specific volume of ice, m/kg.

The calculations based on this formula show that the specific normal pressure of frost heaving at the segregation temperature (T_s) equaling minus 0.3°C is 330 kPa.

In the construction practice two options are typically found. The first one is when the foundations of buildings pass through a permafrost layer and are based on rocks or grounds with low compressibility, and the second one is when the foundations rest in the permafrost layer.

In the first case, it is necessary to calculate the foundations stability not only on the basis of the value of the total tangential heaving force but also to evaluate the total normal heaving force applied only to one foundation. With high frequency and deep foundation laying (Fig.), the latter can be comparable or even lower. The minimum of these values is assumed as the resultant value.

When identifying the causes of deformations or the ones of premature destruction of buildings constructed on thin permafrost, in his practice [*Kazanskiy 2005*] the author applies the estimates to the impact of frost heaving forces based on the following method. The total tangential heaving force in the course of perennial freezing of grounds is calculated according to the method of the regulatory document [*SNiP 2.02.04-88. 1990*], as genetically there is no difference (Table).

In the existing dictionaries, the definition of the term "tangential heaving force" is not entirely adequate to its genetic nature, and therefore the author proposes a definition of his own that is simpler, clearer and directly connected with the genesis.

Table. The total resistance of clayey silt frozen grounds to displacement on the surface of piles with the section of 0.3x0.3m and 0.4x0.4m under different values of permafrost thickness and at the temperature of -1.0 °C (the so-called total tangential heaving force).
The total normal heaving force per one foundation unit is calculated according to the aforementioned formula, proportionally to the area of the building footprint. Meanwhile, permafrost is conventionally assumed as a rigid plate.

Permafrost thickness, m	5	7	9	11	13
0.3 x 0.3 m pile	0.60	0.84	1.08	1.32	1.56
0.4 x 0.4 m pile	0.80	1.12	1.44	1.76	2.08

The tangential heaving force is the result of the combined action of the adfreezing force of ground with a foundation and the normal heaving force that is transmitted to its lateral surface.

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On the Connection between the Parameters of the Water-Ice Phase Equilibrium and Permafrost Longevity

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Abstract

The particularities of the ground moisture crystallization at different pressure and salinity values are described. The connection of crystallization temperatures with permafrost longevity is shown and quantitatively assessed.

Keywords: crystallization; longevity; pressure; salinity; temperature.

The connection of phase-equilibrium parameters can be described with a simple equation (Laboratory methods... 1985):

$$t_f = Pb = P(V_{sol} - V_{liq})T_{th}/Q_{fr} \approx P.\ 0.1\ °C/MPa\ , \quad (1)$$

where t_f – ground moisture freezing (thawing) temperature, °C; T_o= 273(K) – the same at the atmospheric pressure; V_{sol} and V_{liq} – specific volume of the solid (1.09 cm^3/g) and the liquid (1 cm^3/g) phases; P – outer pressure; Q_f= 334 kJ/kg – fusion heat.

Minimum t_f=–22°C is achieved at P=214-220 MPa. At P>220 MPa the sign of tf dependence on P is replaced by the reverse one (Fig. 1). These values t_f= –22 °C = t_{lim} and P=220MPA= P_{lim} characterize the limit equilibrium of the liquid and the solid phases of regular water. The regular water at t < –22 °C and the regular ice (Ice - I) at P>220 MPa do not exist [*Savelev 1991*].

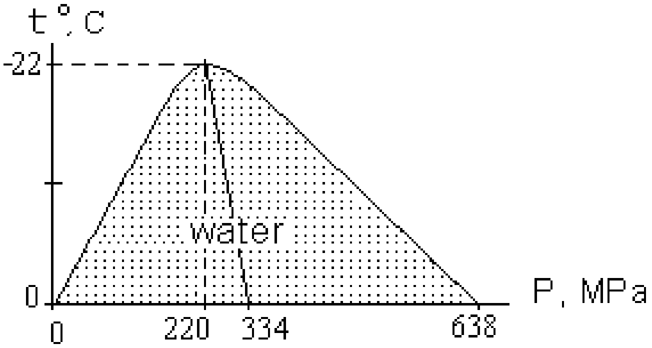

Figure 1. The zone of water existence at negative temperature.

Salinity is another factor of the freezing temperature reduction.

The analysis of the factual material showed:

1) The dependence of the freezing temperature (t_f) on the pressure (P) and on the concentration of the porous solution (Z) that are referred to their limit (eutectic) values is described with the identical equation (Fig. 2).

With regard to this, the freezing temperature equation is received, taking into account both these factors [*Konovalov 2009, 2010*]:

$$\theta = [(P/P_{max} + (Z/Z_{eu})(t_{eu}/t_{min})^{0.83}]^{1.2}, \quad (2)$$

All parameters in (2) are expressed in the relative form:

$$\theta = (t_f / t_{f \cdot min});\ \ H=(P/ P_{eu});\ \ K=(Z/ Z_{eu})$$

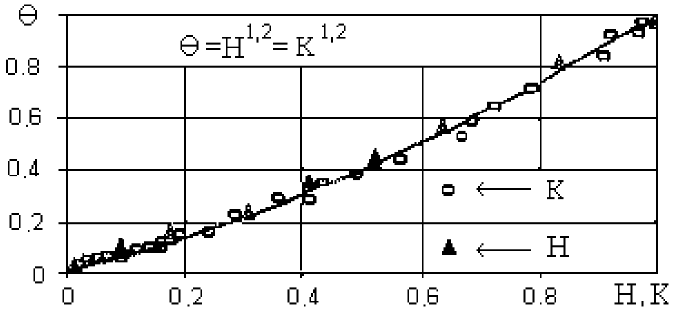

Figure 2. Dependence of Θ on H=P/P_{eu} and K= Z / Z_{eu}

2) The spatial, temperature and heat parameters characterizing the existence zones of the water liquid and solid phases and their deformations in the process of phase transformations are approximately similar. In this case, the similarity factor coincides with the number of months per annum or the average number of hours during the day and night time [*Konovalov 2009*]:

$$V_{sol}/(V_{sol}-V_{liq}) = T_o / -t_{lim}= Q_s/Q_f= j_s / j_{fus} \approx 12, \quad (3)$$

where Q_s – latent heat of ice sublimation (at t = –22 °C Q_s=2830 kJ/kg); j_{fus} =1 – (V_{liq}/V_{sol})=0.083 – relative deformation of ice fusion (change of its volume in the process of fusion); j_s =1 ice deformation in the process of fusion.

3) There are two types (mechanisms) of a solid body destruction: slow, plastic, occurring through the gradual increase of the outer deformation, and spasmodic, brittle, developing by means of fracturing [*Vyalov 1978, Regel et al. 1974, Konovalov 2009, Konovalov 2011*]. The first one is completed by transfer to a liquid-like condition, and the second one - by opening of fractures and falling into pieces. The first one typical of frozen ground and ice works near the fusion point, and the second one works away from it. The longevity equations for plastic and brittle destruction look as follows, respectively:

$$\tau_l = \tau_o \exp[2\ (T_o /T)(1– P/P_m) / j_{fus}] \quad (4)$$

$$\tau_l = \tau_0 (P_m / P)^{1/j_{fus}} \qquad (5)$$

where P_m – pressure of the freezing water that is equilibrium to this temperature and defined on the basis of Formula (1), T (K) temperature.

Figure 3 shows the dependences of conditional longevities $A= j_{fus} \ln(\tau_l / \tau_0) = 2(T_o / T)(1- P/P_m)$ and $B= j_{fus} \ln(\tau_d / \tau_0) = \ln(P_m / P)$ on P/P_m. The bold line reflects the dependence of the real relative longevity (in the logarithmic scale) on the relative pressure, independently from the destruction mechanism.

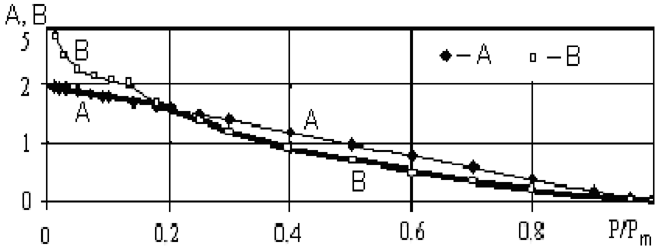

Figure 3. The A and B dependence on P/P_m

It follows from Figure 3 that the longevity is higher for a brittle body at $P/P_{fus} \geq 0.2$ (A>B). This means that critical deformation j_{fus} is reached earlier than the body falls into pieces. Therefore, the longevity and the strength in this zone shall be calculated with equation (5), like for the plastic body. At $(P/P_m) < 0.2$, on the contrary, "plastic" longevity is higher (B >A), consequently, the body is destructed earlier than critical deformation j_{fus} occurs. Therefore, the longevity and the strength in this zone (left in Fig. 3) shall be calculated with equation (4), like for the brittle body.

The baric condition of the dominating work of a brittle or a plastic destruction mechanism $P/P_m = 0.2$ is easily transfered to the temperature one with substitution of P_m in it in accordance with Formula (1):

$$P/P_m = t_{fus} / t = 0.2 \qquad (6)$$

It follows from Formulas (5) and (6) that the "plastic" longevity theoretically tends to infinity at low loads or low temperatures. Indeed, the actual longevity (bold line in Fig. 3) is the finite value in all cases, even if P=0 (at the atmospheric pressure).

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Modeling of Permafrost Thawing in the Case of the Presence of a Thermal Insulation Layer

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Abstract

The methodology of an analytical solution to the three-area problem on the permafrost surface layer thawing in the case of the thermal insulation layer presence is suggested.

Keywords: analytical solution; permafrost; thawing; thermal insulation.

Introduction

The problem of permafrost thawing in the case of the thermal insulation layer presence at the day surface is discussed.

Problem statement

Let us examine the three-area problem for calculation of the thawing depth: $0 < z < h_0$ — thermal insulation layer, area $z < h_0$ is occupied by the thawed and the frozen ground layers separated by the mobile boundary of ground thawing l(t). The temperature field in these layers is described by the equations:

$$a_0 \frac{\partial^2 T_0}{\partial z^2} = \frac{\partial T_0}{\partial t}\text{, at } 0 < z < h_0 \qquad (1)$$

$$a_1 \frac{\partial^2 T_1}{\partial z^2} = \frac{\partial T_1}{\partial t}\text{, at } h_0 < z < l(t). \qquad (2)$$

$$a_2 \frac{\partial^2 T_2}{\partial z^2} = \frac{\partial T_2}{\partial t}\text{, at } l(t) < z < \infty \qquad (3)$$

The boundary conditions look as follows:

$$T_0(z=0) = T_\Gamma, T_0(z=h_0) = T_1(z=h_0)$$

$$\lambda_0 \frac{\partial T_0(z=h_{0)}}{\partial z} = \lambda_1 \frac{\partial T_1(z=h_0)}{\partial z} \qquad (4)$$

$$T_1(z=l(t),t) = T_2(z=l(t),t) = T_\phi$$

$$T_1(z=\infty,t) = T_2(z,t=0) = T_H$$

$$-\lambda_1 \frac{\partial T_1(z=l(t),t)}{\partial z} + \lambda_2 \frac{\partial T_2(z=l(t),t)}{\partial z} = Q_\phi \frac{dl}{dt}$$

Here, λ — thermal conductivity coefficients, Tph and Q_{ph} — the temperature and the heat of the permafrost phase transition. $Q_{ph} = \rho_i LG$, where ρ_i — ice density, L — the heat of ice-water phase transition, G — ground ice content. The temperature at the day surface is defined on the basis of the weather data with regard to the radiation balance.

Analytical Solution to the Problem

The thawing process is divided into three stages: spreading of the heat front in the insulation layer; heating of the insulation layer and of permafrost from the initial temperature to temperature T_{ph} at the "thermal insulation layer-permafrost" separation boundary; and permafrost thawing.

The duration of the first stage can be defined based on integral methods of solving the thermal conductivity equation, on the Bio variation method [*Kozdoba 1975*] or on the averaging method [*Khalikov 1975*].

The temperature distribution in the thermal insulation layer can be assumed in the form of parabolic approximation from coordinates

$$T_0 = T_H + (T_\Gamma - T_H)\left(\frac{L_0 - z}{h_0}\right)^2, \qquad (5)$$

where $L_0(t)$ — the coordinate of the thermal front; value $L_0(t)$ at $z = L_0(t)$ $T_0 = T_H$ is defined from the special variation correlation or the thermal balance integral. The duration of the first stage t_1 is defined on the basis of condition $L_0(t_1) = h_0$. These methods give similar results coinciding well with the accurate solution to the problem obtained by the Fourier decomposition method. According to the first method, $t_1=0,0885(h_0)^2/a_0$, while according to the second one, $t_1=0,083(h_0)^2/a_0$. Here, a_0 is the thermal diffusivity of the thermal insulation layer.

The temperature field is described with the following equations by the beginning of the second stage:

$$T_0(z,t=t_1) = T_H + (T_\Gamma - T_H)\left(\frac{h_0 - z}{h_0}\right)^2\text{, at } 0 < z < h_0, \qquad (6)$$

$$T = T_H\text{ , at } z > h_0$$

At the second stage, the temperature distributions in the thermal insulation layer and in permafrost are assumed in accordance with the equations:

$$T_0^{(2)} = T' + (T_\Gamma - T')\frac{h_0 - z}{h_0}, \qquad (7)$$

$$T_2^{(2)} = T_H + (T_H - T')\left(\frac{L_2 - z}{L_2 - h_0}\right)^2, \qquad (8)$$

Here, $L_2(t)$ - the coordinate of the thermal front in permafrost, at $z > L_2$ (t): $T^2{}_2=T_H$, $T'=T'(t)$ — the temperature at the boundary $z = h_0$. The value of this temperature is found on the basis of the condition of the heat flows equality at $z = h_0$:

$$\lambda_0 \frac{\partial T_0^{(2)}(z=h_0)}{\partial z} = \lambda_2 \frac{\partial T_2^{(2)}(z=h_0)}{\partial z},$$

here, λ_0 and λ_2 — the thermal conductivity coefficients of the thermal insulation layer and of permafrost.

Transformations lead to the equation on the basis of which time of heating t_2 of the "thermal insulation layer - permafrost" separation boundary T'=T_{ph} is defined. To make calculations convenient, let us present this equation in the following form:

$$t_2 = t_1 + \tau\left[\frac{\lambda_{20}^2}{3a_{20}}(\Delta T)^2 + \frac{2}{3}\frac{\lambda_{20}^2}{a_{20}}\Delta T + \left(\frac{1}{2} - \frac{2}{3}\frac{\lambda_{20}}{a_{20}}\right)\ln(1+\Delta T)\right], \quad (9)$$

where $\tau = \frac{h_0^2}{a_0}$, $\Delta T = \frac{T_\phi - T_H}{T_\Gamma - T_\phi}$, $\lambda_{20} = \frac{\lambda_2}{\lambda_0}$, $a_{20} = \frac{a_2}{a_0}$.

It follows from (9) that the time of the beginning of permafrost melting under the thermal insulation layer depends on thermophysical properties of the thermal insulation layer and the permafrost — λ_0, ρ_0, c_0, λ_2, ρ_2, c_2, on the thickness of the thermal insulation layer h0, on the temperature at the day surface $T_G > T_{ph}$ and on the initial temperature of the "permafrost - thermal insulator" system $T_I < T_{ph}$.

The depth of penetration of the thermal agitation into the permafrost zone is defined according to the Formula:

$$L_2'(t_2) = h_0(1 + 2\lambda_{20}\Delta T) . \quad (10)$$

For the third stage, the temperature distribution in the thermal insulation layer as well as in the thawed and the frozen ground layers is assumed on the basis of the Leybenzon's method:

$$T_0 = A_0 z + B_0$$

$$T_1 = A_1 z + B_1$$

$$T_2 = A_2 erf\,\frac{z - \ell}{2\sqrt{a_2 t}} + B_2$$

Determining the integration constants for the temperature in the thermal insulation layer as well as in the thawed and the frozen ground layers on the basis of conditions (8), we receive the following equations:

$$T_0 = T_\Gamma - (T_\Gamma - T_\phi)\frac{\lambda_1 z}{\lambda_1 h_0 + \lambda_0(l - h_0)} \quad (11)$$

$$T_1 = T_\phi - (T_\Gamma - T_\phi)\frac{\lambda_0(z - l)}{\lambda_1 h_0 + \lambda_0(l - h_0)} \quad (12)$$

$$T_2 = T_\phi + (T_H - T_\phi) erf\,\frac{z - l}{2\sqrt{a_2 t}} \quad (13)$$

The equation for determination of the movement law of the phase transition surface l(t) follows from the fifth condition (4):

$$\frac{\lambda_0(T_\Gamma - T_\phi)}{h_0 + \frac{\lambda_0}{\lambda_1}(l - h_0)} - \frac{\lambda_2(T_\Phi - T_H)}{\sqrt{\pi a_2 t}} = Q_\phi \frac{dl}{dt} \quad (14)$$

We will give this equation in the following form: $\frac{a}{b + cl} + \frac{d}{\sqrt{t}} = \frac{dl}{dt}$, where $a = \frac{\lambda_0(T_\Gamma - T_{\phi)}}{Q_\phi}$, $b = h_0(1 - \frac{\lambda_0}{\lambda_1})$, $c = \frac{\lambda_0}{\lambda_1}$, $d = \frac{\lambda_2(T_H - T_\phi)}{Q_\phi\sqrt{a_2\pi}}$.

Equation (14) is solved numerically at initial
condition l(t=t_2)=h_0, where t_2 is defined on the basis of (9).

If we assume in equation (14) that $h_0 = 0$, then it has the analytical solution $l(t)=(\alpha t)^{0.5}$, where α is defined from the equation:

$$\sqrt{\alpha} = -\frac{\lambda_2}{Q_\phi\sqrt{\pi a_2}}\left(T_\Phi - T_H\right) +$$

$$+\sqrt{\frac{\lambda_2^2}{Q_\phi^2 \pi a_2}\left(T_\phi - T_H\right)^2 + \frac{2\lambda_1}{Q_\phi}\left(T_\Gamma - T_\phi\right)} \quad (15)$$

Results of numerical calculations

Testing of the numerical solution to equation (14) at $h_0 = 0$ was conducted on the basis of the accurate self-similar solution to the Stephan's problem and on the basis of the approximate solution by the Leybenzon's method. In the Stephan's problem, parameter α is defined on the basis of the transcendental equation solution [*Tikhonov & Samarskiy 1972*]:

$$\lambda_1 \frac{\left(T_H - T_\phi\right)\exp\left(-\frac{\alpha}{4a_1}\right)}{\sqrt{a_1}\, erf\,\frac{\sqrt{\alpha}}{2\sqrt{a_1}}} - \lambda_2 \frac{\left(T_\phi - T_0\right)\exp\left(-\frac{\alpha}{4a_1}\right)}{\sqrt{a_2}\, erf\,\frac{\sqrt{\alpha}}{2\sqrt{a_2}}} = \frac{\sqrt{\pi\alpha}}{2}Q \quad (16)$$

Parameter α is defined in accordance with (15) by the Leybenzon's method. The numerical calculations were executed with the use of the basic values of thermophysical parameters: We obtained:

$\sqrt{\alpha} = 0{,}8138 \cdot 10^{-3}(\text{м}\sqrt{\text{c}})$, in accordance with equation (15),

$\sqrt{\alpha} = 0{,}72 \cdot 10^{-3}(\text{м}\sqrt{\text{c}})$ in accordance with equation (16).

The results of the numerical solution to equation (14) by the Runge-Kutta method showed the satisfactory conformity with the self-similar solution by the Leybenzon's method (the relative error is 3%).

The suggested model allows us to choose the optimal parameters of the thermal insulation layer, depending on the ground thermophysical parameters, the air temperature and the permissible depth of permafrost thawing.

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The Natural Studies at the Bovanenkovo - Baydaratskaya Bay Route for the Provision of Investigations on the Reliable Operation of Gas Pipelines in Yamal.

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A system of main gas pipelines is designed from the Bovanenkovo gas and condensate field. It will consist of three lines with 1420 mm in diameter and 11.8 MPa pressure, laid on the peninsula with transition across Baydaratskaya Bay. The five-line transition across the bay is assumed to consist of pipes with 1220 mm in diameter.

The route is laid on permafrost with the temperature of -6…-7°C across the whole length. The water content of grounds reaches 80%. The ice content is 15-30%. Ice massifs reach the thickness of several tens of meters; cryopegs are found. The route crosses multiple rivers and creeks falling into the Kara Sea. The natural conditions at the site of crossing of Baydaratskaya Bay are very complex as well.

It is planned to transport the gas chilled till negative temperatures within the peninsula. According to the authors, this does not eliminate the development of adverse geotechnical processes. The provision of stability of the "cold" gas pipeline position in taliks at the sites of river bed crossing is the most difficult. Long-term freezing occurs at the negative gas temperature and it is accompanied by gas pipeline bulging.

The scientifically substantiated practical recommendations are possible only on the basis of the establishment of fundamental regularities in the change of permafrost and geological conditions of pipe bedding, the regularities in heat and mechanical interaction between the pipe and host ground, and long-term probability forecast. The solution is significantly complicated due to complex permafrost conditions, varying gas temperature and varying climatic parameters.

Today there are no calculation methodologies in the existing normative documents of Russia for determination of heave forces acting on the "cold" gas pipeline laid underground in case of freezing of the thawed grounds in its basis. Consequently, the measures developed on the basis of the calculation methodologies of normative documents and applied in practice for provision of the gas pipeline designed position are low-effective because they take into account only the impact of buoyancy forces (preconditioning pipeline floating) on pipelines. There are multiple cases known when pipelines were pushed out to the surface by ring weighting materials designed in accordance with standards, by means of heave forces acting on the pipeline [*Remizov et al. 1997*].

Unlike other engineering structures, the pipelines have some specific features, including low specific pressure on foundation grounds and a high sensitivity to heat and mechanical impacts, with a relatively high flexibility of the structure. This allows the pipeline to take up significant deformations without any hazard of metal continuity loss in the case when thawed grounds serve as a pipe foundation. This is exactly what happens on "warm" gas pipelines of the Urengoy and the Yamburg intrafield reservoir [*Khrenov et.al. 2001, Khrenov 2002*] where the formation of a large thawing halo and the intensive occurrence of cryogenic processes (thermokarst, thermal erosion and bogging) complicate the normal operation of a gas pipeline, but do not form critical situations. Moreover, the high temperature of the transported gas during the first operational years, which caused the formation of a large ground thawing halo around the pipe, enabled the relaxation both of the initial piping stresses (that occurred in the process of its laying) and the ones occurring in the course of further operation, up until now [*Khrenov 2003a*].

Permafrost interacts differently with "cold" pipelines. When grounds get frozen, the pipe mobility decreases abruptly due to its fixing by freezing ground. The statistic data available on the distribution of the number of "disturbances" by seasons shows that the overwhelming majority of them (above 60%) fall on winter (November-March), i.e. during the period of intensive ground frost heave. As a result, the pipe fixed from one side in the frozen massif undergoes a continuously growing pressure from below, from the side of freezing and heaving grounds. Consequently, pipe breakage can be expected at the contact of these sites [*Khrenov 2003b, Khrenov 2005*].

The significant part of natural-technogenic accidents in the system of engineering structures construction and operation in the cryolithozone is preconditioned by defects in their research and design sphere that are associated with lack of information on the natural conditions of construction areas. The aforementioned occurred in full in the Bovanenkovo-Ukhta project, primarily at the Bovanenkovo-Baydaratskaya Bay section.

The project does not take into account any experience of native cold pipeline operation, the results of theoretical studies and the results of model and mock-up experiments abroad. Only underground laying with gas chilling is suggested (as was in the first variant in the 80s).

It was assumed for a long period of time that preliminary gas chilling eliminates the problems of pipeline bulging and breakage. Our researches made it possible to reveal the stages of the interaction process development.

The interaction process is divided into three stages.

General flooding and bogging occur at the first stage. Permafrost gets thawed and thawing halos grow. The process dynamics hardly depends on the temperature of the transported gas.

At the second stage (in the 7th-8th years) of pipeline operation the water leaves the route at many sites, and permafrost returns but becomes more rigid, as compared to the one prior to the beginning of construction. Intensive frost heave occurs. In this case the measures for gas chilling lead to the opposite result - even more intensive heaving occurs. During the short operational period (5-7 years) deformations reach 1 m and more, due to frost heave [6, 7].

At the third stage negative processes are activated or the new ones occur as a result of gas pipeline interaction with permafrost. They cause its deformation [*Khrenov 2005, Scott* *et.al. 2004*]. Such processes include frost heave, thermokarst, thermal erosion and frost cracking.

The long-term experience of pipeline operation in the cryolithozone showed that pipelines on some sites have anomalously high vertical deformations the value of which exceeds much the value of the standard frost heave of grounds in the process of freezing of the seasonally thawed layer. Such sites include minor watercourses, flooded lowlands and hollows.

The crossings across minor watercourses with the talik width of 1060 m should be investigated for assignment of the sites for natural detailed studies, in addition to traditional sites with different lithological conditions in various landscape conditions.

The works for evaluation of the state of the Bovanenkovo-Ukhta gas pipeline being built in Yamal were conducted in the second half of September 2010.

Work organization was initiated since the end of July. Several aspects had to be brought together for the success of this activity:

the information on ground composition and properties;

the forecast of situation development;

the design data;

the information on the actual state of the route in different periods. Extensive natural works should be conducted with the use of aerial photography methods – the information without them is poor and unreliable.

Geocryology specialists worked on board and in the field in the process of post-trenching on the selected key sites. They had the processed research materials and a set of route state evaluation and forecast maps, and also the design data. The involved people have the work experience at the route of research exceeding 10 years. This rendered it possible to quickly identify the processes and evaluate the dynamics of changes in the course of investigation and preliminary processing.

Materials processing should be aimed at GIS formation (if financing affords) and materials analysis that will allow one to start differentiating the route on the basis of operational conditions. This will also allow one to create the tables of the technical state on the basis of the technical state parameters (embankment destruction, floating, underflooding etc.) and define the dimensions of disturbed sites at the first stage. The analysis will enable the specification of the boundary conditions for solution to heat problems and give recommendations for investigations and the development of problems adequate to natural conditions.

Surface investigations (with helicopter dismounting) were conducted in 4 (5th on the laida) points identified at the moment of fly-around with regard to evaluation and forecast maps. Visual and instrumental observations were conducted at each of them, concerning the embankment state, the seasonal thawing depth, the nature and the area of the technogenically disturbed territory, especially in the places of watercourse crossings and in the coastal zone - the laida. The analysis of investigation results allowed us to make the following conclusions:

1. The route of the gas pipeline being built is quite clean. The construction culture is quite high, but there are still many rutted areas, despite the multiple announcements about tundra preservation.

2. The design describes the case of evaluation of the gas pipeline state after construction prior to commissioning. A conclusion is drawn that the whole pipeline will get completely frozen into the ground and will transmit the flood flow (Section 4. 8). Today there are 5-7% of such sites along the length.

3. The current design of the linear part was "re-drawn" from the 1985 design where the thickness of the wall was 14-17 mm. The pipeline cannot be laid according the relief. And the trench needs to be widened at some sections so that the pipe could be laid sideways.

In some cases the width of the trench reaches 18 meters. The backfill embankment volume reaches 15-37 cubic meters per line meter. The drill-and-blast method of trenching assists in that.

4. During the flood period the following occurred: movement of the thawed water in the trench, ground thawing and formation of a talik zone near and under the pipe. The depth of thawing halos alongside of the pipe makes up 1.5-2 m and above by the end of September. The width is up to 20 m.

Polystyrene foam insulation gets swollen with water, and re-distribution of snow with intensification of flooding along the route is possible in winter. The embankment starts destructing.

5. A trench with a 1420 mm pipe catches the surface and the intraground runoff in many places on flat slopes and redirects it in two variants: concentrating it, activating thermal erosion processes and forming large puddles and lakelets (a small lakelet up to 1.0 m deep and about 200 sq.m in area is noted in this case), and in the form of a surface runoff, which will cause thermokarst during the operational period.

6. Natural surface disturbances by heavy machinery are noted along the whole pipeline (this can be seen on all profiles and aerophotos). They vary in area and intensity of destruction of the soil and vegetation covers. This can lead both to thermokarst and thermal erosional processes during a warm period of the year in case of high ice content in the active layer and often close bedding of polygonal wedge ice and massive ice.

7. Almost the whole filled trench is significantly over-moistured (slopes and low surfaces). This led to the intraground runoff, solid material removal and water stagnation in the trench. This will inevitably lead to irregular ice segregation and frost heave in such conditions even along the non-operating pipeline during the freezing season.

8. The careless construction of the embankment above the trench will inevitably lead to the change in the snow accumulation process, and therefore in the water reserve. This will adversely influence the spring flood flow.

9. The design documentation describes the 16.3 km long sites exposed to solifluction. Aerovisual observations allow us to affirm that slope processes are active at a significantly longer part of this pipeline. Almost all destruction processes act both in natural and disturbed conditions in the seasonally thawed layer. Gradual or stepwise change of temperature and moisture conditions causes complex movement and mixing of grounds with different genesis and composition. Landslide phenomena of different scale and genesis are very typical of the Yamal Peninsula. If solifluction is caused by gradual

ground thawing, is expressed in the slow flowing down the slope and is noted in all natural subzones with permafrost, landslides that are possible along the route will look absolutely differently: tragically fast and large-scale sliding of thousands of cubic meters of over-moistured dusty grounds.

10. It should be admitted that the pipeline does not operate according to the design.

11. Extensive and irregular heaving with creation of multiple critical situations will occur after the chilled gas-in. Frost heave is acknowledged to be insignificant in the construction design and in the production environmental monitoring design.

12. No pipeline monitoring is conducted. Multiple programs do not work. No investigations were conducted at the route prior to or at the moment of study. The flights of multiple commissions around do not count.

Potentially hazardous sections were chosen at the gas pipeline on the basis of the analysis of research materials (including the forecast maps of the ground and pipeline state after construction), the design and examination materials (with the accompaniment on a small digital device Hasselblad) and satellite observations of large scales. Further detailed surface studies are reasonable on these sites.

Crossings across minor rivers along the route require detailed surface works as well. The crossing of the Nyakhar-Yakha River at Stake 1035 was examined ground-level.

Investigations were conducted for determination of a set of measurement means and methods at the sites of research. Ground and pipeline wall temperatures, moisture content, pipe and ground displacements, porous water pressure in the ground, stresses in the pipe and heave forces should be measured. Sets of devices and measurement systems were chosen. A set per one site costs approximately 20 million rubles. The investigations must answer the following questions:

the necessity of looping construction at talik crossings and at challenging sites;

the determination of critical situations at talik crossings. The development of permissible operation criteria for specific pumping modes;

the determination of gas transportation modes providing for reliable operation in different periods.

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Study of the workers' diet in the North during different seasons

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Human nutrition is one of the most important factors influencing the health of population. It plays an important role in the adaptation of people to northern conditions. The nutrition problem cannot be solved in the same way for such different regions like the Far North, Central Russia, the Caucasus or the Central Asia, because the peculiarities of a person's metabolism depend on the specific climatic and geographical conditions [*Methodological recommendations 1984*].

Numerous publications studying nutrition indicate the increase in the caloric value of the food consumed by the population of the northern regions of Russia (on average by 20% and more) as well as the change in the food's chemical composition (increase in the consumption of lipids and proteins). This is caused not only by a higher basal metabolism due to intense thermoregulation of human body but also by additional energy inputs necessary to overcome the resistance of cumbersome warm clothes and by general technical conditions associated with more difficult operation of machines and mechanisms [*Kandror 1968, Boriskin 1973, Volovich 2001*].

Seasonal change in a person's energy inputs as the main criterion for the evaluation of the difficulty of labor is studied in paper [*Galkin, Zabolotskaya 2008*]. The authors proposed a hypothesis on an indirect effect of changes in a worker's energy input on the injury probability in different climatic conditions. We have already noted [*Galkin, Khusainova 2010*] that a higher accident rate at the oil and gas enterprises of the northern regions during the cold season might be also caused by seasonal change in energy inputs.

In order to confirm the assumption on seasonal change in energy inputs of workers and, consequently, in the caloric content of the food consumed, there was performed a study of the diet of the workers of one of the oil and gas enterprises located in the north of the country. The workers were polled in two stages (in summer and winter). The respondents had to fill in a special questionnaire. All the respondents worked at the enterprise as oil and gas production operators. This work belongs to the medium-difficult labor category and is carried out outdoors during more than half of the shift. The data treatment included the calculation of daily caloric content of the food consumed during three days by each respondent. The average daily value was then calculated. The comparative analysis of the data obtained was conducted after all the questionnaires had been treated. The season when the poll took place was taken into account.

The results of the research performed indicate that the average energy value of the workers' diet is 2378 kcal (t = -35°C) in winter. This exceeds the average energy value of the diet of the workers polled in summer equal to 1877 kcal (t = +7°C) by 26%. The confirmation of the hypothesis on the seasonal change in energy inputs of the workers in the northern areas depends on the necessity of comparison of the results obtained with the conclusions delivered by other authors. A study of the uncontrolled diet of soldiers whose work belongs to the category of hard and very hard labor is presented in [*Barton, Edholm 1957*]. Despite the difference between the difficulty of the labor of the workers polled (their occupation belongs to the medium-difficult labor category as it was mentioned above) and the soldiers and, consequently, different dietary demands, the results obtained are in good general agreement. This implies the existence of a general regularity and enables to use the experimental data presented in works [*Galkin, Zabolotskaya 2008, Barton, Edholm 1957, Galkin 2000*] for further analysis of the impact of energy inputs during the work on the seasonal aspect of the injury rate among the workers of oil and gas enterprises of northern regions.

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New Constructions in Continuous Permafrost Regions of Zermatt at Matterhorn Glacier Paradise, Swiss Alps

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Zermatt aspermafrostresearchregion

The tourist resort Zermatt is located at about 1600 m a.s.l. and is surrounded by high mountain ranges that often reach more than 4000 m a.s.l. This location therefore profits of a dry and sunny climate that results in a high glacier equilibrium line of about 3400 m a.s.l., and in vast unglaciated permafrost areas at a large vertical extension. Sporadic permafrost may occur well below 2600 m and continuous permafrost above about 3600 meters. The *Gornergrat rack railway*, constructed more than 100 years ago, reaches an altitude of 3100 m a.s.l., crossing potential permafrost terrain in the uppermost 3 km above about 2800 m a.s.l.

On the other hand, numerous tourist facilities provide easy access and logistics to all permafrost sites, and the Zermatt region is therefore especially suitable for permafrost and periglacial studies in the Alps. The research group of Giessen university started permafrost research in 1982 [*King 1990*] and continues geophysical studies and permafrost monitoring until today. The conference poster gives an inventory of existing constructions on probable and proven permafrost sites and describes the challenges encountered during the last 30 years with original new temperature dataform Matterhorn Glacier Paradise.

Zermatt as international tourist resort

Initiated by the successful climbing of the Matterhorn (4477 m) in July 1865, Zermatt has started as an internationally well-known tourist resort in the second half of the 19th century. At the end of the 19th century, railways have been constructed, and then there were even plans to build an elevator up to the Matterhorn.

Gornergrat may be reached by a 9.3 km long rack railway line constructed between 1896 and 1898. The uppermost 500 meters have been added at its end in the year 1909 and the *KulmhotelGornergrat* was opened in 1910. The railway track and the hotel were mainly used in summer until the early fifties. Winter skiing became more and more attractive in the sixties when the hotel started to open also in winter. In the year 1985 two new astronomic observatories were added to the northern and southern towers and this caused a substantial additional load of the subsurface. The northern tower that was erected on frozen moraine material started to settle due to permafrost degradation. Today, ground temperature measurements show, that the ground below the tower is probably not frozen for a depth of about 10 meters (the active layer at undisturbed sites is less than 2.5 meters, the MAAT is -3.3 °C). This must be attributed to heating of the basement for almost 20 years [*King & Kalisch 1998*]. Actually, subsidence seems to have stopped.

Ski tourism triggered the construction of many ski lifts, chair lifts and cable cars in the 1960 allowing year-round tourism. The necessary additional infrastructure erected in the permafrost areas consists of hotels, restaurants and mountain huts, stations buildings of railways, funiculars and ski lifts, and other related constructions as masts, tunnels, elevators, shelters for vehicles, workshops, subsurface water pipes (for drinking water, artificial snowing of ski-runs), sewage, communication and electricity lines. Engineering geologists as well as the responsible persons for this infrastructure have become increasingly interested in the distribution and the characteristics of permafrost in the Zermatt area, as there have been problems due to permafrost degradation. These installations allow skiers to use a total of about 200 km ski runs, including the ski region of *CourmayeurMont Blanc* in Italy. Today Zermatt is a touristic centre in the Alps with all together 14,000 beds and more than 1.8 million official overnight stays per year.

Klein Matterhorn cable car, elevator, guest house

The touristic infrastructure consists of the cable car constructed in 1981 leading to the top station at 3820 m a.s.l., an elevator to the viewing platform at the mountain peak (called Matterhorn Glacier Paradise, 3883 m) and a new guest house at the southern exit (Figure 1). Mean annual air temperatures were measured at the cable car station since 1998 and range between -6 °C and –8°C at the altitude of 3820 m a.s.l.

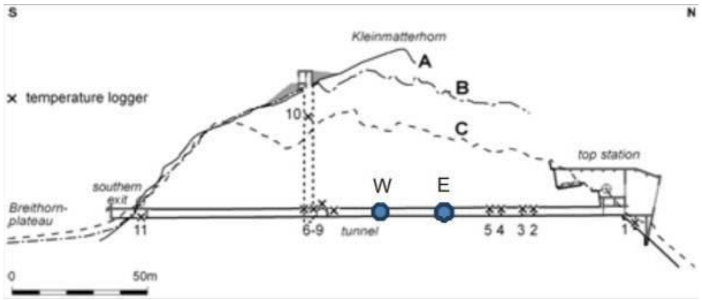

Figure 1.Matterhorn Glacier Paradise with the location of the elevator shaft, the new tunnels "W" and "E" and selected temperature loggers. A, B and Cindicate cross sections.

A tunnel connects the cable car top station with the ski runs on the southern side, where a guest house offers shelter for 120 persons in the restaurant and 40 tourists to stay overnight (www.minergie.ch). The guest house has been constructed according to the *Minergie standards*, a registered quality label for low-energy consumption buildings, and opened in summer 2009.

In the year 1981, bedrock temperatures as low as –12°C were reported during the construction of the tunnel [*Keusen & Haeberli 1983*].Over the past 30 years, these temperatures have risen to –3 to –2°Cin the vicinity of the tunnel. This is due to heating and to the heat brought into the tunnel by the more than 490,000 visitors per year. Additional heat was created by almost 70,000 elevator movements per year, transporting tourists to the mountain top at 1883 m a.s.l.. In summer 1997, melt-water created problems when refreezing in the elevator shaft [*King et al. 1998*]. The electric elevator engine as main heat source has been transferred in summer 2011 to a new elevator building on top of the shaft. A cooling effect could be registered already in summer 2011 (Figure 1, sensors #6, #10). Altogether, temperatures are monitored since 1998 at eleven different sites in order to take countermeasures if necessary.

Tunnels for viewing platform and cable car

The capacity of the existing cable car to Klein Matterhorn does not meet the increasing demand of winter tourists. A second cable car will be constructed in summer 2012. It will run parallel to the existing one from *TrockenerSteg* (2939 m a.s.l.) to the *Klein Matterhorn*. Whereas the top station of the existing cable car enters at the northern, almost vertical slope of the mountain peak, the *new cable car* will lead to the western slope of the mountain peak. The tunnel “W” blasted in summer 2011 connects with the existing tunnel. At this site, other constructions are also in progress, as e.g. a 10 kV power line. The tunnel “E”leads towards eastto a viewing window that allows the tourists a spectacular glance to the 4164 m high *Breithorn* mountain peak above and the cascading glacier below.

Two holes up to 4.5 m deep were drilled in summer 2011 in new the tunnel “W” (sites W1 and W2), another two in the eastern tunnel (sites E1 and E2). All four sites are instrumented with 6 sensors each that register temperatures at depths from near surface down to 3.0 and 4.5 meters, respectively. Here, the loggers register hourly values since September 2011. The mean temperature of the bedrock at sites W1, W2 and E2 ranges between -1 °C and -2 °C, the differences between winter and summer temperatures are very low, and daily temperature fluctuations do not exist as the tunnels have no connection with the outside air temperature (except during the construction periods in September 2011 and after May 2012).

The temperatures measured at siteE1 contrast strongly due to its location outside the viewing window. The site depicts the daily fluctuations of the temperatures in an almost vertical rock-wall exposed towards south. On sunny days, the daily temperature range is much larger than the range of the corresponding air temperatures measured at site E2. The temperatures climb to more than +10 °C in late September and early October 2011, when the air temperatures lay between +2 °C and -2 °C with daily frost cycles.Permafrost could not be reaches with the lowermost sensor, and the active layer is more than 3 meters deep. This illustrates that weathering at similar locations effects much greater depths on a yearly base, giving origin to the production of large boulders and debris. This data givesalso valuable information to engineers for constructions of rockfall and avalanche protection devices on permafrost.

Other sites and projects

An interesting site for permafrost and glacial studies at Matterhorn Glacier Paradiseis the *ice palace*. Since summer 2011 this tourist attraction can be accessed from the southern exit via two elevators leading to an ice tunnel about 12 meters below the glaciers surface. Interesting thermal interactions existbetween the permafrost bedrock that is in direct contact to the glacier ice. Great care has to be taken that there is no heat transfer from buildings to the glacier ice. Maps of the glacier palace and a cross-section are shown on the conference poster.

Future projects involve the construction of an additional cable car from Klein Matterhorn to *TestaGrigia* (3479 m) at the Italian border. This will allow the skiers accommodated in the hotels in Italy to enjoy the Zermatt ski areas and to return to their hotel in *Courmayeur* in the evening or in case of bad weather. A tower on top of Klein Matterhorn reaching up to 4000 meters a.s.l. is also under discussion - detailed plans exist.

A view to the registered or extrapolated MAAT indicates that permafrost exists not only at Klein Matterhorn (3820 m, -7.5 °C) but at numerous other sites as:TrockenerSteg (2939 m, -2.2 °C), Rothorn, Rote Nase and Hohtälli (3100 to 3286 m, -3.1 to -4.2 °C), and TestaGrigia (3479 m, -5.3 °C). A MAAT of about –1°C hints to patchy permafrost occurrences, at less than -5°C continuous permafrost may be expected.

Conclusions

Degradation of permafrost due to climatic change may become a serious threat to installations of high mountain tourist centers. Therefore, these facilities have to be maintained properly. Information of the managers of these installations and of authority officials is a necessary duty for permafrost scientists working in these areas.

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Assessment of Vegetation Suppression Resulting from the Effects of Geocryological Processes on the Basis of the Remote Sensing Data

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Due to the fact that the majority of Russian hydrocarbon fields are located in the permafrost distribution conditions, the study of geocryological processes impact on natural systems and on the facilities of field development is one of the priorities. Geocryological processes can include natural gas hydrates formation. Their genesis and distribution area are confined to permafrost distribution areas. Gas hydrates are destroyed under the influence of external factors, and the formed hydrocarbons seeping onto the surface have a negative impact on the natural environment. Moreover, their emissions during the wells operation cause outages and fires.

One of the most intensive ways of hydrocarbons micro-seeping to the day surface is ruptures of high permeability. Hydrocarbon of gas hydrate origin that seeps to the day surface has a negative effect primarily on vegetation.

The theory of micro-seeping emerged in the late 20th century. It is connected with the fact that both carbon (C_mH_n) and non-carbon (H_2S, CO_2, H_2, CO, He etc.) but chemically active components are constantly subtracted from the deposit through the overlying seal. When migrating, they are able to reach the day surface, changing the geochemical characteristics of the landscape above the deposit. At the same time, extensive gas hydrates deposits were found in permafrost zone and it was determined that the majority of natural gases CH_4, C_2H_6, C_3H_8, CO_2, N_2, H_2S etc.) form hydrates. Methane and carbon dioxide hydrates are the most common. Their average occurrence depth is 250 – 800 m.

Changes in vegetation spectral curves under the influence of chemically active substances were studied by Chang and Collins [*Chang & Collins 1983; Collins 1983*] both in laboratory and in natural environments. A steady change in vegetation spectrum was discovered at wavelengths from 680 to 750 nanometers. The red border lies within this range. When vegetation oppression takes place, it moves in the direction of short waves (in the direction of blue) not more than by 20 nanometers on average. Such phenomenon is called a "blue shift" (Fig. 1).

Currently there is a possibility of identifying ruptures and vegetation suppression areas based on the modern remote sensing data. When compared, it allows us to identify the areas of carbohydrates micro-seeping to the day surface. For identifying the vegetation suppressed condition, there are commercially available multispectral spacecrafts WorldView-2 and Rapideye. They possess the channels that are required to register the reflectivity in the outer red area within the range from 680 to 730 nanometers.

The technique of suppressed vegetation areas identification and the generalized experience in the field of forecasting and searching deposits are reflected in [*Vanyarkho et al. 2010*].

Calculation of areas with suppressed vegetation with the use of the multispectral space image was tested at the Urengoy field [*Baranov, Vanyarkho, Kiselevskaya & Kozhina 2011*]. A "blue shift" was detected along the active rupture and around the field facilities there. Similar work was conducted on the territory of the Zapolyarnoe field and in the Kamchatka coastal area.

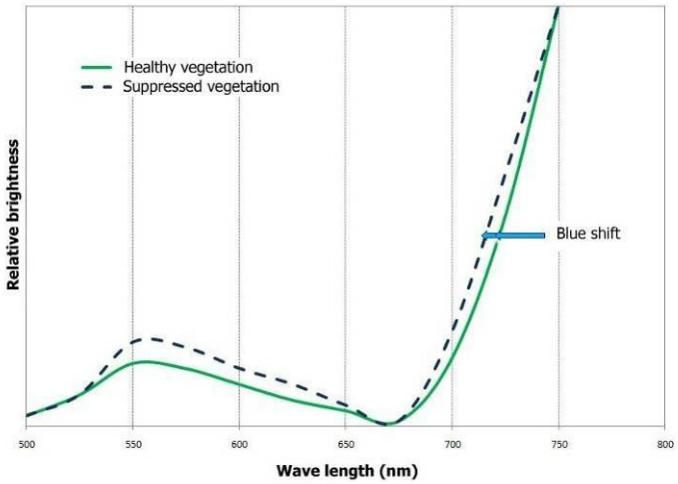

Figure 1. Vegetation spectral curves and the "blue shift" phenomenon.

Calculation results revealed directions of active ruptures in the fields with high permeability, where vertical micro-seeping of chemically active elements is possible, including hydrocarbons from gas hydrates.

Identification and mapping the areas of hydrocarbons micro-seeping may serve as one of the search indications of the occurrence of hydrocarbons, including gas hydrates that are valuable for the prospective alternative energy source and important for ecological and anthropogenic monitoring of northern fields' territories.

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Differences of the Frost Heaves in Sandbeds

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During the freezing of grounds their volume often changes and frost heaves are formed due to the differences of freezing in area and in depth. Frost heaves are most studied for natural conditions. [*Orlov 1962; Nevecherya 1996; Mackay 1979 and others*]. This process is accompanied by ice formation that is most extensively described in the work of P.A. Shumskiy [*1955*]. On the territory of engineering facilities in the cryolithozone frost heaves are also observed [*Grechishchev 1990*]. During the period of their formation and development, the surface of the heaves cracks, and sometimes it is accompanied by explosions that occur due to internal pressure [*Gevorkyan 1992*].

When carrying out geocryological monitoring in 2010 - 2011, frost heaves occurring on the territory of sandbeds were studied. It was determined that there are two types of frost heaves depending on the initial environmental conditions in the ground. The reasons for formation as well as the stages of existence of frost heaves were examined.

The area where observations were conducted was located on the site of a gas processing plant that was backfilled with sandy material. The dimensions of the site were 500×600 m, and it was located on the Zapolyarnoye oil and gas condensate field, in the north of the West Siberian Plain, in the interfluve area of the lower reaches of the Taz and the Pur rivers.

Backfilling of the sites for construction with sand began in the spring of 1999 and was completed in the autumn of 2001. The first formations of frost heaves on the territory of the gas processing plant were recorded in the spring of 2006, and in the following years they appeared with varying intensity. Moreover, some frost heaves are formed in the same areas year after year with a slight movement (up to 2 m). This movement is associated with a change in the annual distribution of snow during the winter.

Figure 1 (a, b) shows the position of the groundwater table and permafrost table for the month of October, during the period of maximum thawing of the ground. In the first case (a), the permafrost table was at the depth of 3.0 m and more from the surface, while groundwater table varied from 0.5 – 0.7 m and less. For another option (b), – the thawed layer did not go beyond the limits of the sandbed, and it was 2.2 – 2.6 m, while the groundwater table was the same as in case (a).

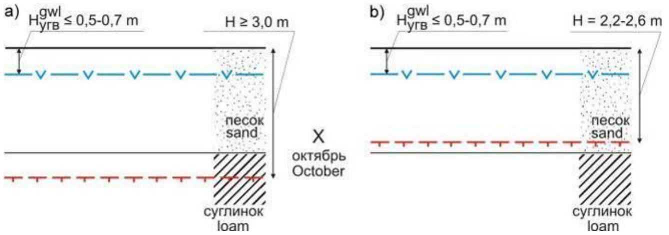

Figure 1. Ground conditions at the beginning of freezing

The freezing rate of the sandbed was higher under large vented crawl spaces, roads where snow was removed and adjacent areas, as well as in relatively dry sandbed grounds. In the areas where the snow cover thickness reached 0.5 – 0.7 m at the beginning of December and where excessive flooding was recorded, the freezing started later, and hydraulically enclosed volumes of water-saturated ground were formed in different areas on the territory of the gas processing plant, as shown in Figure 2 (a, b) and Figure 3 (a, b).

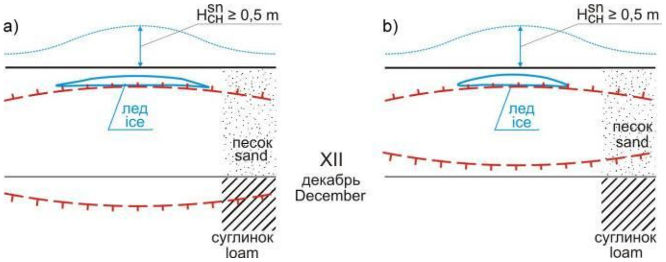

Figure 2. The process of ground freezing in December

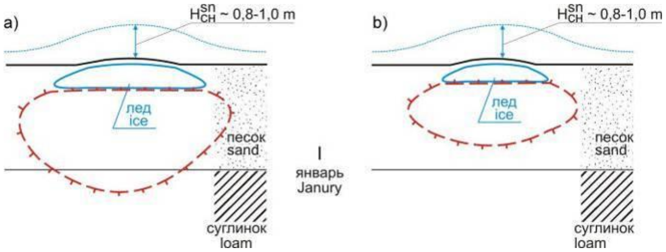

Figure 3. The state of the freezing ground volume in January

Frost heave formation is completed by March-April, Figure 4 (a, b). The frost heave height was 0.3 – 0.8 m, while higher frost heaves were typical of case (a).

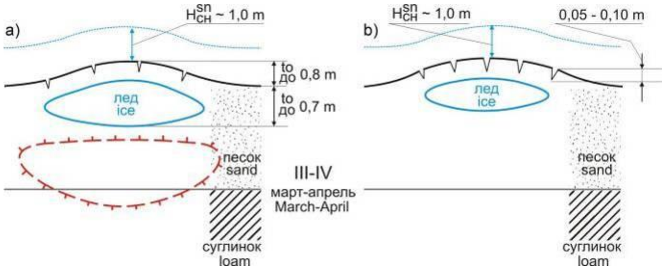

Figure 4. Frost heave after termination of growth

The diameter of a round frost heave reaches 5 – 6 m. The ice core base is located at the depth of about 0.7 m from the ground surface, the depth of cracks in the ground above the core is 0.05 – 0.10 m. Through these cracks thawed waters are discharged during the freezing in January and February. The main difference between the frost heaves is that for case (a), thawed ground is preserved under the heave, and in case (b) thawed ground freezes over completely.

When the frost heaves start thawing in late May – early June, the following particularities are observed (Fig. 5 (a, b)).

For case (a), when the thawing front of thawed grounds under the frost heave was reached, there was sinking of the ice core into the water-saturated sand of the sandbed with formation of negative landforms with the depth of up to 0.1 m and a network of cracks along the outer perimeter of the ice core due to the subsidence.

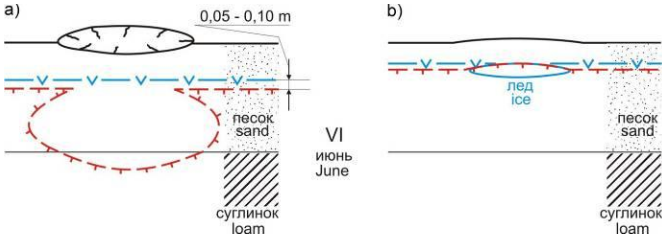

Figure 5. Ground conditions with frost heaves in June

In case (b), when thawing occurs, the depth of ice core thawing is, on the contrary, not as great as that around it. It happens due to the high specific heat capacity of ice, as compared to the surrounding frozen sand. Externally, a frost heave differs from the ground surrounding it by a slight elevation or (and) ground cracks that are washed out with liquid precipitation and meltwater.

In the course of the study the following results were obtained:

1) the most favorable ground and external conditions for the formation of different types of frost heaves in fill sand grounds were determined;

2) the stages of formation and existence of frost heaves in winter and summer were identified;

3) some of the morphometric characteristics of frost heaves (height, circumference etc.) that were formed in sandbeds were obtained.

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The Geoportal Project of MSU: "The Geoinformation System of a Coastal Area of the Yugor Peninsula"

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Abstract

The developing field of web-mapping makes it possible to implement a remote access to a variety of spatially-oriented data with the possibility of collaboration within a working group as well as with provision of a free access to research results for a wide range of users. With educational and research purposes, the project "The geoinformation system of a coastal area of the Yugor Peninsula" was created on the basis of the MSU geoportal. The project contains the results of the multi-year field observations and the results of their subsequent office analysis. The structure of the project contains remote sensing data, spatially attached descriptions of the field route points, photographs of typical landforms and landscapesas well as thematic maps drawn on the basis of the obtained data.

Keywords: geoinformation system; thermal denudation; thermocirques; Yugor Peninsula.

Introduction

The project "Geoinformation system of a coastal area of the Yugor Peninsula" was created as a part of the MSU geoportal development. The employed geoportal technolo-gies make it possible to visualize and analyze the spatial data as well as to exchange them using open communication networks. Available satellite imagery databases are supplemented with the field study materials and with the results of remote sensing data analysis. The MSU geoportal website is accessible at any place of the world where the Internet is available.

Scientific research and educational goals pursued in the creation of the geoportal project for a coastal area of the Yugor Peninsula located to the east of the village of Amderma:

1. the study of morpholithogenesis of the Arctic plains for predicting the development of hazardous relief-forming processes,
2. the systematization of the results of the study into the cryolithological, geomorphological and landscape structure of the territory for the joint analysis of the obtained data,
3. the determination of the complex of relief-forming processes that develop on the arctic coasts in the conditions of widespread massive ice deposits in order to use the obtained results in the series of lectures on “Cryogenic processes on the plains and in the mountains”.

The basic data

The works on the coast of the Yugor Peninsula, in the area of the village of Amderma, are carried out since 1999 [*Cherkashov et al. 1999; Kizyakov 2005; Leibman & Kizyakov 2007*]. The main attention is paid to the study on the distribution and properties of massive ice deposits as well as to the development of thermal denudation and thermal abrasion within the coast. Various complexes of thermal denudation processes and the landforms connected with their development were determined.

In the course of route observations carried out as a part of field studies, the following activities were conducted: mapping of the relief and relief-forming processes of the coastal area, and typification of shores located within the 45 km long study area. These works resulted in the creation of a geomorphological map of the study area that allowed us to evaluate the distribution of thermal denudation landforms and the length of various types of shores. In the structure of the attribute table, each geomorphological outline gets information on the relief morphology and relief nature. The information on the presumed age is added for terrace-like surfaces. The coastline is divided into segments with different coast types, depending on the correlation of thermal abrasion rates and thermal denudation rates on the coastal cliff. When superimposing the coastline divided into segments on the geomorphological map, elementary areas of the cliff were singled out. Within these areas, one dynamic type of the coast corresponds to each outline of the coast relief. The identified rates of coast retreats allowed us to predict the coastline location in 50 years.

The thermocirques growth dynamics and the coast retreat rate were identified based on the repeated observations at the monitoring sites as well as on the comparison of the current location of thermocirques' edges and cliffs with the results of interpretation of the data from aerial photographs, space images and topographic maps (the data were collected at different times). In order to evaluate the dynamics of the coastline and of thermocirques growth for a long period of time, we used remote sensing data. The data included the aerial photographs of 1947, the topographic maps of 1969, the space image of 2001 as well as the results of the field topographic survey at the key site that were obtained in 2001.

The current rates of thermocirques growth were measured directly at the monitoring sites that we organized in 2001-2001.

The obtained retreat rates of the thermocirques walls and of the cliff made it possible:

- to calculate the volumes of the material removed from thermocirques and to compare it with the volume of material flowing into the sea during the retreat of thermal abrasion coasts [*Kizyakov et al. 2006*],

- to evaluate the factors that influence the coasts retreat rate within the study area [*Leibman et al. 2008*].

Project Structure

The accumulated field data, the office analysis results and the drawn thematic maps were summarized within the framework of the integrated geoinformation system with the possibility of further addition of information. The systematization of spatially oriented data within the project facilitates the access to the data of field observations.

The following layers are included in the project:

1. Space images:
- Landsat7, ETM+ 2001 (15 m),
- SPOT 4 2011 (10 m),
- Terra/Aqua, MODIS (250 m).
2. The 1:25 000 scale digital model of the relief.
3. The 1:60 000 scale aerial photographs, 1947
4. The drawn thematic maps:
- the 1:25 000 scale geomorphological schematic map,
- the 1:25 000 scale vegetation map,
- the map of landscape complexes (of facies level) at the key sites.
5. Table-text information:
- the points of field descriptions of relief and relief-forming processes,
- the points of field descriptions of plant associations,
- the archival data from the Amderma meteorological station (data from the "Russian Weather" server http://meteo.infospace.ru).
6. The points of photographs of the typical landforms and landscapes that were obtained in the course of fieldwork of 1999-2012, including the repeated photographs of thermocirques at the key areas.
7. Cryolithological sections of the key areas.
8. Information on the development rate of thermal denudation processes:
- the retreat of thermocirques' edges,
- coastline retreat,
- the volume of the material carried into the coastal zone,
- the prognosis of coastline retreat.

For users' convenience, the data on the development of the thermocirques under study were grouped in separate reports on each key site: a textual description of a thermocirque, information on the equipped monitoring site, the scheme of the changes in the position of thermocirques' edges over the observations period and photographs.

The materials included in the geoportal project were created and processed on the basis of the software of the following companies: ESRI, Leica Geosystems and R&D «SCANEX».

Conclusions

The project of the Yugor Peninsula coastal area located to the east of the village of Amderma was created in order to summarize the data on the cryolithological, geomorphological and landscape structure of the territory and to analyze the spatial interconnections with consideration of the natural ecosystems dynamics.

An open type system was created for adding new information sources of all kinds – raster, vector and table-text ones.

The plans for 2012 include: organization of a super highly detailed survey, determination of the location of thermocirques' edges and of cliffs within the key sites and creation of a series of maps of the vegetation index dynamics.

All the study materials are open to pubic access. The project authors have extended rights to edit and change the project as well as to add new geoinformation.

The project can be accessed through the following link: 93.180.19.34:8082/Yugorsky.

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Temperature Regimes in Traditional Iñupiat Ice Cellars, Barrow, Alaska, USA

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Introduction

Historically, ice cellars excavated in permafrost have been essential to Arctic residents. They remain so today. Iñupiat people in Barrow, Alaska, have many of these cellars, some of which were created almost a century ago, while others were established recently and continue to be enlarged. These traditional facilities allow secure, year-round frozen storage of subsistence harvests over long periods. Average consumption of wildlife resources in the Arctic region is about 296 kg/person/year, almost three times the mean U.S. per capita consumption of fish, poultry, and meat at 101 kg/person /year [*Wolfe & Bosworth 1994*]. Replacing these harvests with alternative food would cost each family thousands of U.S. dollars each year. Hence, these subsistence harvests are central, not only to the local diet and cultural heritage of the area, but also to its economic well-being. Temperatures within the cellars are critical because bacteria can damage meat even at temperatures below the freezing point. For optimal storage of meat, the U.S. Department of Agriculture recommends temperatures below -18°C [*USDA 2010*].

Climatic change has been suspected of compromising and damaging ice cellars in some northern communities, with thaw and spoilage of meat occurring in a number of cases in northern Alaska, including in the communities of Point Hope, Kivalina, and Barrow [*e.g., Sakakibara 2008, Brubaker et al., 2009*]. Investigation of temperature regimes in these cellars is critically important for the continued well-being of residents.

Study Area

Barrow, Alaska, (71.3°N, 156.5°W) is the northernmost community in the USA, and the largest native settlement in the circum-Arctic region (~4200 residents in 2010, down from 4600 in 2000). Barrow has a long history of scientific research and is the location of the Barrow Environmental Observatory.

Barrow is situated on the coast of the Barrow Peninsula, which separates the Chukchi and Beaufort Seas. Lakes comprise almost 25% of the land surface, vegetation is a complex of sedge-moss wetlands, soils are gelisols, and permafrost underlies the ground surface to a depth of nearly 400 m. Maximum summer thaw depths are ~30 cm in undisturbed tundra, but may reach >100 cm in urban areas. Modern buildings are elevated 1-2 m above ground level on piles and the road network is comprised almost exclusively of unpaved 2 m thick, graded sand and gravel fill.

Table 1.Characteristics of the ice cellars included in the study, including depth, distance from the coast (measured perpendicular to the coastline), mean annual temperature (2005-2010), and the range of mean monthly temperatures.

Ice Cellar Owner	Depth to Bottom	Distance from Coast	Mean Annual Temp.	Mean Temp. Range
	m	m	°C	°C
Brower's Cafe	2.7	25	-6.6	7.0
Ron Brower	4.9	~400	-8.1	6.4
Native Village	5.6	~250	-7.4	7.8
Richard Glenn	5.3	~1000	-7.0	4.3
Harry Brower	6.6	52	-8.1	5.2

Beginning in August 2005, HoboPro® miniature temperature data loggers were installed in the ice cellars of four local residents and the Native Village of Barrow organization as part of the Circumpolar Active-Layer Monitoring (CALM) project's program of observations. Cellars had a range of characteristics (Table 1). Access to the cellars is through bulkhead doors, four of which are located within a small building that functions as an Arctic entry, although the door to one cellar is unprotected.

The data loggers were programmed to record at hourly intervals. Logger locations were chosen opportunistically, on a small shelf or secured to a ladder or beam within the cellar. The data loggers are downloaded at least once each year and the batteries replaced. Data are then processed into daily and monthly means. Mean daily air temperature data were obtained from the U.S National Weather Service (NWS) site in Barrow for 2005-10 and processed into monthly means. The NWS data were used in this study owing to the proximity of the site to the cellars within the village of Barrow.

Several interviews have also been done with cellar owners, focusing specifically on the construction, maintenance, performance, and historical and modern use of their cellars and others in the immediate area.

Results and Discussion

Between 2005 and 2010, the maximum daily temperature observed in the ice cellars ranged from -5.6 to -3.4°C, and mean annual temperatures within the ice cellars ranged from -8.1 to -6.6°C (Fig. 1). The mean annual air temperature during the same period was -10.1°C. The annual temperature cycle in the ice cellars lags behind that of the air by several months during the summer but much less during the winter. The warmest cellar temperatures of the year were observed between October and December, and the coldest temperatures were found between February and April. The difference between warmest and coldest monthly temperature was from 4.4 to 7.8°C in the cellars, while the NWS air temperature had a 31.4°C range.

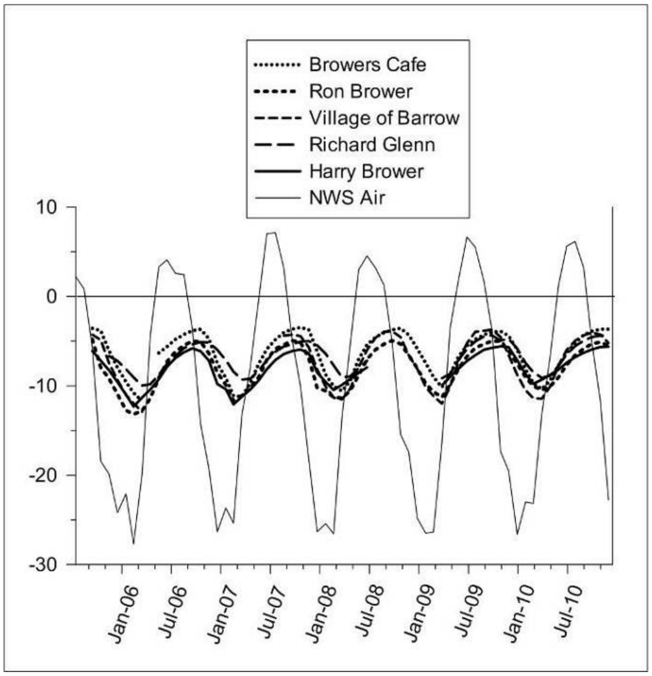

Fig 1.Time series of mean monthly temperature (°C) at the five ice cellars over time, as well as mean monthly air temperatures from the NWS station just south of the village from August 2005 through December 2010. A solid line indicates 0°C.

Permafrost at depth in northern Alaska has been documented to have warmed, particularly since the late 1970s [*Smith et al., 2010*]. Ice cellars generally have temperatures close to those of the surrounding permafrost. It is uncertain ifthese ice cellars are warmer now than in the past. The ice cellar located next to what is now Brower's Café is near a shaft and cellar excavated by the Ray Expedition during the first International Polar Year in 1882-3. The expedition observed constant temperaturesof -11.0°C at 11 m depth at the bottom of the shaft [*Ray et al., 1885, 338*] and found that within the adjoining cellar at a depth of ~5 m,the "temperature never rose above[-5.6°C]" [*Ray et al., 1885, 24*]. At one of the colder and deeper cellars included in this study, sloughing from the walls has been observed over the past decade, and accelerating over the past two years. While these sites are both quite close to the coast and not necessarily representative of conditions at all of the ice cellars, such observations underscore the need for vigilant monitoring of cellar temperatures.

Predicting temperature within anice cellar is complicated by construction practices, which involve mounding, compacting, and waterproofing the ground surface above the cellar and ongoing maintenance to annually evaluate and enhance the waterproof nature of the cellar. Most of the cellars have small buildings covering their entrance, which can allow snow to drift around the exterior, as well as provide insulation by preventing air exchange. Ongoing work is examining differences in soil properties (particularly salinity), humidity, and impacts of surface cover. Soil properties and the amount and distribution of ice within the soil matrix also affect the structural integrity of cellar walls. Cellars have collapsed in response to external disturbances such as nearby explosions. Additional observations focused on the relative effects of these various factors are needed.

Conclusions and Further Research

From the five years of observation in Barrow's ice cellars, several preliminary conclusions can be drawn:

- The five cellars examined are well below freezing, despite some evidence that they may have been colder in the past.
- Longer-term temperature measurements in these and other cellars are needed to confirm that the temperatures in them are stable and also representative of other cellars within the region.
- Further examination of factors contributing to collapsed and failed cellars, including storm events, sufficiency of modern maintenance relative to historic work, excavation and construction techniques, and the use of explosives at nearby locations, should be pursued.

Acknowledgments

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Modelling subsurface heat flow in permafrost during a marine transgression in the Western Laptev Sea

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Introduction

The transition from onshore to offshore permafrost

Most submarine permafrost is relict terrestrial permafrost that was inundated by seawater as a result of sea level rise and/or coastal erosion. The marine transgression brings about a change from sub-aerial to submarine boundary conditions for permafrost: sea bottom temperature is generally warmer than ground surface temperature, and salt water infiltration thaws pore space ice. Permafrost degradation rates in the near-shore zone (< 10 m water depth) are complicated by sedimentation, water column heat and mass transport, sea ice dynamics (especially the timing and duration of bottom-fast ice) and diffusive transport processes within the sediment column. As a result of the interaction between these processes, the transition of terrestrial permafrost to offshore permafrost remains poorly understood [*Taylor et al., 1996*]. This study focuses on modelling results for this transition.

Modelling efforts

Several studies have employed numerical modelling to the transition of permafrost to offshore conditions. An early quantitative investigation was carried out for two sites in the Beaufort Sea, Alaska [*Harrison & Osterkamp, 1978*]. Therein, the system of partial differential equations describing the underlying processes of submarine permafrost aggradation and degradation including salt diffusion was solved analytically for a simple limiting case to the conditions at Elson Lagoon and Prudhoe Bay to discuss the breakdown of the diffusive regime in salt and heat transport. Taylor et al. [*1996*] employ a one-dimensional thermal diffusion model in order to interpret the paleoenvironmental history of the Beaufort Shelf, Canada. Geothermal modelling of the temperature profiles and best fit comparison with offshore drill holes allowed for local dating of the time of marine transgression. Romanovskii and Hubberten [*2001*] calculated the evolution of permafrost thickness through the last four climatic cycles (400 ky) on the scale of the Laptev Sea Region, Russia. Leaving out short-term temperature fluctuations as well as salt diffusion and their influence on the upper permafrost horizon, they showed that permafrost has been preserved throughout all transgressions as ice-bearing permafrost for the larger part of the shelf depending on water-depth isobaths and geothermal heat flux. Recent work [*Dmitrenko et al., 2011*] has shown that extended summer-ice free periods in the eastern Siberian shelf, containing the Laptev Sea, have led to an increase of bottom water temperature of 2.1°C since the mid 1980s. Modelling suggests that significant effects on permafrost thickness and gas stability from the current warming can be expected by the end of the next millennium.

Open questions and objectives

Submarine permafrost degradation from above occurs most rapidly in the near-shore coastal zone of the shelf (< 10 m depth) [*Rachold, 2000*]. Our objectives are to employ meso-scale numerical calculations (10^1 to 10^2 m, 1000s of years) in connection with borehole data to model the transition of permafrost from onshore to offshore conditions. In order to identify key processes driving the degradation of permafrost following inundation in the near-shore zone, an initial simple approach neglecting known key aspects, e.g. mass transfer and sedimentation, is used. We seek to explain whether the observed temperature profiles are consistent with stable permafrost conditions or may be indicative of rapid degradation in the Laptev Sea region. Future refinements to the model are discussed below.

Study Site

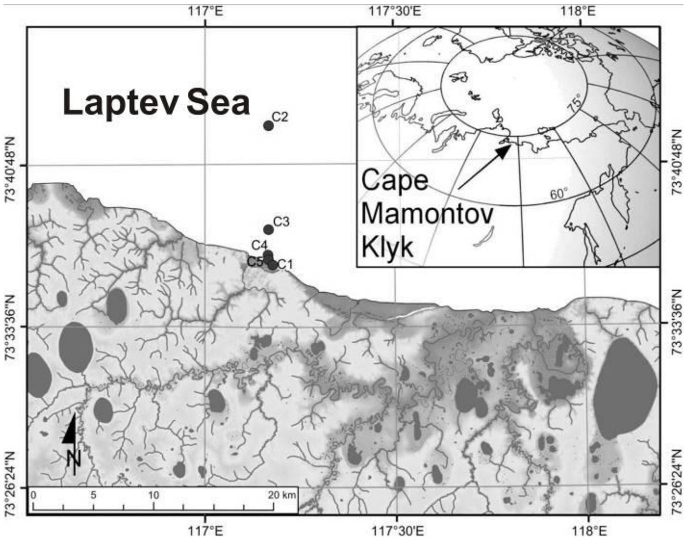

Figure 1. Location of Cape Mamontov Klyk and the series of five boreholes in the western Laptev Sea.

Five boreholes were drilled into the permafrost in the western Laptev Sea in 2005. Cores recovered onshore (C1, terrestrial, 100 m from the coastal bluff) and offshore (C2 to C5, marine, up to 11.5 km from the coastline) were analyzed for composition, including grain-size, and organic, ice and water contents. These composition data are used in this study to parameterize the numerical model of heat flow.

Modelling

The initial temperature profile from the terrestrial borehole C1 is taken as upper portion of the terrestrial permafrost temperature profile and initial condition for the transgression model. Initial coastal erosion of the top 25 m layer of ice-complex rich soil and changed surface temperatures are taken into account when numerically solving the heat transfer equation

$$c_{eff} \cdot \frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(\lambda \frac{\partial T}{\partial z} \right) \qquad (1)$$

Freeze-thaw processes are considered in a three phase heat capacity / conductivity model

$$c_{eff} = \sum_i c_i \theta_i + L_f \frac{\partial \theta_w}{\partial T} \qquad (2)$$

where c is capacity, θ_i volumetric fraction of phase *i*, L_f latent heat of freezing, and λ thermal conductivity parameterized according to De Vries [*1963*] based on measured sediment properties and temperature.

Upper boundary conditions following transgression are given by the change in profile height due to initial coastal erosion and the bottom water temperature in the Laptev Sea shelf of -1.5°C. Sediment composition parameters are derived from field and laboratory analysis and are supplemented by data from Yershov [*1998*] for depths without measurements. The lower boundary is set to a constant geothermal flux of Q = 53 mW/m^2 as appropriate for the study region [*Romanovskii & Hubberten 2001*].

Table 1. Description of observed core sedimentological units, their ice saturation and the mean thermal conductivities (λ_{mean}) calculated or estimated based on sediment composition and temperature.

Depositional environment	Ice saturation	Elevations [m a.s.l.]	λ_{mean}
Marine, interglacial	0	offshore: -35 to -6	0.7-1.5*
Terrestrial, interglacial	0.4-0.9	onshore: +26 to +27	0.1-1.2*
Ice complex, glacial	0.4-1.0	onshore: +5 to +26	2.2*
Terrestrial, glacial	0.1-0.6	onshore: -34 to +5 offshore: -64 to -35	2.6 ±0.1 (n = 175) 2.6 ±0.1 (n = 50)
Lagoonal, glacial	0-0.1	offshore: -77 to -64	0.6-1.0*

* values taken from Yershov (1998)

Analysis and Outlook

In order to analyze details of the transition to offshore permafrost, measured temperature profiles will be compared to the modelled sediment temperature development between the times t_1 & t_2 corresponding to the time of sea transgression from location C2 to C1. Of special interest is the thaw depth or, more accurately, the evolution of the depth of the ice-bearing permafrost table as the one most discernible observable in the field.

Additionally, a best fit analysis is attempted of the C2 temperature profile to the simulated temperature evolution in time to give estimates about transgression rates and whether currently observed erosion rates have persisted throughout the inundation process of several thousand years.

As expected, results indicate deviations from measured field data. These deviations, especially of the position of ice-bearing permafrost table, are interpreted as the consequence of important processes, such as salinity diffusion and its contribution to permafrost degradation from above, that were not accounted for in the model. Including these processes, e.g. marine sedimentation rates, salt infiltration, and possibly even bottom-fast ice effects in the very near-shore area (< 2 m depth), will be subsequent steps in order to attempt a convincing picture of the transgression from one borehole position to the other.

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The Construction of an Optimal Climate Projection for the Assessment of the Consequences of Climate Changes in the Cryolithozone of Russia

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Introduction

To assess the impact of climate change on permafrost, we need climate projections that exhibit acceptable accuracy in the cryolithozone. In modern studies, most frequently used projections are ensemble projections of changes in air temperature and precipitation, obtained by averaging the results of calculations based on several hydrodynamic models (multi-model projections) or on the same model with different initial conditions (mono-model projections). This helps to minimize random errors typical of each individual model. However, it is not clear how the model for creating a multi-model ensemble projection should be selected. Initially, it was assumed that the more models are used, the more reliable it is. It is now believed that the models of admittedly poor quality should be excluded. We developed a method of testing and selecting hydrodynamic models for constructing a multi-model ensemble projection that is optimized for studying the effects of climate change in the cryolithozone of Russia.

Model quality assessment

We used the results of calculations for 21 hydrodynamic models from the IPCC database for the period of 1900-1999, having calculated the main climatic parameters that influence the dynamics of natural systems in the cryolithozone.

The publication [*Anisimov et al. 2011*] showed that the condition of natural systems in the cryolithozone (including permafrost and vegetation) can in many respects be described by three climate indices:

- the sum of temperatures of the warm period (for permafrost) or of the period with temperatures above 5°C (for vegetation). Since these are statistically connected characteristics, any of them can be used in models testing.
- the sum of temperatures below 0°C that characterizes the severity of winters – an important limiting factor for vegetation in the conditions of continental climate.
- the dryness index that is equal to the ratio of temperatures above 5°C to the annual precipitation.

In the context of what was mentioned above, it is reasonable to assess hydrodynamic models according to these indices. For comparability with the works of other authors, we also added the mean annual air temperature and precipitation rates to the list.

To assess the quality of hydrodynamic models, we compared the trends of the aforementioned indices calculated with the help of these models with observation data from weather stations located in the cryolithozone of Russia and areas directly adjacent to it. We averaged the data related to the regions with homogeneous climatic changes during the modern period. At the same time, for meteorological stations we considered the "weights" proportional to the "influence area" of each of them in the selected region. The methodology of such zoning is described in the publications [*Anisimov & Zhiltsova 2011*, *Anisimov et al. 2011*]. Such an approach enabled the reduction in the random errors of model projections by averaging over a large area, and it also enabled the assessment of the accuracy in reproducing regional characteristics of contemporary climate changes.

Discretization in time is as important as zoning for quantitative assessment of the modern climate dynamics. Time discretization is determination of boundaries of climatic periods or epochs characterized by common statistical characteristics of the climate parameters and by their relation to the same general population. Time discretization makes it possible to reasonably select a time series model and to carry out a statistical analysis of the observation data. As it was shown [*Anisimov et al. 2011*], even in the simplest time series model in the form of a linear trend, the choice of the datum point and of the period duration has a strong influence on the magnitude of the regional temperature trend, and it can even change the sign of the precipitation trend value in some regions.

In the work [*Anisimov et al. 2007*], three different models of surface air temperature for the regions of Russia were compared in the form of a stationary time series, a linear trend and step changes. It was shown that out of the three models that were discussed, the time series model in the form of a linear trend is the best one to describe the dynamics of air temperature in the modern period covering several last decades. In the work [*Anisimov et al. 2011*], the authors examined the issue of where to set the lower boundary of this time period in different regions. With the help of statistical criteria, it was shown that the modern warming period in the north of Central and Eastern Siberia began as early as in the 1960s. By the 1970s it began all over Western Siberia and in the Far East, and the warming trend was clearly detected in other regions of Russia only closer to the 1980s.

The trends of the aforementioned climate indices were calculated for several time intervals: the 30-year period at the end of the 20th century (1970-1999) that was characterized by the largest climate changes; the entire period of instrumental observations in the 20th century (1900-1999), and the modern climate period determined individually for each weather station. In the final assessment, most of attention was paid to the accuracy in reproduction of the given characteristics in the modern period defined as the period in which it is impossible to single out the turning points of the temperature trend [*Anisimov et al. 2012*]. Comparison based on such a period seems to be the most correct, since it enables the most accurate assessment of the actual warming trend value in the given region.

The obtained characteristics were compared to the observation data, and, based on the results of this comparison, ranking of the models was carried out for each climatic parameter. When selecting models for composing the final ensemble, a special attention was paid to the elimination of different versions of the same model as well as of the models giving projections that correlate with each other very well. This was done for the final projection to include the models with the same "weights" that (the models) well reproduce the modern climate but, at the same time, produce different predictions for the future. Based on the results of the ranking, the models were rated, and several best models with the rating above the average one were selected. On the basis of the selected models, ensemble projection of temperature and of precipitation was constructed. Ensemble projections with the use of 2, 3, 5 and 7 best models were compared to the observation data and with the projection created on the basis of all models. According to this comparison, the projection that best reproduced the chosen characteristics was selected.

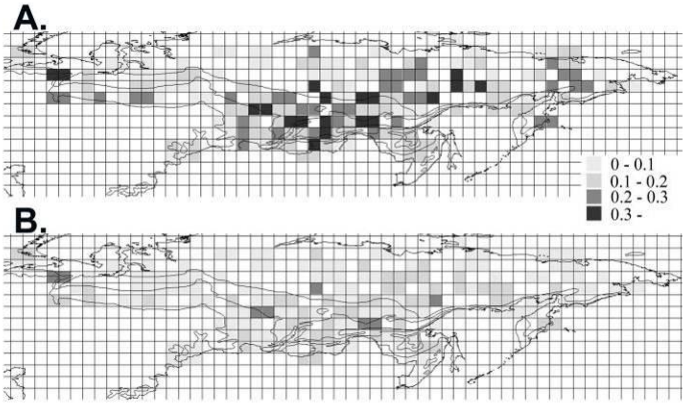

Figure 1. The annual temperature trend errors (°C/10 years) for the modern period in the cryolithozone of Russia for the ensemble of all models (A) and for the ensemble of 3 best models (B).

Conclusions

The results showed that the ensemble projection constructed on the basis of 3 best models reproduces climatic characteristics better than the projection based on 21 models, and in relation to some of its parameters it is better than each separate model. The ensemble projection constructed on the basis of 7 models reproduces modern climate insignificantly worse. However, it is more likely to reproduce the range within which the future climate will fall. The proposed method of preliminary selection of the best models and of their combination into an ensemble renders it possible to reduce the uncertainty of a climate projection at the regional level.

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Physical Properties of Thawed Grounds and the Existing Methods of Their Reinforcement

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Abstract

The paper presents an analysis of permafrost conditions of the foundation grounds in the buildings in the city of Yakutsk undergoing deformations and the existing methods of chemical ground grouting in respect to such foundation grounds.

Keywords: buildings and structures; ground; grouting; reinforcement; thawing.

The number of buildings and structures under the threat of collapse in Yakutsk has been increasing every year. Incorrect operation of buildings (leaking utilities, heat losses to foundation grounds) leads to the formation of local taliks under them. The formation of thawed sections significantly deteriorates the bearing capacity of buildings and structures.

The basic method used to reinforce foundation grounds is that of ground freezing in winter. However, the freezing of thawed zones under the buildings is complicated, since it is not possible to install cooling standpipes under the buildings constructed on piles, because there is no place for the drilling equipment in the ventilated crawl space. Besides, the freezing of water-saturated grounds leads to the occurrence of cryogenic processes and phenomena resulting in deformations of frozen foundation grounds and of the building itself.

By now, foundation grounds can be reinforced by means of chemical ground grouting. There are several methods of chemical ground grouting with solid stone output (silicatization, tarring, etc.). All of them have been used in the places of thawed grounds distribution. However, they have not been used for the grouting of thawed zones in permafrost.

Therefore, the purpose of this study is to review the existing grouting methods and to choose the optimal one that can be applied for the grouting of water-saturated unfrozen foundation grounds in deforming buildings located in the permafrost zone.

Typically, the construction of buildings and structures in Yakutsk is performed with the preservation of permafrost in foundation grounds. At certain sites local permafrost thawing, caused by incorrect operation of buildings and structures (hot water leakages from heating networks, substantial heat losses in foundation grounds of the buildings constructed on soil additions) or by laying of surface heating networks too close to foundation grounds, leads to the deterioration of the bearing capacity of foundation grounds and, consequently, to uneven deformations of buildings.

In 1980-90’s, NRO Polarex conducted a comparative analysis of geotechnical conditions that had existed before the construction of buildings, along with the analysis of permafrost conditions of foundation grounds formed during the buildings’ operation. The conducted investigations covered:

- permafrost conditions before construction and those formed during the operation of a building (lithological composition, ground temperature, moisture content, salinity, design parameters of nominal seasonal thawing depth and temperature)
- depth of the formed thaw basin
- possible cause of the formation of the thaw basin under the building

Investigations covered 26 sites in Yakutsk. In terms of lithology, the grounds forming the thaw basin are typically represented by fine-grained and silty sands. Only in two cases clayey silt and sandy silt were observed.

Before the construction the grounds below the active layer were solid and frozen. The thickness of the active layer was 2.7-2.9. The moisture content of frozen grounds fell into a broad range from 0.2 to 0.6. After the formation of a thaw basin during the operation of a building, the grounds are characterized by moisture content close to 100%. In addition, the salts from the active layer and closed taliks may migrate into the thawing zone under the impact of gravity forces and cryogenic squeezing-out. The full description of the salinity prior to the construction and after the operation of a building is not clear, since salinity materials are often not present in the geotechnical investigations of past years. However, in almost half of the sites unfrozen grounds of the thaw basin demonstrate high salinity that varies within a wide range of values - from 0.2 to 0.8%, reaching 1.2% in sandy silts. The depth of a thaw basin varies from 2.5 to 16 m. More than half of the buildings under the threat of collapse studied in Yakutsk are built on foundation posts with very low ventilated crawl spaces (up to 1.5 m). The laying depth of such foundation posts does not exceed 4.5 m. Almost in all cases, the depth of the thaw basin exceeded that of the foundation laying.

Buildings under the threat of collapse included those built on pile foundations, foundation posts and girder foundations. Reinforcement works were performed at several sites built on girder foundations and foundation posts. These works included the reinforcement of foundation grounds with the cement hooping and the freezing of the near-pile space in winter. Unfortunately, no monitoring of foundation settlement has been carried out after the completion of reinforcement works. So, it is not possible to estimate the reliability of the method.

In foundations grounds of the buildings constructed on piles, the depth of a thaw basin is typically lower that that of foundation laying. Reinforcement works were performed on some buildings under the threat of collapse built on pile foundations. For example, the piles of the buildings of school No. 29 and those of the residential house with the milk cook-room (44 Ordzhonikidze street) were reinforced. After the completion of reinforcement works, geodetic observations have been performed only for the building with the milk cook-room. The observations carried out from 1987 to 1989 revealed uneven foundation settlement. The difference between the settlement of corner piles on the right side of the building during the period of observations was 11 mm. The settlement process is annually progressing with the velocity of 3.8 mm. The uneven character of settlement is determined by grounds salinity. The maximal salinity of grounds up to 6 m was observed under the lower face of the corner pile from the right front side of the building. It is also the point where the maximal foundation settlement is observed. Uneven settlement led to the fracturing of the foundation girder and the occurrence of fissures in the neat work. In this case, therefore, the reinforcement of foundation grounds did not eliminate the deformation of the building itself.

These reinforcement methods are rather expensive. Besides, the reinforcement of foundation grounds themselves, as well as their freezing, does not eliminate the causes of buildings' deformations. Frozen foundation grounds remain vulnerable to surface water entering into the crawl space, which means their new thawing begins. The possible development of cryogenic processes remains the most difficult problem in terms of the freezing of water-saturated foundation grounds.

The search for reliable methods of foundation grounds reinforcement in the cryolithozone is an urgent issue of modern urban construction.

The analysis of permafrost conditions of the foundation grounds in the buildings of Yakutsk undergoing deformation and of the existing methods of chemical ground grouting reinforcement showed the following results.

The most effective methods of water-saturated taliks grouting in the cryolithozone include:

- single-bath silicatization (silicofluoride formulation)
- tarring by carbamide resin
- cement stabilization

Each of these methods has its own advantages and disadvantages.

All of the listed methods may be introduced into the practice of repair, renewal and engineering preparation of water-saturated foundation grounds.

As it has been already noted, the methods of chemical ground grouting have not been widely used in permafrost environment. Therefore, several issues related to the practical implementation of the above-mentioned methods should be considered. They include:

- assessment of the thermal effect of grouting solutions or electric current on the permafrost around the thaw basin
- study of the injection of grouting solutions within a closed space
- processing of technological parameters of grouting: injection pressure, viscosity and density of solutions, etc.
- possible use of grouting for water-saturated grounds with high salinity.

All these problems, along with those that will inevitably emerge during grouting, can be solved only experimentally. So, it is necessary to perform a series of laboratory and pilot production works aimed at practical training of the skills of the application of particular chemical ground grouting methods in permafrost conditions.

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The Connection Between the Supercooling Temperature and the Frozen Ground Strength

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Abstract

This article describes the particularities of ground moisture crystallization at latent and visible stages. The connection of supercooling temperature as well as of crystallization temperature with the frozen ground strength and longevity is shown and quantitatively assessed.

Keywords: temperature; supercooling; crystallization; strength; longevity.

Figure 1 shows a typical ground thermogram in the freezing-thawing cycle [*Tsytovich 1973*]. Ice structure formation begins when water temperature drops below + 4°C. Upon reaching the negative temperature $t_{sc} < t_{cr}$, the density of water reduces down to the density of ice, the temperature increases stepwise up to t_{cr}, and the first ice crystals appear. The temperature of ground above t_{sc} depends on its thermal properties and environment temperature t_c. Generally, t_{sc} is equal to the temperature that would be established in this location even in the absence of phase transitions (in dry ground). If the heat exchange parameters are the same on all sides of the ground sample, then $t_{sc} \approx t_c$ [*Grechishchev et al. 2005*]. However, during the ground tests conducted with the help of standard equipment at t_c equaling approximately -5°C and lower, as a rule, $t_{sc} > t_c$ [*Tsytovich 1973; Konovalov 2009*]. This is connected with the dependence of t_{sc} on the duration of supercooling τ_{sc}. Figure 2 shows the graphs of this dependence for clayey silt with different moisture content (experiments 1 and 2) [*Grechishchev et al. 2005*]; the points represent experiment results; the curves are their approximations:

$$\tau_{sc} = \tau_{min} \, (t_{min} / t_{sc})^{1/g} = \tau_{min} \, (t_{sc} / t_{min})^{-1/g}, \qquad (1)$$

where τ_{min} and t_{min} are the minimum time and the temperature of supercooling for this point of time that is also minimum according to the experiment data; g - dimensionless empirical coefficient.

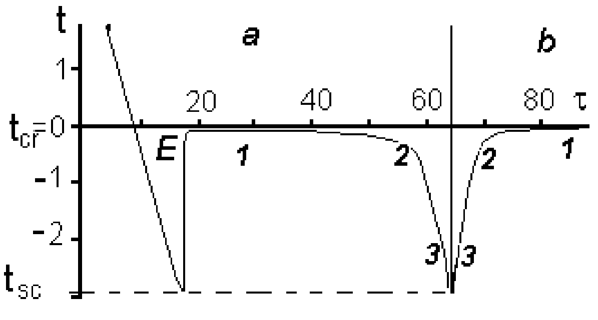

Figure 1. The curve of freezing (a) and thawing (b) of sand (E, 1, 2, 3 – the characteristic sections of the curve)

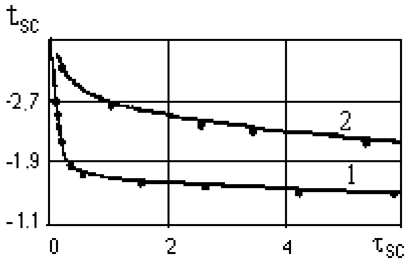

Figure 2. Connection between t_{sc} (°C) and τ_{sc} (10^5s)

The g value is close to the relative deformation of crystallization $j_{cr} \approx 0.091$, and the maximum supercooling (instantaneous, with τ_{sc}, equal to the atoms oscillation period) equals minus 22-25°C, when the experimental data are substituted in (1). This is close to the minimum temperature at which normal water is still able to exist [*Konovalov 2009*]. Therefore, the change limits of t_{sc} and t_{cr} are roughly the same: 0 and -22°C.

(1) suggests that for each ground

$$t_{sc} \, (\tau_{sc})^g = t_{min} \, (\tau_{min})^g = £ = \text{const} \qquad (2)$$

The £ value is determined by the results of determination of several random (not necessarily marginal) pairs of t_{sc} and τ_{sc}. Let us estimate it, for instance, for the conditions of experiment 1 in Figure 2: clayey silt with the moisture content of 26. 2%, t_{cr} = -0.45°C, $g \approx 0.1$; t_{min}= -3.3 °C and τ_{min} = 30 s. If we substitute these figures in (2), we get: £ ≈ -4.6 (°C .s $^{0.1}$). Using (2) we can determine the minimum temperature of cooling t_c, when the t_{sc} value is still observed. In particular, at t_{sc} = -4.6°, the τ_{sc} value equals 1 s, at -5° it equals 0.43 s, and at -8° it is only 0.004 s. It is clear that in this case t_{sc} is registered at t_c not lower than -5°C. When t_{sc} rises, the value of τ_{sc}, on the contrary, increases and at t_{sc} = -1, τ_{sc} is already approximately 2 months.

Visible crystallization stage includes three sections (Fig. 1). In the first one, when $t = t_{cr}$=const, free water freezes. Osmotic and absorbed water freezes in the second and third ones. Osmotic water freezes within the temperature spectrum between the values of t_{cr} and t_{sc}. Thawing progresses in the reversed order.

Figure 1 shows that thawed grounds' supercooling temperatures can be compared to certain, equal in value, freezing (thawing) temperatures of osmotic water. This means that they can also be compared to its stressed-deformed state in the frozen condition, including the long-term strength P and longevity τ_l determined by the formula: [*Konovalov 2009*]):

$$\tau_l = \tau_{min} (P_{max} / P)^{1/jp}, \qquad (3)$$

where τ_{min} – minimum longevity that is in equilibrium with instantaneous (maximum) strength P_{max}, j_p is the peak relative deformation.

The P_{max} value is determined by the phase equilibrium equation:

$$t_{cr} = P (V_s - V_l) T_o / Q_{ph} = Pb, \qquad (4)$$

where $T_o = 273(K)$; V_s and V_l are specific volumes of solid and liquid phases; P is the external pressure; Q_{ph} is the latent heat of melting (freezing).

The j_p value in (3), like g in (1), is close to the melting deformation j_m (approximately 0.083-0.12) (1), and P_{max} is determined from equation (4), where instead of t_{cr} we substitute the current temperature of frozen ground $t < t_{cr}$ and $P = P_{max}$, then $P_{max} = t / b$. After these transformations, the longevity formula looks like this:

$$\tau_l = \tau._{min} (t / bP)^{1/jp} = \tau._{min} (t / t_{cr})^{1/jp}, \qquad (5)$$

From the comparison of (1) and (5) we can see that they differ only in the the opposite nature of the connection of temperature and time: the lower the temperature is, the shorter the embryo phase of ice structure is, but the longer the period of its visible existence is.

Maximum (conventionally instantaneous) strength corresponds to minimum supercooling temperature. Therefore, if we substitute $t = t_{sc}$ in (5), we will get the expression for the evaluation of the peak (maximum possible) longevity of this ground.

The suggested assumption about the connection of t_{sc} with the strength and the longevity of frozen ground is principally new. But if the supercooling temperature of ground before it starts to freeze equals its own temperature in the frozen state [*Grechishchev et al. 2005*], which often cannot be registered with devices because of the low τ_{sc}, this connection becomes obvious, since the dependence of P and τ_l on the frozen ground temperature was reliably determined a long time ago [*Vyalov 2000; Tsytovich 1973*].

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The Impact of the Gas Main Construction on the Dynamics of the Coasts in Western Yamal

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Abstract

Strong anthropogenic impact on the coasts dynamics is observed in Western Yamal, in the area of the landfall of the underwater transition of the Bovanenkovo-Ukhta gas pipeline. Its most hazardous types are removal of sediments from beach and coastal bar, dredging at the Yarayakha River's mouth and interception of sediments' drift with the help of a cofferdam. This leads to coasts erosion in some areas and to sediments accumulation in others.

Keywords: coastline; anthropogenic impact; morpholithodynamics; sediments transportation.

Two principal types of coasts are distinguished on the western coast of Yamal, in the area of the landfall of the underwater transition of the Bovanenkovo-Ukhta gas pipeline that is currently under construction. The first type is represented with a low accumulative coast. It appeared to be most exposed to technogenic changes, as the gas pipeline landfall is located within the coast of this very type. The second type is an abrasion coast with a distinct cliff.

The anthropogenic disturbance degree of the coastal area relief depends on the intensity of anthropogenic activity that influences the relief as well as on its resistance to anthropogenic disturbances and on its self-recovery capacity.

Accumulative coasts are generally more resistant to anthropogenic impact [*Sovershaev, Kamalov 1992, Kamalov et al. 2006*]. The main morpholithodynamic processes here are accumulation of sea sediments and aeolian transportation. Besides, most of the buildings are situated within accumulative coasts, since they are more stable and suitable for construction. Abrasion coasts are more susceptible to anthropogenic activities. However, they are much less exposed to anthropogenic disturbances. Construction itself is not carried out on them. The main types of anthropogenic disturbances are the motion of heavy vehicles and contamination with construction waste.

According to the results of the field studies, there were determined the following types of direct anthropogenic impact on the relief within the landfall of the underwater transition of the gas pipeline that is under construction:

1) construction of large artificial positive landforms, which leads to additional sediments income to the coastal area in the given place;
2) construction of artificial concave landforms, removal of sand material from the beach, mud flats and from the underwater shore slope, which leads to erosion and narrowing of mud flats and of the beach as well as to reconstruction of submerged bars system;
3) deformation of the surfaces of mud flats, beach, coastal bar and of layda during construction and during motion of heavy track machines or heavy vehicles as well as destruction or disturbance of soil and vegetation cover, which leads to intensification of erosion.

Among the indirect kinds of anthropogenic impact, the following ones are distinguished:

1) appearance of anthropogenic accumulative forms in the coastal area connected with the change in the sediments drift (e.g. filling of the re-entrant corners formed with buildings);
2) appearance of concave landforms on the beach and on mud flats caused by the intensification of erosion resulting from the disruption of the sediments transportation or from the change in the cross profile of the beach;
3) intensification of deflation at the disturbed surfaces.

Sediments transportation in the construction area is determined by three main factors. The first one is the alongshore sediments drift that is caused by the local lithodynamic situation. The second one is the intensity of the natural drift of material coming from the coast as a result of abrasion and of removal by rivers as well as the dimension of this material. The third factor is the sediments drift transformation caused by the anthropogenic factor.

The most hazardous anthropogenic disturbances from the perspective of the coastal system stability are the following:

1) Due to the fact that the places of extraction of construction materials that are safe from the perspective of morpholithodynamic situation were not considered in advance, the extraction of sand material for construction purposes is carried out without a certain plan and without consideration of the consequences. The sand material is most actively extracted from the surface of the coastal bar and the beach between the Yarayakha River's mouth and the cofferdam (see Fig. 1). The surface deformation and the vegetation destruction at the coastal bar leads to intensification of deflation, which means that it intensifies the process of extracting sand material from this area. This creates the sediments deficit in this coast area, which leads to its erosion. Apart from that, the lowering of the coastal bar surface creates favorable conditions for penetration of storm surges towards the interior of the dry land, which only intensifies the erosion of the coast as well as of the roads and embankments located on it.

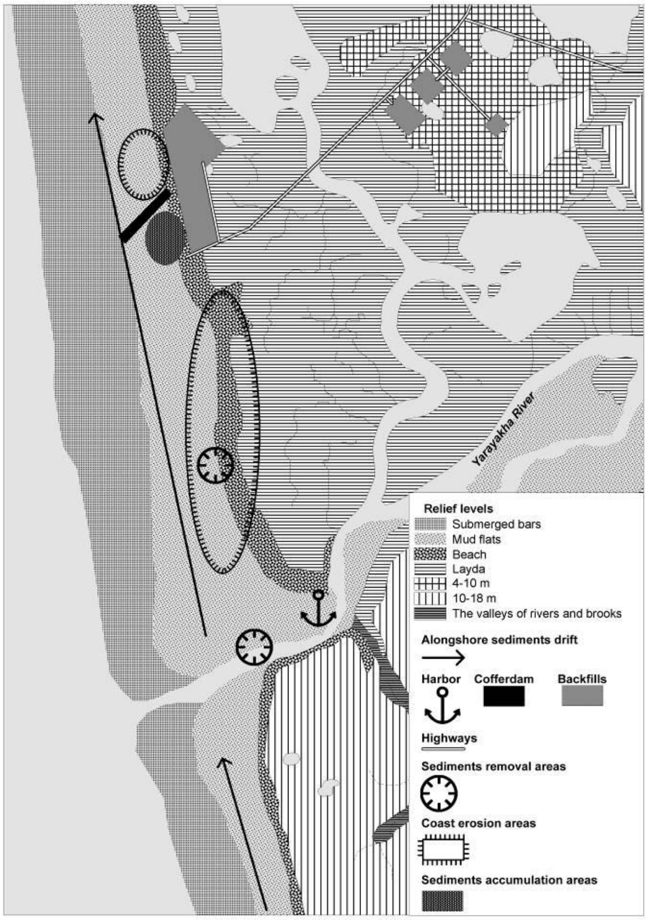

Figure 1. Anthropogenic disturbances in the coastal zone of Western Yamal, in the area of gas main construction

2) During the construction of a harbor at the Yarayakha River's mouth the following operations were carried out: dredging of the fairway for construction of an approach channel and aggradation of coasts for construction of harbor buildings at the surface. This created the sediments deficit at the Yarayakha River's mouth, which led to a partial interception of the sediments drift coming from the south, and, as a result, it led to the increase in the sediments deficit and to the erosion of the coast between the Yarayakha River's mouth and the cofferdam.

Cofferdam construction resulted in the accumulation of sediments in the re-entrant corner to the south of the cofferdam and in the erosion of the coast to the north from it.

In natural conditions, the coastal bar completely absorbs the wave energy even during extreme storms [*Kamalov et al. 2006*]. The change in the coastal bar morphology entails the change in the conditions of waves destruction and, therefore, the entire change in the morpholithodynamic regime that can cause unfavorable and hazardous consequences. The coastal system will tend to reach a new equilibrium, which will cause reformation of the coasts and of the floor with the rates that were not considered in the construction project.

In order to reduce the impact of the pipeline construction on coastal systems, it is first of all necessary to stop the removal of sediments from the area of the coast between the the Yarayakha River's mouth and the cofferdam. Extraction of sand material without the risk of activation of coast erosion in the pipeline construction area can be done in the discharge zone of the alongshore sediments drift (e.g. from the mud flats or the beach near the Cape of Mutny at 4 km to the north from the construction site.

Thus, the anthropogenic impact on the relief and on the sediments transportation in the coastal zone of Western Yamal reduces the stability of the entire coastal system and intensifies the abrasion process [*Ogorodov 2010*]. The nature of Yamal is very vulnerable and ensuring of the geoecological safety under the condition of the increasing anthropogenic pressure is of primary importance.

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Study of Permafrost Processes within the Area of Ridge-Pool Bogs Located on the Territory of Sibirskie Uvaly Nature Park

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Expeditions to study permafrost processes within the area of ridge-pool bogs located on the territory of Sibirskie Uvaly Nature Park were held in 2011along the following routes:

1) Glubokiy Sabun Recreation Center – Megeno-Nek-Kuy bog – cordon on the Lippyng-Ink-Igol River (62º31'4.53" N, 81º39'48.25" E) – upper reaches of the Lippyng-Ink-Igol River;

2) Glubokiy Sabun Recreation Center – Granichnyi cordon – Konekhlog-Igol river mouth – Zhuravlinaya river mouth. A rather wide range of activities were carried out in the area of Glubokiy Sabun Recreation Center.

During the expedition along the first route, a study of upland surfaces in the interfluve area of Lippyng-Ink-Igol and Ukum-Igol rivers was carried out in order to determine whether the frozen grounds were preserved in that area (test holes 1 and 2). Similar studies, which were carried out at the end of July 2010 (25.07) in the interfluve area of Lippyng-Ink-Igol and Ukum-Igol rivers (test hole 2), revealed presence of frozen grounds at the depth of 1 m, but on August 9, 2011 this was not confirmed.. This can be attributed to less severe winter conditions of 2010-2011, as compared with winter temperatures of 2009-2010.

A survey of Kuer-Kuy bog (62º33'49.7" N, 81º37'49.1" E) was conducted on 09.08.2011. The survey revealed the presence of a permafrost lens in the upland ridge-pool bog. The bog ridge had the following dimensions: height – 0.57 m, length – 3.20 m, width – 2.10 m. The lens was located at the depth of 38 cm, and 40 cm on the side. The lens thickness was 35 cm. Air temperature on the day of 09.08.11 was 23ºC, water temperature – 13ºC, frozen peat temperature – -0.6 ºC, thawed ground temperature – 1.3 ºC, water temperature around the lens – 2ºC.

Figure 1. Conducting works to determine the thickness of frost penetration (35 cm).

Next, the bog was probed in order to reveal the presence of frozen rocks. As a result, 600 meters were covered northward, and along the entire distance there were 11 hits in frozen peat. This figure shows that for every 100 m there are almost two areas with ridges which have frozen peat with the negative temperature at their base. This peat is preserved in the summer period.

On 11.08.2011 a key area for recording the temperature of frozen peat in the ridge-pool bog was established 1.2 km northwest of Glubokiy Sabun Recreation Center (Fig. 2). Thermal borehole 8 (62º26'51.2"N, 81º40'02.0" E) is 1 m deep.

On the surface and at the depths of 20, 40, 60 cm, 1 m a DS1921G-F5 type thermochron was installed. In the frozen peat there is a DS1921Z-F5 type thermochron installed at the depth of 60 cm. Frozen peat is 20 cm thick and it occurs at the depth of 50 to 70 cm from the surface of the ridge. Thawed peat occurs at the depth of 0 to 50 cm from the surface. The ridge height is 70 cm, its width is 4 m, and the length is 10 m. The thermochrons were activated at 00:01 on 12.08.2011. During the field work the frozen grounds temperatures were determined and the following results were obtained: 11.08.2011 16:50 – -0.500 °C; 17:00 – -0.625 °C; 17:10 – -0.625 °C; 17:20 – -0.625 °C; 17:30 – -0.625 °C. The air temperature at the time of measurement was 19 °C, and at the point of contact of frozen and thawed ground the temperature was 3 °C. The peat deposit structure was determined in the area 5 meters from the borehole: 0-0.20 – sphagnum tirr, 0.2-0.8 – light brown sphagnum peat of low degree of decomposition, 0.8-2.50 – brown sphagnum peat, diluted, moderate degree of decomposition, 2.50-2.60 – light gray medium-grained sand.

Figure 2. Determining the thickness of thawed and frozen layers.

Frozen grounds temperature in the summer of 2011 on the ridge-pool bog was -0.625°C. In the future, we will continue to study the temperatures of the upper part of the layer of annual heat exchange in the ridge-pool bogs located on the territory of Sibirskie Uvaly Nature Park.

Large-scale Zoning of the Kharasavei Field according to Suitability for Underground Storage

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Abstract

Permafrost conditions within the Kharasavei gas-condensate field have been studied in terms of suitability for underground storage. The field has been divided into environmental geological suitability zones using a map of natural landscape systems to the scale of district. The distinguished suitability zones were scored proceeding from several permafrost factors that pose major risks to the construction and servicing of underground storehouses.

Keywords: Environmental geological suitability; Kharasavei field; suitability score; underground storage; zoning.

Introduction

The Kharasavei gas field is located in the western side of the Yamal Peninsula in a subzone of Arctic moss-lichen tundra, in the zone of continuous permafrost. The field has been developed since the mid 1970s. The safety of construction and operation of engineering structures in permafrost areas largely depends on responses of local landscape systems to anthropogenic loads. It is thus important to assess permafrost conditions and to divide the territory according to suitability for engineering development on the basis of landscape and ecosystem responses.

Methods

The permafrost conditions of the area have been assessed in terms of suitability for underground storage according to several principal environmental geological criteria using a 1:25 000 map of natural landscape systems. The suitability criteria are, namely: ground temperature, content of ice (especially massive and wedge ground ice), and surface geological processes. Factors in the three groups were scored 1 to 5, with point 1 corresponding to the simplest and most suitable (favorable) conditions and point 5 to the most complicated unsuitable (unfavorable) conditions.

Ground temperature as an indicator of potential existence of cryopegs

Suitable landscapes are those with ground temperatures below -5°C (scored 1), which are drained flat watersheds (plakors) and steep slopes occupied by tundra upon sandy and loamy substrates, as well as weakly drained tundra slopes upon loamy sand and loam substrates.

Rather suitable are landscapes with ground temperatures below -3°C (scored 2). At these temperatures, natural cryopegs may exist in saline soil and man-caused cryopegs may arise as well. Areas of ground temperatures above -3°C are unsuitable (scored 5).

Ice content and ground ice in shallow subsurface

The presence of massive and wedge ground ice in shallow subsurface may pose risks to the underground storage infrastructure and to the storehouses themselves. The risks are associated with periglacial processes, both the existing natural processes and those the production-related activities may trigger. For the zoning purposes, the ice content of permafrost has been assumed as the weight coefficient ½. This amount is underestimated taking into account the limitation that building storehouses upon continuous permafrost with high ice contents is impossible.

Surface geological processes

Underground storage is especially sensitive to such permafrost-related processes as thermal erosion, thermokarst formation, and landsliding while other diverse hazards that may occur in the study area can be successfully mitigated.

Landscapes are scored 5 if thermokarst, thermal erosion, and landsliding are widespread (predominating) and 4 if they are of secondary importance.

The coefficients of the three parameters were used to calculate the total risk index (PGP):

$$PGP = IT + 0.5\ II + IP,$$

where IT is the ground temperature, II is the ice content, and IP stands for surface geological processes.

Results

The calculated PGP values range from 2.5 (most favorable or suitable conditions) to 12.5 (least favorable or unsuitable conditions). River valleys and floodplains, laida areas, and swampy kettles and gullies are absolutely unsuitable for underground storage irrespective of their PGP score.

The PGP estimates were used for mapping and zoning (Fig. 1), with three groups of suitability zones distinguished: rather suitable, poorly suitable, and unsuitable for underground storage.

The lowest risk index (PGP = 2.5) corresponds to drained flat watersheds and low-grade slopes occupied by tundra upon sand and sandy loam substrates, as well as weakly drained tundra on watersheds and deflation fields. Less suitable are the following landscapes: drained and gullied tundra slopes; weakly drained tundra and fen (pool) complexes; suffosion sinkholes associated with tundra on loamy sand where most hazardous processes can develop, as well as fens with high ground temperatures.

The conditions for underground storage are the least favorable (PGP > 6.5) in kettles with polygonal plateau bogs and drained low-grade slopes with tundra on loamy sand and loam substrates where ground ice lies close to the surface (PGP = 8.5…9.5).

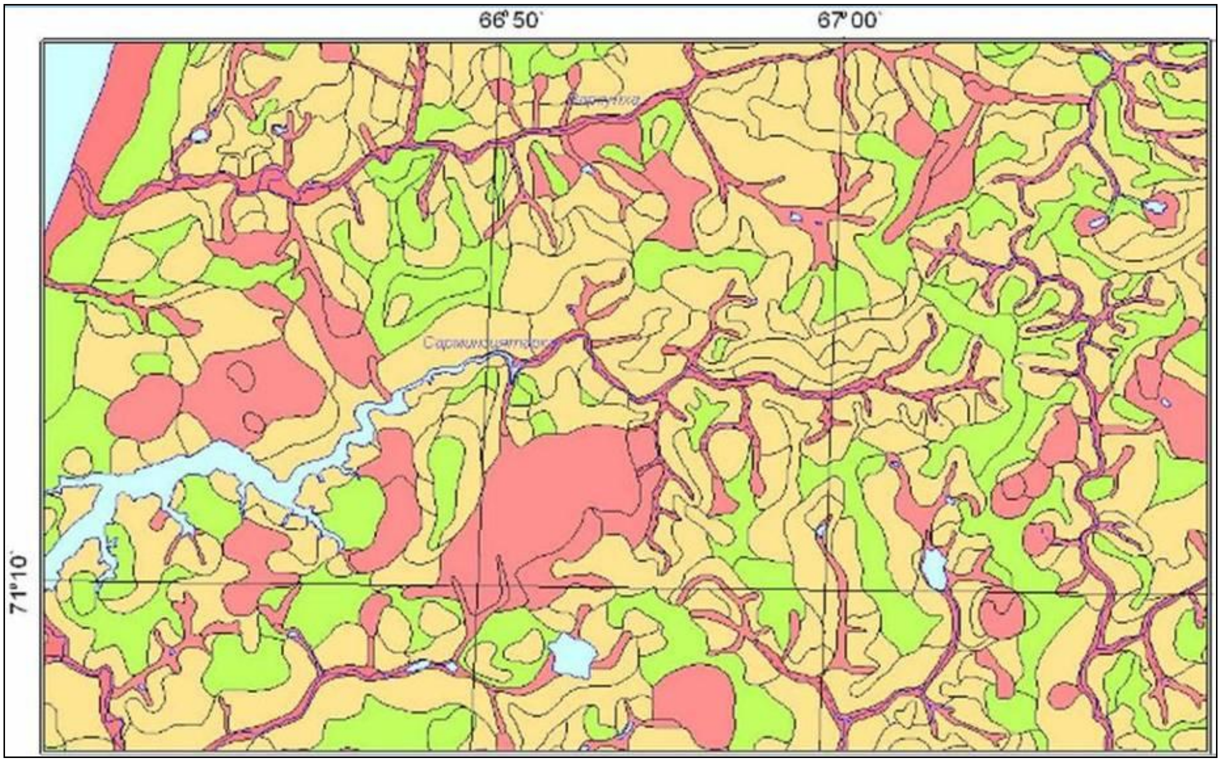

Fig. 1. Map of Kharasavei field with zoning according to suitability for underground storage. PGP = 2.5…4 (green): rather suitable; PGP = 4…6.5 (yellow): poorly suitable; PGP >6.5 (red): unsuitable

Thermokarst suffosion sinkholes occupied by tundra and polygon bogs, kettles with polygonal plateau bogs, as well as polygon bogs and tundra fen (pool) complexes are likewise least suitable for underground storage because of warm ground temperatures and presence of ground ice (PGP = 7.5…8).

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Updating the Geocryological Map of the Russian Federation

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Abstract

The Geocryological Map of the USSR published in 1991 has been broadly used for research and teaching purposes, for exploration surveys in remote lands, for environment and permafrost monitoring, as well as for predicting changes in permafrost conditions. However, the map needs updating because the 20-30 years which elapsed after the map had been compiled is a long time for such a rapidly changing object as the permafrost.

Keywords: Cartographic and geoinformation models; geocryological Map of Russia; landscape system approach

Introduction

More than twenty years have elapsed after the previous version of the "Geocryological Map of the USSR" was published. It has been a classical map (Fig. 1) which has had many different uses besides research and education. It has been used daily for exploration surveys in remote parts of Russia, for laboratory work and planning new field investigations and monitoring, as well as for predicting permafrost changes in natural conditions, under climate effects, and under anthropogenic loads. The users of the map render much respect to the mapping team leaded by E.D. Ershov and K.A. Kondratieva.

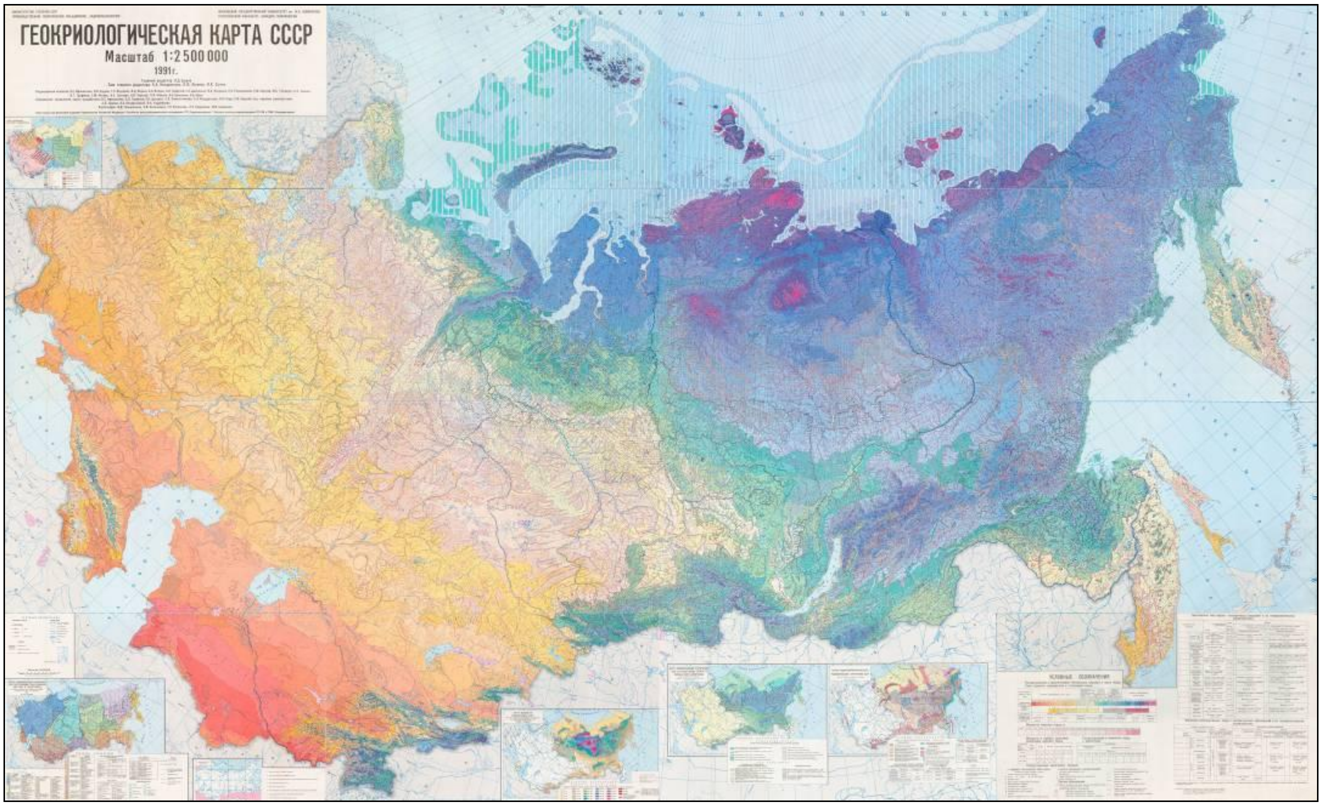

Fig. 1. Geocryological map of the USSR. Scale 1:2 500 000. Edited by E.D. Ershov, Moscow, 1991 (an image)

However, the cryosphere is one of most rapidly changing spheres of the Earth. The field data and calculations behind the Map of 1991 synthesize at least a decade of studies that preceded the publication. Thus, the map images the natural setting and the scientific ideas of experts in permafrost and other allied subjects as they were about twenty or thirty years ago. This is quite a long time for such a mobile system as the permafrost responding to geological processes in the lithosphere, to global change, and to human activity. The current changes are especially critical for shallow permafrost which is the principal object in research and development applications.

Thus, updating the Map is an urgent task, and it has made a special topic of the research program at the Earth Cryosphere Institute SB RAS (Tyumen) since 2010; before that time relevant work was performed as part of other projects. At the time being, the following key points in the new mapping strategy have been formulated.

Basic mapping approach

The mapping strategy stems from the landscape system approach. The state and evolution trends of the permafrost setting in the Russian high latitudes depend on the state and dynamics of natural and cultural landscapes. Landscapes, in turn, are controlled by interactions of the geosphere with the atmosphere, the hydrosphere, and the biosphere, as well as with technological systems. Thus, the landscape approach is applied to data synthesis and map compiling which allows producing maps of different landscape components, synthetic and zoning maps.

Expected mapping product

Form

The updated Map will be a set of cartographic and geoinformation models that result from quantitative and qualitative assessment of internal (among different elements) and external (with other Earth's spheres) interactions of landscape systems. The principal product will be in the form of a digital map providing user-friendly presentation and synthesis of the available data. Additionally, the Map will exist as a classical visually convenient printed version (prepared for publication), with insets and legends.

Scale

The scale of the updated map will meet the standard requirements for 1:2 500 000 paper geological maps. The working scale of regional map models will be from 1:1 000 000 (or 1:500 000) to 1:2 500 000, to provide appropriate generalization of global and regional (local) data.

Implementation

The Geocryological Map of Russia will be implemented as a digital model with the respective databases. The reliability will depend on availability of field data. The well documented areas of the country (important economic zones and agglomerations) will be key points mapped to a larger scale (1:1 000 000 to 1:500 000, or more detailed if necessary). The data from key areas will be used for extrapolations, on the basis of the digital map as a spatial (2D) model, to a user-specified confidence probability, provided that there are sufficient statistical criteria for justifying the extrapolations quantitatively.

The map will provide information on the background and current natural and anthropogenic conditions, to a required accuracy and reliability, and at the same time will make basis for predicting potential changes in permafrost-related parameters of landscapes.

Theoretical basis

Map models of permafrost are based theoretically upon ideas of the hierarchy of landscape systems and its correlation with the hierarchy of geological bodies as the substrate of the landscapes, while permafrost databases make the factual basis.

Graphic basis

The updated map uses the digital elevation model of Russia as its graphic basis, of the scales 1:2 500 000 for the final map and 1:1 000 000 (1:500 000) for regional models, if necessary.

Information basis

The information will be presented in a piecewise-continuous form, with a tie to the system of neighbor contours that are statistically quasi-uniform with respect to some set of geocryological parameters. The quasi-uniform contours make up a hierarchy consistent with the hierarchy of landscape systems, over which the parameters of permafrost are generalized. The contours of higher hierarchic levels correspond to landscape super-provinces (terrains) and provinces (or sub-provinces), i.e., correspond to the natural climate and geological zoning of Russia. The lower-rank contours correspond to geomorphically, hypsometrically, and biogeographically expressed landscapes (areas, districts, localities) that develop upon a single geological basis and are involved into a single complex of surface processes.

Permafrost parameters for each contour are estimated on the basis of a certain set of field data and are checked against available engineering-geological and geocryological surveys, as well as against data of continuous and campaign monitoring at control sites.

Contour basis

At present, a large amount of digital and paper maps of Russia are available that image elevation, physiographic, geological, socio-economic and other patterns. The information they present has been updated to different degrees. Most of contours for the new geocryological map will be imported from those maps taking into account their reliability and relevance to permafrost conditions. Some boundaries, especially for highland terrains, will be newly generated with regard to altitude zones and directions of slopes. Special reference will be made to the new 1:1 000 000 Geological Map of Russia.

Incorporation of a New Technology of Thermal Stabilization of Foundation Grounds at the Facilities of the Zapolyarnoe Oil and Gas Field

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The Zapolyarnoe oil and gas field is located in the north of Tyumen Oblast in the Pur-Taz interfluve and is one of the world's largest gas fields with the capacity of 35 billion m^3 of natural gas per year. The field is exploited since 2001.

The engineering-geocryological conditions of the field are characterized by great complexity, heterogeneity and dynamism. This is especially true for the bedding conditions and temperatures of frozen grounds: there are areas of confluent and non-confluent permafrost, permafrost table varies from 1-3 m to 5-10 m and more, and mean annual temperatures vary from 0.3°C to minus 2.5°C. Moreover, according to the survey data, the upper 6-10 m of the section are characterized by clayey composition of deposits and a considerable ice content of these deposits reaching 0.4-0.6 unit fractions due to ice inclusions, which can cause formation of large subsidences when they start to thaw. Intensive manifestation of heaving processes, thermokarst and thermal erosion is also observed.

At the design stage, a large amount of experimental research, including tests at a special test site, and mathematical modeling of thermotechnical processes were carried out in order to develop reliable and effective solutions for bases and foundations of buildings in such complex conditions. For the first time, the ability of frozen grounds to bear considerable loads, as well as the possibilities of modern vapor-liquid seasonal cooling devices – vapor-liquid heat stabilizers – were used in full capacity in the projects. One of the features of the foundation construction is the local freezing of thawed grounds and (or) lowering of the temperature of frozen grounds down to the negative design values in the areas of grounds that receive the load from the above-ground structures. Thanks to this, bearing ice-ground pedestal piers are formed (Fig. 1). These piers work in conjunction with pile foundations, taking most of the loads passed on to the foundations.

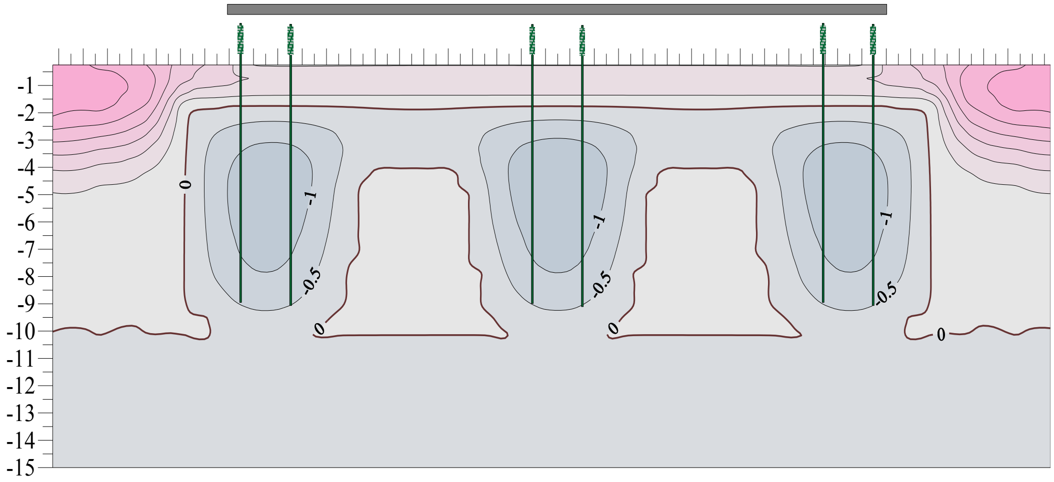

Figure 1. Ice-ground piers under the building with a vented crawl space on non-confluent permafrost after the 1st cycle of the heat stabilizers operation

As studies and field observations demonstrated, thermal stabilization is a prerequisite for reliable operation of the pillars of trestles, towers, pylons and other structures under which snow may accumulate and hinder the decrease in grounds temperatures during the cold season.

Thermal stabilization of grounds was conducted at the main field facilities: complex gas processing plants (CGPP), industrial bases, worker's residential villages, tank farms and methanol bases, gas turbine power plants and other facilities. The effectiveness of thermal stabilization activities is shown in Figure 2 for the case of CGPP-1c that includes 108 buildings. According to the observational data of the "Gazprom Dobycha Yamburg" LLC research permafrost laboratory, there was a significant decrease in grounds temperature (from minus 0.7 down to minus 3 degrees and lower) in the area of these buildings already after the first two years of operation of buildings foundations with installed thermal stabilizers. The designed technical solutions enabled reduction in the number of piles by 3 times and also enabled a decrease in the depth of their penetration into the ground, making the cost of the work of foundations construction decrease by 1 billion 165 million rubles in current prices. The economic benefits for three CGPPs (1c, 2c and 3c) were more than 3 billion 500 thousand rubles.

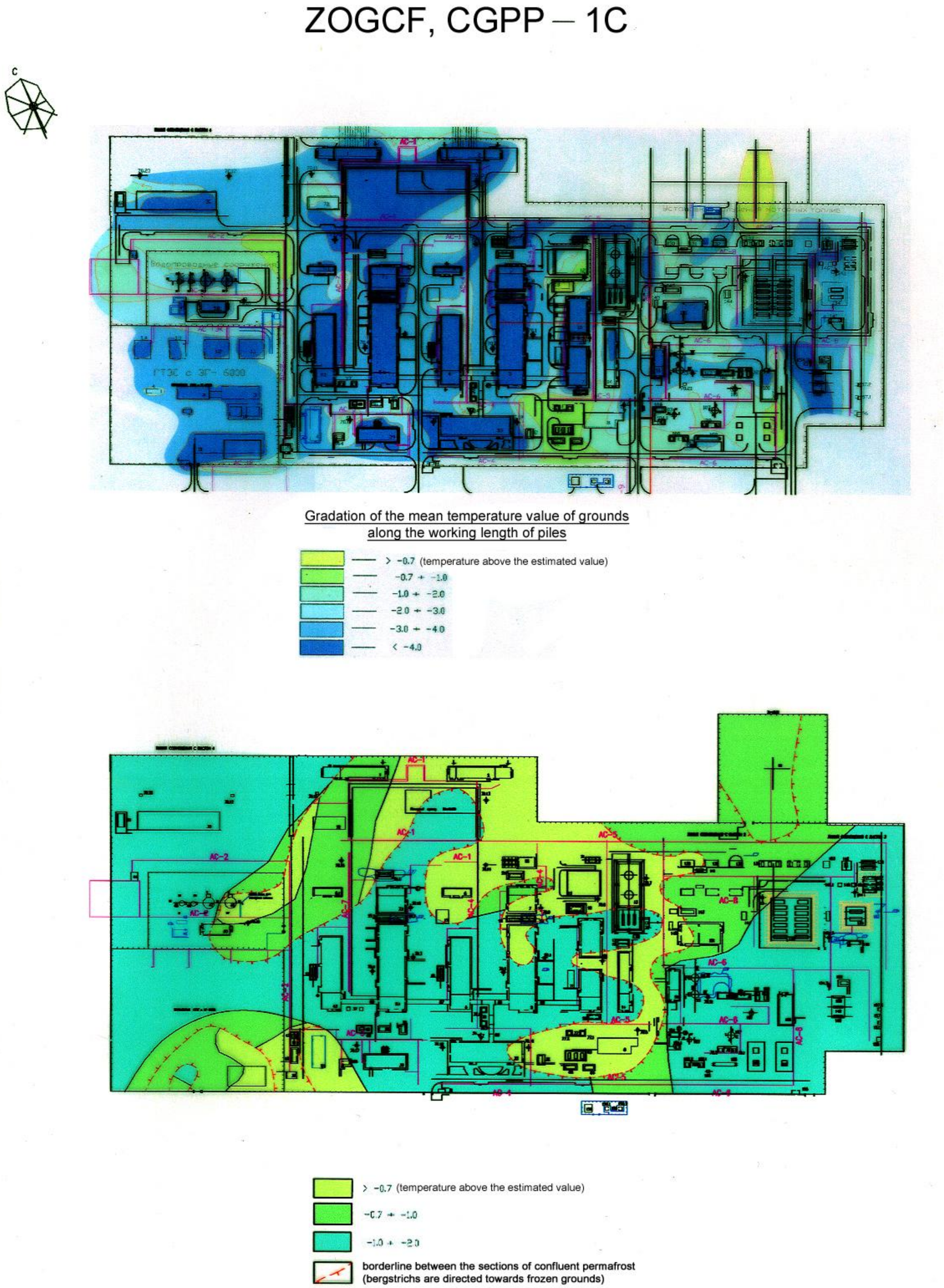

Figure 2. Temperatures of foundation grounds at the site of CGPP -1c before thermal stabilization (below) and after two years of thermal stabilizers operation (above)

A combined analysis of permafrost C depth distributions and multi-model permafrost thermal dynamics to estimate C pools vulnerable to warming

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C.Tarnocai, T.Jorgenson, W.J.Riley

We present a combined analysis of observed soil C stocks and modeled permafrost thermal dynamics to estimate the total quantity and form of C that will be vulnerable to thaw under global warming.

Our analysis of soil C distributions identifies C content in permafrost soils by suborder, depth, and horizon type, in order to assess the vulnerability of C to warming. Fig. 1 shows mean profiles of C stocks by depth and suborder.

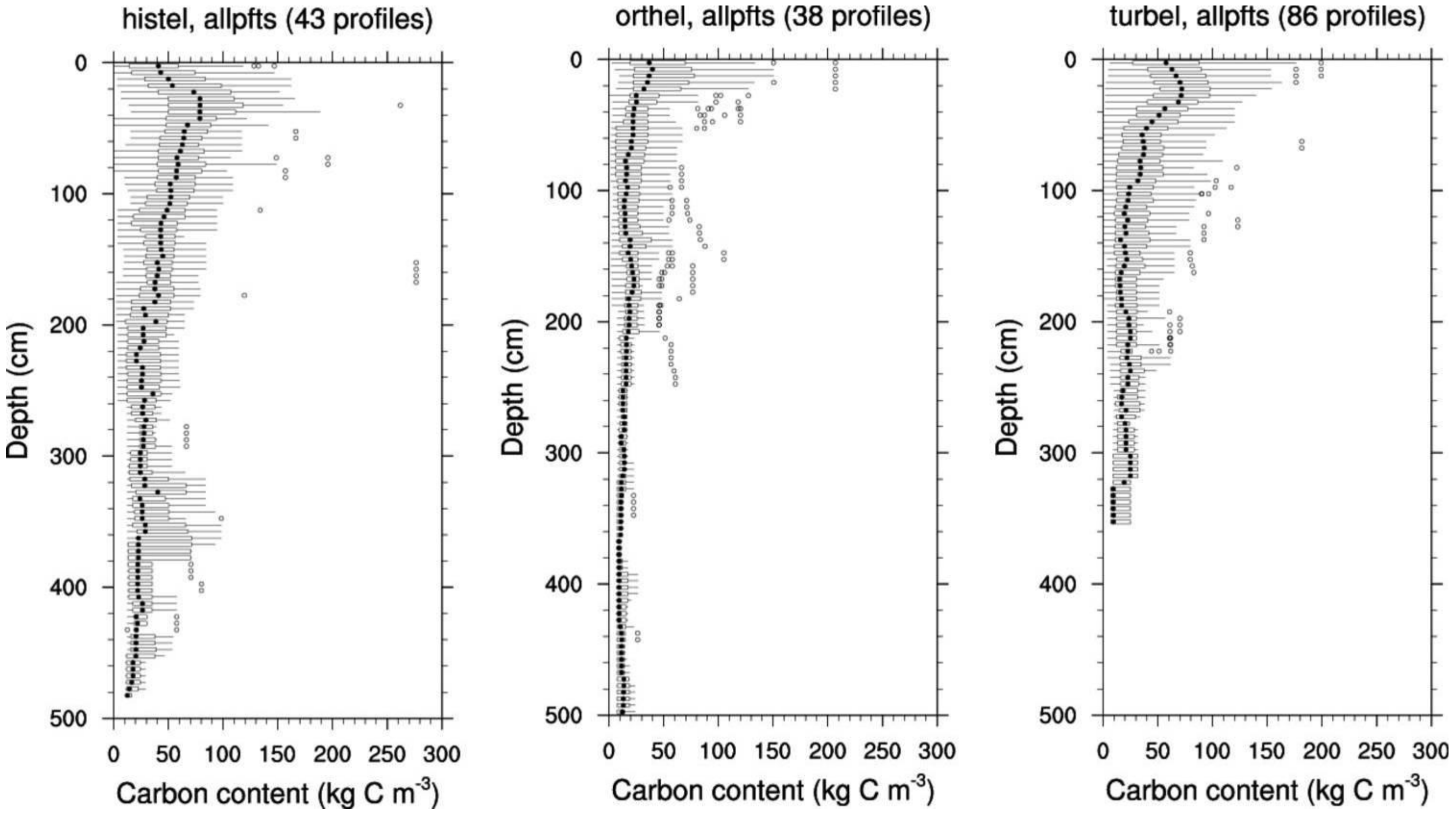

Fig. 1: Carbon content for permafrost soils, by suborder and depth, for upper 5 meters.

We combine these estimates with modeled assessments of permafrost evolution from global climate models. We consider the total C made vulnerable to warming to be proportional to the change in soil area at a given depth that is below the active layer of permafrost soils; for example we use the Community Climate system Model (CCSM4) as a tool for calculating expected changes to this distribution (Fig. 2)

In addition, we have examined the set of climate models from the Coupled Model Intercomparison Project 5 (CMIP5) archive that is being used as a basis for the next Intergovernmental Panel on Climate Change (IPCC) assessment, to examine both the soil thermal dynamics under the current climate as represented in these models, as well as the modeled response to future warming. Fig. 3 shows changes to the total permafrost area as predicted by these models.

The CMIP5 models show a wide range of soil thermal behavior under the current and future climates, and we define diagnostics for the models in order to assess the likely future response of the atmosphere-land system at high latitudes to warming.

The combination of modeled thermal response to warming with estimates of the depth distribution and form of soil C for permafrost soils allows an estimate of the total stocks of carbon expected to thaw under the climate change scenarios, and we discuss the implications of this on the quantity and vulnerability to disturbance of the various soil C pools.

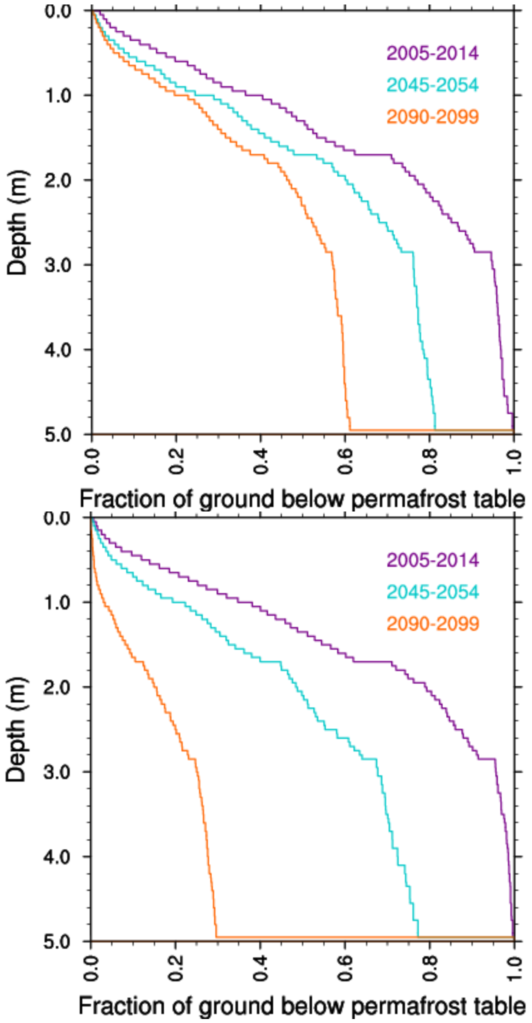

Fig. 2: Changes to expected Active layer thickness distributions from the CCSM4 model under climate change scenarios (RCP4.5 and RCP8.5)

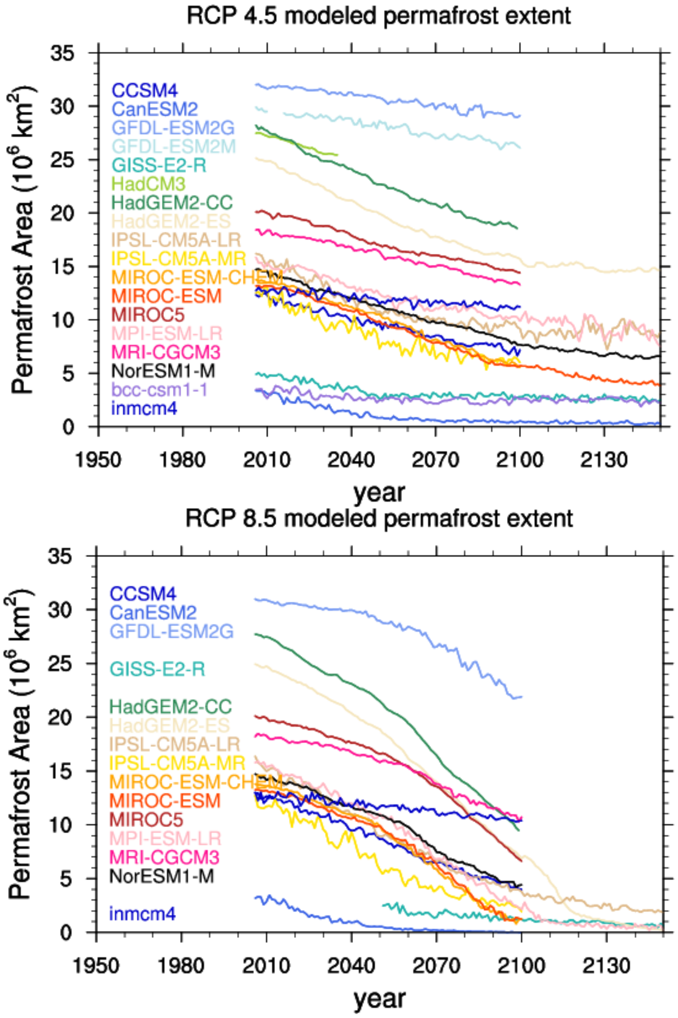

Fig. 3: CMIP5 model predictions to permafrost extent under two warming scenarios (RCP4.5 and RCP8.5)

Radar Differential Interferometry for the Analysis of the Geocryological Processes Dynamics

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During the recent years the satellite radar survey of the Earth intensively develops. Radar data has numerous advantages over the optical materials of remote sensing: all-weather capability, independence from the time of the day in the surveyed area and frequency of surveying of the same area. The traditional product of interpreting the radar data is the current detailed models of the locality. In addition, using diachronous radar images for the same territory (radiolocation pairs) provides a unique opportunity to calculate centimeter and sub-centimeter relief shifts over the corresponding time interval. This technology is called radar differential interferometry. By the accuracy of obtained results it can be compared to geodetic measurements. In contrast to them, the information about the changes in the relief surface is obtained not only within the leveling line but also for the entire cover area of the radiolocation pair, which amounts to tens (for large-scale works) and hundreds (for regional works) square kilometers, depending on the type of the radiolocation satellite whose data are used.

Technologies of obtaining highly detailed models of the locality and models of earth surface shift are actively used in Gazprom VNIIGAZ LLC in order to solve a number of geological and geological-surveying tasks. When studying the territory of fields and pipeline corridors that are located within permafrost distribution area, these studies are always accompanied by creation of maps of geocryological processes manifestation. Such maps are created by interpreting highly detailed or detailed optical space images. They enable identification of the objects with the dimensions of 0.5 - 2 m in the locality. The map of geocryological processes manifestation demonstrates the distribution of various stages of thermokarst, polygonal-ridge and polygonal-ridgeless relief, heaving peatlands, areas of development of solifluctional deformations of the day surface, hydrolaccoliths, thermal abrasion coasts and thermal erosion gully rills, modern water-logging of the fields' infrastructure facilities etc.

Composition, characteristics and dynamics of frozen grounds' state are genetic conditions of activation of geocryological processes manifested on the surface in the form of specific genetically predetermined landscape elements.

It is rather often that in the shift models obtained with the help of differential interferometry there are areas of coherency loss that do not contain data on the shift. This phenomenon can be caused by various reasons. The reasons are partly technical, for example, the radiolocation pairs and the parameters of their interpretation that are poorly selected. Other reasons are connected with natural processes – excessive water-logging of ground and great changes in the surface over the given period of time. As a rule, such areas are excluded from the analysis. The joint analysis of maps of geocryological processes manifestation and models of relief shifts in a number of fields located in the Yamal peninsula and in the interfluve of the Pur and the Taz Rivers demonstrated that coherency loss zones often correlate with the areas of polygonal relief development. Two conclusions can be drawn from this: The first conclusion is about the high rate and the high intensity of heaving. The second conclusion is that the areas of coherency loss that were previously often excluded from the analysis possess a lot of useful information about the course of geocryological processes.

The comprehensive analysis of the maps of manifestation of geocryological processes distribution and shift models makes it possible to identify and assess the intensity of thermoerosive, thermoabrasive and thermokarst processes, solifluctional degradations, the growth of frost heaves and heaving peatland massifs posing a serious hazard to accident-free operation of infrastructure facilities of fields and pipeline systems.

The models of relief surface shifts provide extensive and accurate information about the geometric changes in cryogenic elements of a landscape over the given period of time, which allows us to draw conclusions not only about the dynamics of cryogenic landscape elements, but also about the changes in frozen grounds' state.

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Statistical Analysis of Genesis Indicators of Late Cenozoic Deposits at the North-East of Yakutia

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The study of deposits' genesis is impossible without the consideration of their properties and content. In order to reconstruct the conditions of deposits accumulation, a whole set of parameters and indicators is used: particle size distribution, chemical properties, content and quality of organic substance, concentration of biogenic gases. Each of these indicators reflects certain conditions of deposits' formation.

In the course of studying the North-East of Yakutia an extensive database on stratigraphy, genesis, content and properties of deposits was collected [*Sher 1971, Resolutions... 1988, Konishchev & Plakht 1991, Rivkina et al. 1992; Kholodov et al. 2003, Rivkina et al. 2007*]. But a statistical analysis of the available material was not conducted before. This work is aimed at identification of the most important indicators for genesis interpretations and development of stratigraphic models. The collected data make it possible to reconstruct the conditions of accumulation and freezing of deposits on the North-East of Yakutia in the Pleistocene.

Materials and methods

420 deposit samples of the Late Cenozoic era were selected from the database. These samples were collected in the North-East of Yakutia in the course of the *Beringia* paleoecological expedition. Each sample had stratigraphic referencing and a number of paleogeographical indicators was established for it. The following indicators were used for the statistical analysis of each sample: content of sand fractions (1-0.05 mm), dust (0.05-0.001 mm) and clay (<0.001 mm), ratio of ions Ca/Cl in water extract [*Konishchev & Plakht 1991*], solid residue, pH, total carbon content and methane concentration.

The total number of analyzed samples was as follows: 20 samples of the Tumus-Yarskaya Suite, 100 – the Olersky suprahorizon, 40 – the Keremesitsky suprahorizon, including 25 samples of the Maastakh Suite, 20 – the Konkovskaya Suite, 40 – the Khallerchinskaya Suite, 130 samples of edoma, 40 – of alases and 30 samples of modern alluvium. Table 1 gives average characteristics for each group of deposits.

A step-by-step nonparametric discriminant analysis with the introduction of each parameter according to the F-value was conducted to enable statistical interpretation. Wilkinson's lambda was used to assess the role of each variable [*Puzachenko 2004*].

Results and discussion

The total discrimination accuracy (division of samples into groups) is 50%. The most variable parameters are dust and sand content, which is explained by their extreme values. Most of the values (75% of all cases) fall in the range from 20 to 70%. Great spread of values is typical of methane content, the Ca/Cl ratio and solid residue. pH is a critical parameter as, despite small variability of absolute values, it has defined values for deposits of certain genetic groups. The total content of carbon and clay fraction in all samples vary slightly and are not of much importance. Therefore they are not used in the discriminant analysis. The statistical analysis showed that different parameters are of different significance. Significance criteria for each variable are given in Table 2. Based on the Wilkinson lambda, the CH_4 content and the Ca/Cl ratio are the most significant parameters. Methane content makes it possible to single out edoma, the Maastakh Suite and the Khallerchinskaya Suite where methane is missing or its content is minimum. The Ca/Cl ratio is an indicator of marine or territorial genesis, it allows to single out the deposits of the Konkovskaya and Maastakh suites. Dust fraction and solid residue in the model are excessive as the weight of one value in the discrimination model is not high and cannot serve as an unconditional indicator. The content of sand fraction allows us to distinguish deposits of the Tumus-Yarskaya, Maastakh and Khallerchinskaya suites. The last parameter introduced into the discrimination model is the pH value. Since the pH dispersion is insignificant (from 6.5 to 8), it decreases the accuracy of the model classification. Methane content makes it possible to distinguish edoma deposits with an adequate accuracy. For all used parameters of deposit groups, except for methane concentration, Mahalanobis distances were calculated [*Puzachenko 2004*]. They showed that the deposits of the Olersky suprahorizon and alases are the most similar to the edoma deposits. The accuracy of differentiation of these deposits without methane content is low and the result is erroneous, as 93% of alases and 90% of the Olersk deposits were classified as edoma after the statistical analysis. After the CH_4 content was introduced into the discriminant analysis, the error was significantly decreased: up to 25% for alases and 19% for the Olersk deposits. For edoma samples the classification accuracy after methane introduction reached 100%.

The classification equations resulting from the discriminant analysis also confirm high importance of the CH_4 concentration. The coefficients for methane in all groups vary from 0.7 to 1.2, while for other parameters they are much higher (5.2-27.1). These data confirm the earlier obtained results about the role of methane as an indicator of paleoenvironment [*Rivkina & Gilichinskiy 1996*].

The discriminant analysis for genetic types of deposits was performed in the same manner [*Resolutions... 1988*]. In total 6 groups were used: syncryogenic alluvial, ice complex, alas complex, epicryogenic lake and alluvial, epicryogenic alluvial-marine, syncryogenic alluvial-marine. The analysis showed that methane concentration is also the most important parameter when discriminating the samples. Along with methane, the Ca/Cl ratio has much weight. The generated classification equations have the lowest indices of the CH_4 content. For syngenetic deposits they are equal to 0.27-0.43, for epigenetic deposits – 0.64-0.69.

Table 1. Characteristics of material composition of the Late Cenozoic deposits at the North-East of Yakutia.

Suite	Sand, %	Dust, %	Clay, %	Ca/Cl	C-total, %	pH	Solid residue, mg/l	methane, ml/kg
Tumus-Yarskaya Suite	57.57	34.37	8.06	0.39	0.82	7.33	0.15	6.64
Olerskaya Suite	52.91	37.42	9.67	2.46	2.11	7.36	0.12	7.34
Keremesitsky suprahorizon	10.29	76.67	13.05	0.79	1.51	6.9	0.08	2.89
Maastakh Suite	91.55	3.24	5.21	0.2	0.48	7.76	0.12	0.33
Konkovskaya Suite	60.94	32.16	6.89	0.22	0.9	7.56	0.35	4.92
Khallerchinskaya Suite	70.67	18.37	10.96	1.49	0.89	7.45	0.06	0.33
Edoma suprahorizon	41.19	51.41	7.39	1.6	1.24	7.84	0.11	0.21
Alas Complex	37.19	54.83	7.98	0.34	1.73	7.17	0.15	5.96
Modern alluvium	46.38	47.86	5.76	0.6	0.84	7.12	0.06	3.21
All samples	47.94	43.83	8.24	1.03	1.23	7.38	0.14	3.34

Table 2. Significance of variables used in the discriminant analysis

	$C(CH_4)$	Ca/Cl	Dust	Solid residue	Sand	pH
Wilkinson's lambda	0.67	0.46	0.32	0.21	0.15	0.11
Accuracy of classification after the input of a parameter, %	28	29	30	38	45	39

Thus, the methane concentration can serve as the most important indicator when differentiating the Late Cenozoic deposits of the North-East of Yakutia. The distribution of methane through the section makes it possible to separate the deposits of edoma suprahorizon from overburden alases and more ancient underlying sediments (the Olerskaya and Konkovskaya suites). Due to the absence or low content of methane in edoma suprahorizon, methane cannot be used for distinguishing horizons. Moreover, methane cannot serve as a reliable indicator for distinguishing sincryogenic deposits, such as edoma, the Maastakh Suite and the Khallerchinskaya Suite. In this case it is necessary to use other parameters for stratification of a section. When edoma lies in the Maastakh Suite that is poor with methane, like in the middle reaches of the Chukochya and Alazeya rivers [*Sher 1971*], stratification can be performed on the basis of the sand fraction content and the Ca/Cl ratio. The same indicators enable the differentiation between edoma and the Khallerchinskaya Suite.

Conclusions

Methane can be considered the most important paleogeographical indicator among all others. The methane content can indicate the genesis and the conditions of deposits' freezing. When using methane content with other parameters and taking into account the regional stratigraphy, it is possible to perform a statistically valid stratification of sections.

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Estimating Societal Costs from Infrastructure Damage due to Climate Change-Induced Permafrost Degradation in Alaska

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Introduction

Numerous examples of infrastructure damaged by degrading ice-rich permafrost abound in the literature and in the media. Many of them are spectacular and are attracting public notice as climate change warming receives substantial media attention (U.S. Arctic Research Commission Permafrost Task Force, 2003).

Such failures are presumed to be more widespread and costly to society in the future if northern regional temperatures rise sufficiently to cause widespread degradation or elimination of currently frozen terrain.

A question being asked by public managers and political leaders is, “How much is this going to cost to deal with in the future?”

The answer of course depends on the magnitude of the expected climate warming. Since no one really knows the answer to that, it's best to provide estimates assuming different levels of the forecasted warming.

The next step is to assess how typical the infrastructure damage examples really are. Do they represent widespread similar site conditions and structure response? Or are they rare outliers that have little effect on the overall concerns and costs?

The “ISER” Study

The University of Alaska Anchorage, Institute of Social and Economic Research (ISER) study estimated future costs for Alaska public infrastructure at risk from climate change. These include assets owned by local, state, and federal governments that are critical for delivering goods and services (major roads, bridges, airports, harbors, the Alaska Railroad and some utilities).

ISER noted that obtaining accurate information about the public infrastructure in Alaska is difficult because government agencies do not necessarily have reasons to collect and maintain that information [*Larsen et al., 2008*]. Nevertheless the study's authors made a creditable effort to design a model and approach to the problem.

They concluded that the projected cost of Alaska’s public infrastructure at risk from rapid climate change could add \$3.6–\$6.1billion (+10% to +20% above normal maintenance and replacement) to future costs for public infrastructure from now to 2030 and \$5.6–\$7.6 billion (+10% to +12%) from now to 2080. These costs result from annualized replacement costs for nearly 16,000 structures. They include effects of not only permafrost thawing, but also increased flooding and coastal erosion.

However there are two assumptions made in the ISER study model that have significantly increased their estimate of the costs forecasted over those likely to actually occur:

The ISER model assumes that 70% of the facilities in the discontinuous permafrost zone (50-90% frozen) will be underlain by permafrost. However, throughout Arctic regions, and certainly in Interior Alaska, facilities have long been preferentially located to avoid frozen ground and ice-rich permafrost. It’s more likely that less than 30% of the facilities are on frozen ground and, of those, many of them will be on sites with low ground ice content such as frozen gravel floodplains, terraces and bedrock [*Cole et al., 1999, see Fig. 2*].

Similarly, the ISER model assumes that 30% of the facilities in the sporadic permafrost zone (10-50% frozen) will be on permafrost. It’s more likely that less than 5-10% of the facilities are on frozen ground.

The ISER study assumes that dramatic thaw settlement will occur on frost susceptible soil that renders the infrastructure unusable and loss will equal 100%. This is likely a substantial overestimate of the effects of permafrost thawing on these sites.

For instance, many structures will have been in place for 50 to 100 years. In the case of roads and railroads, their construction will have completely altered the surface heat balance by destruction and replacement of insulating vegetation and groundcover. Asphalt pavement greatly increases surface temperature. These alterations alone increase the soil surface temperature by many times any estimated climate warming. Consequently a substantial thaw bulb already exists underneath such structures. Over the years maintenance has already accommodated substantial thaw settlement for sites that previously contained ice-rich soils.

Alaska Railroad

The Alaska Railroad between Nenana and Happy Hill in Fairbanks would be an example of infrastructure that traverses the thick ice-rich retransported frozen organic silt of Goldstream valley. In many places, as the ice-rich soil has thawed and settled, 90 years of gravel ballast emplacement employed to restore the railroad to grade has left it with an unfrozen 'bulb' of gravel (5 to 6.5 m deep) underlying the track through much of Goldstream valley [*Fuglestad 1986*]. In at least one location there is over 18 m of emplaced gravel ballast over permafrost. It's unlikely that the railroad would have to be abandoned and moved to a different site. The permafrost table is now very deep and additional warming affects at that depth are likely to be small.

Buildings

Similarly for buildings on frost-susceptible soils, it is unlikely they will suffer a complete loss of value if permafrost thaws in the area. There are a number of things that building owners can do to deal with warmer temperatures. Like the railroad example above, if the building is old and built on a site disturbed many years ago, the permafrost table may already have retreated. Buildings on pilings with a ventilated crawlspace underneath may be cooling soil temperatures below their preconstruction undisturbed state [*Rooney & Riddle 2004; Shur & Goering 2009*]. Rooney and Riddle go on to urge that long-term performance of buildings in warm permafrost areas be monitored so that,

> "appropriate design concerns can be addressed and that global warming "doomsday" forecasts of imminent adverse impacts on structures be put in proper focus. In other words, solutions have been and can be utilized to properly construct and maintain facilities for the intended design life in regions of warming permafrost."

Other Structures

The other classes of Alaskan infrastructure that have had only limited publicly available evaluation for potential maintenance and replacement costs due to climate change are:

- Industrial facilities (such as the oil and gas production infrastructure at Prudhoe Bay and the Alyeska pipeline).
- Private business property in towns and cities (stores, warehouses, office buildings etc)
- Private housing
- Private and cooperative electric utilities

An approach to evaluating these assets located in municipalities is the use of the computerized tax assessment rolls maintained by Alaskan local governments (cities and boroughs). This presentation will present results from the analysis of structure valuations versus site soils and thermal state.

Conclusions

Finally, for a complete evaluation of the effects of increased societal costs due to warming temperatures on northern infrastructure, offsetting costs should be deducted from forecasted increases in expense. One obvious category of this type of benefit is the reduction in energy costs because fuel consumption for space heating will be lower. Some believe that the energy savings from decreased demand for heating in northern regions are likely to be offset by increases in the temperature and duration of the warm period, leading to greater use of air conditioning [*Instanes et al., 2005*]. However, the vast majority of buildings in the North do not have air conditioning and their owners will realize cost savings that can be used to offset increased maintenance expense from soil thawing.

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Methanogenic Community of Two Permafrost-affected Siberian Peat Bog Soils

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Northern bogs and tundra are responsible for one third of methane emissions that enter the atmosphere from waterlogged landscapes [*Fung et al. 1991*]. Lowlands of Western Siberia covered with bogs are the most extensive area of bogs distribution in the world [*Panikov 1994*]. Bogs cover 27% of the territory of Western Siberia [*Peregon et al. 2008*], including 29% of the territory located in the tundra zone [*Romanova 1985*]. Due to the enormous expansion, these bogs occupy several climate zones each of which is characterized with its own methane emission flux [*Matthews & Fung 1987*].

The goal of our work was to conduct a comparative study of microbial communities of methanogenic archaea in peat horizons of two bogs located in the southern and typical tundra.

Peat samples were collected during August 2010 in the key areas in the typical (Gyda) and southern (Yasavey) tundra.

The Yasavey key area (southern tundra subzone; coordinates: 67.35° N, 78.91° E) was located at 15 km to the south of Tazovskiy village in Yamalo-Nenets Autonomous Okrug. This area is confined to the left-bank terrace of the Taz River. Permafrost is located at the depth of 30 cm. Peatlands are shallow and the thickness of the peat layer does not exceed 50 cm.

The Gyda key area (typical tundra subzone; coordinates: 70.90° N, 78.53° E) was located at 5 km to the east of Gyda village in Yamalo-Nenets Autonomous Okrug. The area is confined to the watershed area with poorly expressed relief. The thickness of peat deposits was 25-30 cm. The permafrost boundary was located at the depth of approximately 30 cm.

To assess the response of the methanogen community to the addition of substrates, the peat samples were incubated anaerobically in a medium simulating the composition of peat pore water at +15°C and in the absence of light. The composition of the gas phase was monitored through periodic measurements by using gas chromatography analysis. The dynamics of the concentration of acetate in the culture medium was monitored with the help of high-performance liquid chromatography. The reaction of methanogenic archaea community was determined by the changes in the structure of the clone banks of the 16S rRNA gene fragment obtained by reverse transcription of the corresponding ribonucleic acids that were singled out before and after the incubation of the samples.

The formation of methane in anaerobic microcosms of the Gyda key area was stimulated by the addition of H_2/CO_2 and acetate. At the same time, these substrates had no significant effect on methanogenesis in the samples from the Yasavey key area, which indicates the absence of substrate limitation for the formation of methane as well as the fact that it originated from endogenous substrates. The analysis of the 16S rRNA clone banks obtained from different variations of the samples incubation demonstrated the dominance of the representatives of *Methanosarcina* and *Methanosaeta* genera in the peat samples of typical tundra. In the samples collected from both key areas there was a significant increase in the concentration of acetate with the addition of H_2/CO_2, especially in the presence of the methanogenesis inhibitor (bromoethanesulfonic acid), which indicates high activity of acetogenes.

Thus, by comparison with the peat samples from the southern tundra bog, the microbial community involved in the formation of methane in the samples from the typical tundra showed a significant response to the addition of substrates and greater accumulation of methane, which indicates its high potential methanogenic activity.

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Thermal Interaction of the Underground Gas Pipeline with Permafrost on the Bovanenkovo - Ukhta Pipeline Section

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The gas pipeline route passes through an area with complex geocryological conditions. There are zones of continuous, island-like and discontinuous permafrost here.

The investigated section of the Bovanenkovo - Ukhta underground gas pipeline route is located in the region of mostly continuous permafrost distribution of the Bolshezemelskaya Tundra (the North of the European Russia). Here, the permafrost thickness is 300 m, the temperatures at the depth of zero annual amplitudes vary from -1 to -3°C [*Geocryology… 1988*]. The seasonal thawing depth of the grounds is 0.5 – 1.6 m on this section. The upper part of the section consists of the Quaternary deposits of small thickness, predominantly of clayey silt and sandy silt containing a large amount of boulders and pebble (15-20%), and a peat layer that beds from the surface and is 10 – 40 cm thick.

Thermal interaction between the underground gas pipeline and the permafrost can cause hazardous cryogenic processes and a significant depression of the permafrost table [*Kozlov et al. 2001*]. Forecast evaluation of thermal interaction shall be therefore carried out for each individual case. To this end, there was solved a mathematical and numerical modeling problem.

The calculation was carried out in accordance with the finite difference method using the Teplo software developed by the Geocryology Department of the Faculty of Geology at Lomonosov Moscow State University.

The modelling was carried out in order to determine the multi-year dynamics of the development of the thawing halos around the "warm" gas pipeline buried in the ground (i.e., the pipe lies in a trench) at the depth of 1 m (from the upper generating line of the pipe).

The problem was treated considering changes in the pipe heat insulation parameters and gas transportation temperature regime.

The results of the modeling are thawing halos reaching 1.5 m, which may initiate adverse processes due to yearly pulsation.

Proposals on the specification of heat insulation efficiency and optimization of the temperature regime of the gas transported were made based on the forecast results.

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Petroleum Development Prospects in Arctic Russia: Economic Appraisal in the National Perspective

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Any economic activity, which pursues large-scale political and social (not purely economic) goals, is eventually appraised in terms of financial and economic indicators. The system of these indicators commonly presents various costs (of material, human, natural, and financial resources) in the monetary form. The efficiency of the activity is judged by comparing the targets and the actual performance.

There are three main issues in the development of high-latitude permafrost territories and related economic activity, namely:

(a) disposing subsoil resources unique in terms of both nature and economy;
(b) aiming at geopolitical goals and objectives in the context of national security;
(c) maintaining environmental and biological sustainability of unique high-latitude ecosystems.

Not all relevant objectives and priorities are appraisable in terms of proper economic performance. It is more reasonable rather to treat them as prerequisites and conditions for sustainable socioeconomic and environmental development of permafrost regions.

This development inevitably runs a number of economic risks associated with (i) high costs of construction and servicing of engineering structures and objects with due regard for the behavior of permafrost; and with (ii) long cycles of research and production (anticipating research and monitoring with special systems). The major risks can be mitigated by

- designing new advanced technological systems and development processes;
- setting up a system of scientific support;
- integrating scientific knowledge with ways and skills traditionally employed in local economic activity.

It is important to create appropriate institutional conditions for running such projects, among which international cooperation and integration of local communities in the course of appraisal and decision making (with main emphasis more on the expected project results than on technologies).

Projects in permafrost areas are as a rule large-scale and long-lasting. They concern both subsoil use (mineral and hydrocarbon resources) and building the infrastructure (from roadways to towns). Very few such projects can, and should be, evaluated with standard methods applying the criteria of payback, efficiency, profitability, etc.

Their performance shows up rather as the total value of benefits from the large-scale projects than as payback in specific projects (in this case payback, even if there is any, is possible only with made-up support from price or tax preferences). The benefits have to be considered in the framework of external links, such as "project – subsoil use", "project – development of allied industries", "project – creating sustainable living and labor conditions for people”, etc. Unfortunately, many projects realized by today in the high-latitude areas meant short-term effects and hardly could meet the above requirements.

The expected advantages should be rather synergetic than linear and should ensure economic diversification and sustainable socioeconomic and environmental development of the territories [*Kryukov et al. 1995*].

Much of research activity at the Institute of Economics and Industrial Engineering (Novosibirsk) has focused on approaches to evaluating large-scale projects in terms of their impacts on the economy of territorial systems (for justifying management decisions for economic development of Siberia).

Our team has carried out a pilot investigation in order to estimate the contribution of three large petroleum provinces into cost efficiency growth: shelf, including the Arctic shelf; West Siberia where production is prospected from deeper subsoil than the currently available level; and East Siberia with Far East.

The problem was solved through optimization modeling (analysis and prediction) of cash flows [*Kuleshov and Marshak 2002, 2006; Kryukov and Marshak 2009*]. The models additionally included conditions for production growth in the provinces for each year. Modeling was run as 458 × 533 linear programming. The quality of results was judged according to maximization of cost efficiency. All (available and raised) financial resources were assumed to be disposed following the actual regulations of the Central Bank.

None model for either province fitted the solution “plan”. To put it different, *neither the suggested ways of medium-term production enhancement, with regard to the period of construction and achieving the projected production capacity, nor growth of specific investment, can increase the cost efficiency measured as the cash flow margin (price difference between raised and invested funds).*

Note that modeling has been in the fixed prices of 2011, but the results remain the same at twice higher external prices (up to 200 US dollars per BOE).

See Table 1 for the amounts of specific investment for petroleum production growth in the three provinces

Table 1. Specific investment for petroleum production (in prices of 2010)

	Sector average	West Siberia	East Siberia	Shelf
Oil, rouble/ton	926	2085	3500	1830
Gas, rouble/1000 m^3	316	1070	1450	8612

In modeling experiment, mandatory production growth was specified separately for each petroleum province.

The five models (Fig. 1) were:

(1) zero variant: no production in any province;
(2) user-specified general annual production limits; solution gives the shares of each province;
(3) production growth due to West Siberia only;
(4) production growth due to East Siberia only;

(5) production growth due to shelf only.

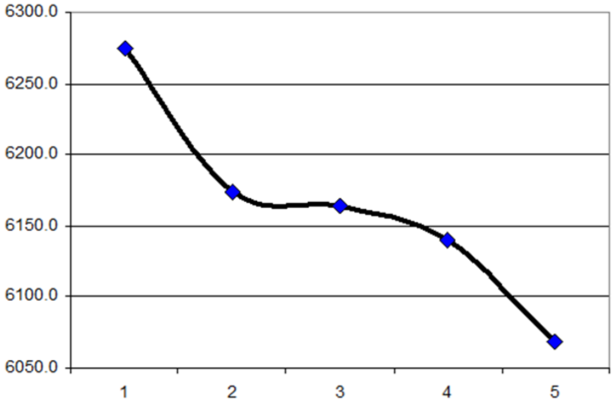

Fig.1. Dynamics of cash flow margin for different models (1 to 5).
Horizontal axis – Billion rbl, in prices of 2011
Vertical axis – Model numer

Thus, it is obviously unreasonable to treat the development of new producers, especially in high latitudes, in terms of pure cost efficiency in the medium or long run. This development can rather provide additional sources for modernization of national economy and for its sustainable development.

In this respect, one more modeling experiment included mandatory commissioning of new plays. Table 2 shows principal macroeconomic performance indicators in the model.

Mean annual growth in gross domestic product in this model is 4.1% against 3.17% in the previous case. Although the mandatory startup of new plays causes a 5% decrease in commissioning fresh capacities in other sectors of national economy and a 3.5% decrease in the revenue of the financial sector, it ensures growth in the gross domestic product, in real incomes of people and, generally, in the tax basis.

According to the results of modeling (with a sophisticated aggregate analysis and prediction of cash flows in the whole national economy), this development scenario requires raising long-term money for the three provinces. For this there are three sources feasible in the foreseeable future:

(a) direct involvement of government into projects (a widespread practice, for instance, in Norway);

(b) economic preferences (preferential royalty fields, with zero subsoil tax and customs for a certain period of time: is coming into practice also in Russia);

(c) involvement of foreign partners and promotion of joint projects (e.g., there is successful experience from the Sakhalin project and agreements of the Russian *Rosneft* and *NOVATEK* companies with world largest oil-and-gas companies).

Table 2. Principal macroeconomic performance indicators, with mandatory commissioning of new plays (bln rbl, in prices of 2011).

	years:	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gross domestic product		54363	55533	56147	57916	59427	60719	62365	64412	67436	78072
	Costs for consumptive use	37820	38247	38895	39983	39612	39440	40227	41379	41877	45721
including:	** household*	18205	18570	18941	19320	19706	20100	20502	20912	21331	21757
	** offices*	19615	19677	19954	20663	19905	19340	19725	20467	20547	23964
	Gross capital	9890	10382	9991	10344	11432	12217	12584	13003	14957	22915
	Net export	6652	6904	7261	7590	8384	9062	9553	10030	10602	9435

The support of long-term socioeconomic and environmental interests of permafrost regions lies mainly with proper localization of benefits from new successful projects. The top priorities in this localization cover the whole scope of problems that may arise while dealing with permafrost.

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Particularities of Syncryogenic Deposits Microstructure

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Introduction

Cryogenesis as a zonal type of lithogenesis is most pronounced in syncryogenic deposits, which are characterized by the correspondence of geological and cryogenic age [*Romanovskiy 1993*]. The deposits transformation begins in the active layer during cyclic freezing and thawing. The transition of the deposits into the frozen state in the base of the layer of seasonal thawing occurs, as a rule, in conditions of excess water content, which ensures a high ice content of the deposits. Thawing of the deposits above the top of permafrost is not observed every year. It results in a rhythmic permafrost accumulation and formation of belt-like cryostructure.. It is in this layer that a specific structure of syncryogenic strata, which reflects the facies conditions and geocryological history of grounds transformation, is formed In very fine-grained deposits, the microstructure fixates the structural bonds between the skeleton particles, aggregates and ice inclusions [*Microstructure... 1988, Rogov 2009*] and defines the key engineering-geological properties of grounds: porosity, permeability, soaking capacity etc.

Methods and object of study

The most typical example of syncryogenic deposits is the ice complex, which is widely distributed in the coastal lowlands of the north-east of Russia. The paper presents the results of studying the microstructure of the deposits of the Kolymskaya lowland and delta of the Lena River. They are characterized by the homogeneity of their dispersion composition (up to 75% of coarse-aleurite fraction), high porosity, ice content and peat content [*Konishchev 1981*]. The study of the microstructure was conducted in thin sections of the grounds, which were prepared by cryogenic drying, and with the help of replicas of frozen deposits by the methods of optical and electron microscopy using spectral microanalysis. Thin sections were produced at the National Research Center of Potsdam, Germany.

Results

Microstructure of the ice complex deposits, of facies with both high and low ice content, is characterized by the presence of ring structures which are associated with differentiation of mineral particles by orientation [*Konishchev, Rogov 1985*]. The following primary types of ring formations are observed:

simple formations are composed of mineral fragments, which are radially oriented, distant from each other or have point contacts: fracture-fracture, basal plane-fracture; fissuring of quartz grains was recorded primarily in the fragments exposed to ice schlieren (Figure 1a,b);

complex formations are represented by aggregates of the fragments with clay filler, plant residues and smaller aggregates; the orientation of the grains varies from radial on the periphery to concentric closer to the center of the aggregate; clay particles form envelopes on the fragments surface and fill the pore space; between the grains with the basal plane-fracture contacts wedge shaped pores are distinguished; cementation of the aggregates by iron-silicon and carbonate compounds is observed (Figures 1c, d);

partially destroyed formations with a clay core and concentric cracks, accordant with the structure of the aggregates; the peripheral parts of the aggregates and fragments partially lost their old orientation, i.e. they are captured by the new differentiation (Figure 1e).

Ring structures are volumetric as in the grounds microstructure they are observed in both vertical and horizontal sections; they form single rings or adjoint groups within the larger aggregates (Figure 1f).

The structure of the ring microstructure of the deposits is connected with the development from simple radial forms to concentric complex aggregates. Transformation of the structural bonds in syncryogenic deposits goes from volumetric aggregation contacts [*Microstructure... 1988*] to the point contacts, and then to the most stable bonds: areal coagulative bonds and cementational bonds, up to and including the formation of authigenic minerals (Figure 1g).

Differentiation of fragments and clay particles is determined by the intensity, duration of cyclic freezing and facies conditions. Maximum structuredness of the deposits was recorded in floodplain facies of the ice complex with a high content of aleurites and plant residues.

The structural bonds ensure preservation of ring formations even after the thawing. Ring differentiation of fragments and clay nodules are found in alas deposits, in modern, buried soils and slope deposits of the paleocryogenic area (Figure 1h). Particularities of grounds microstructure can serve as an indicator of syncryogenesis after permafrost degradation.

Acknowledgments

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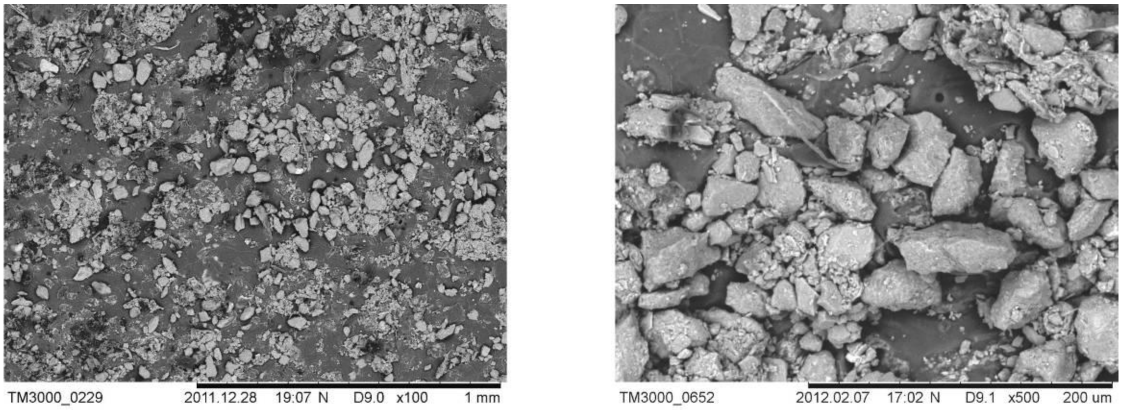
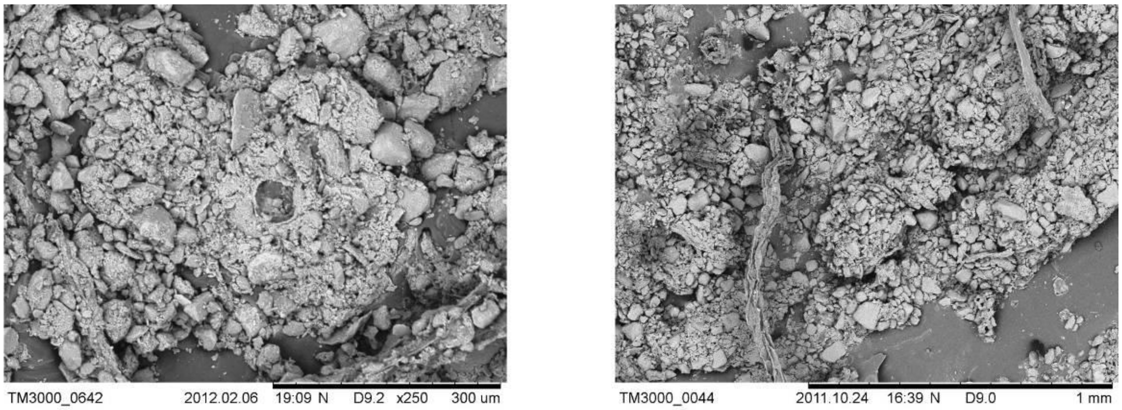
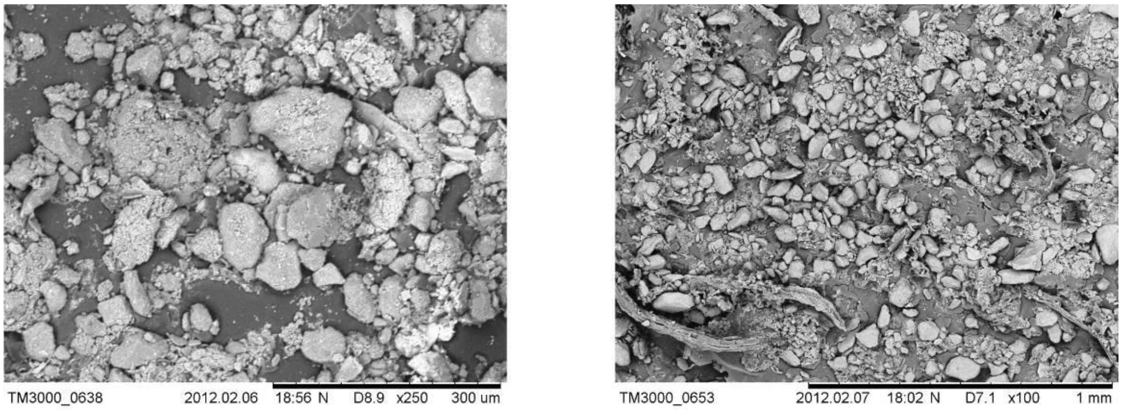


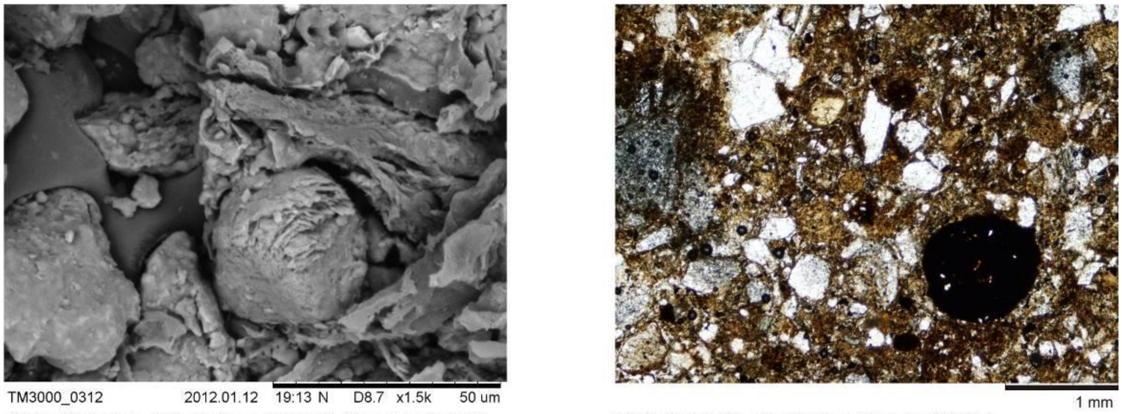
a) Ice Complex, Kolymskaya lowland (*channel facies*) b) Ice Complex, Kolymskaya lowland (*channel facies*)



c) Ice Complex, Kolymskaya lowland (*flooding facies*) d) Ice Complex, Kolymskaya lowland (*flooding facies*)



e) Ice Complex, Kolymskaya lowland (*flooding facies*) f) Ice Complex, Kolymskaya lowland (*channel facies*)



g) Ice Complex, Kolymskaya lowland (*flooding facies*) h) Buried soils, Predbaikal Flexure (*Malta*)

Figure 1. Ring microstructures of the deposits.

Engineering Protection of Pipelines from Hazardous Engineering-Geological Processes in Northern Regions

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When constructing and operating pipelines and along-route in-site facilities in the northern regions, normally it is necessary to develop a project of engineering protection of the territory from hazardous permafrost-ground processes and phenomena initiated by anthropogenic impacts. The situation is complicated by significant variability of engineering-geocryological conditions along the pipeline route (alternation of areas with thawed and permafrost grounds, presence of icy, strongly-heaving and decompacted grounds, etc.) In such situation the quality and volume of accepted technical solutions significantly influence the future material and technical expenses for maintaining the operational reliability of pipelines and along-route in-site facilities.

The project of engineering protection is developed by stages, beginning from the analysis of the facility and ending by selection of specific technical solutions.

Analysis of initial data and classification of engineering-geological conditions of a pipeline route

The preliminary stage when developing a project of engineering protection for pipelines and along-route in-site facilities is an analysis of initial data: terrain profiles along pipelines, plans, reports on geotechnical investigations, data on architectural-building solutions and other documentation.

On the basis of initial data, a pipeline route is classified by engineering-geocryological conditions, with singling out typical geocryological columnar sections. Basic parameters considered in classification determine the impact on the bearing capacity and stability of the pipeline foundation. This is a differentiation of thawed grounds and permafrost, division of permafrost into merging and non-merging, distinguishing the areas of short-term permafrost, taliks, ground ices, sections composed of icy grounds, yielding grounds etc.

At the initial stage a pipeline route is zoned by geomorphological and technological parameters: identification of pipeline sections crossing watercourses, ravines, existing pipelines and motor roads.

The pipeline route is divided into zones, with identification of sections with developing adverse permafrost-ground processes (or potentially hazardous sections).

Development of technical solutions

Based on the results of the aforementioned works of the preliminary stage, a specific package of measures is prepared for reduction or elimination of negative impacts of particular processes, depending on the method of pipeline laying.

Fundamentproekt OJSC developed different technical solutions and measures for engineering protection (including those confirmed by patents) justified by forecast thermotechnical, strength and deformation calculations as well as by operation experience intended for ensuring stability and operational reliability of underground and above-ground pipelines and along-route in-site facilities affected by a wide range of hazardous processes such as erosion and thermoerosion, landslides, rock glaciers and solifluction, cryogenic heave of grounds, thermokarst, swamping, underflooding etc.

A wide range of technical solutions used for engineering protection of underground pipelines and along-route in-site facilities in different geomorphological and geocryological conditions includes the following basic measures that are required most often:

- Surface drainage (including multi-level water drainage at along-route in-site facilities with construction of motor ways depressed below grade, in-site storm sewage system and out-site drain ditches) with the use of trench drains and ditches having various configurations and mounted with the help of different materials, such as geogrids, flexible concrete mats (UGZBM), electric-welded longitudinal seam steel pipes and drainage mats.
- reinforcement pipe sections laid in river beds and flood plains at the intersections of watercourses, using different anti-erosion materials, such as spatial geogrids and flexible concrete mats;
- protection from surface erosion and suffosion processes in backfill grounds of pipeline trench, using geotextile materials and recultivation materials, for example, biomats;
- thermal stabilization of foundation grounds of underground pipelines at intersections thereof with existing pipelines transporting high-temperature products. Thermal stabilization measures employ different types of seasonal cooling systems as well as heat-insulation materials. Frozen-ground barriers are made for protection from underflooding by intrapermafrost ground waters.

Conclusions

Engineering and geological conditions in the northern regions are characterized by diversity and variability, therefore there is no universal system for development of engineering protection projects. Each project is developed individually for a specific region with its geocryological, geological, climatic and other peculiarities.

The main task of engineering protection is to preserve natural water-and-thermal balance of the area. The measures considered above make it possible to perform this task and ensure stability and bearing capacity of foundation grounds of pipelines for the entire operation life. They are economically efficient, reliable and environmentally safe.

It is quite necessary to develop an efficient network of geotechnical monitoring with manual or automated measurement method for each specific case. For the periods of construction and operation of pipelines and along-route in-site facilities the territory must be equipped with a necessary quantity of elements (thermometric wells, hydrogeological wells, ground deformation benchmarks, etc.) for monitoring of facilities and prevention of emergencies.

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A Satellite Based Monitoring Scheme for Lowland Permafrost – Potentials and Uncertainties

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Abstract

In this study we present an operational permafrost monitoring scheme using a multi-satellite approach in combination with a transient permafrost model. The created forcing dataset and the model results are intensively validated against long term observations at a tundra site in the Lena River Delta in Siberia. The first results show that operational permafrost monitoring with reasonable accuracy is possible based on a joint dataset of multiple remote sensing products. However, severe limitations are caused by uncertainties in the parameterizations of the soil and snow thermal properties. The assimilation of further satellite products such as surface moisture from synthetic aperture radar (SAR) might help to reduce these uncertainties of subsurface parameterizations.

Introduction

Satellite based earth observation became an indispensable tool for the investigation of climate change especially in remote areas such as the Polar regions. For most of the cryosphere components such as glaciers, ice sheets, and sea ice, satellite monitoring and change detection is well established since several decades. For permafrost, however, which represents the largest component of the Arctic cryosphere operational satellite monitoring schemes do not exist so far. One of the biggest challenges for a satellite based monitoring is that permafrost is a subsurface thermal phenomenon which cannot be directly observed by remote sensing techniques. Nevertheless, an operational scheme for satellite observation of permafrost temperatures and the freeze and thaw dynamics of the upper ground layer (active layer) would be highly beneficial for Arctic research. This is especially true for active layer monitoring of wet tundra landscapes where large amounts of carbon are stored which might be exposed to microbial decomposition with increasing thaw depths.

Methods

In this study we present a possible permafrost monitoring scheme based on a numerical heat flow model which is forced by multiple satellite products and initialized by weather reanalysis data. The used forcing and initialization dataset includes the land surface temperature (LST), the snow cover albedo, and the snow water equivalent (SWE). For the temperature forcing we make use of the MODIS LST products MOD11A1v5 and MYD11A1v5 which deliver daily surface temperatures at a spatial resolution of about 1km. For the evolution of the snow cover we use the daily GlobSnow SWE product with a spatial resolution of about 25 km. In addition, the MODIS snow cover products MOD10A1v5 and MYD10v5 are deployed in order to cope with the scale differences between the LST and SWE datasets. We use the additional snow product to infer the timing of snow cover accumulation and ablation at the target resolution of 1km. Although the obtained forcing dataset spans from 2002 until today, it is not long enough to reach stable temperature conditions in the deeper soil layers. Hence, we use a model spin-up period from 1979 until 2002 forced by ERA-interim weather reanalysis and GlobSnow data.

The proposed monitoring scheme is extensively tested at a typical wet tundra permafrost site in the Lena River Delta in northern Siberia. The forcing data and model results are compared to field measurements of surface temperature, snow depth, permafrost temperature profiles, and active layer depth.

Preliminary results and outlook

The main focus of this study is on model uncertainties in the annual freeze-thaw dynamics of the active layer, as well as on the long-term evolution of the permafrost temperatures. Our results indicate that active layer dynamics and long-term permafrost temperature evolution can be sufficiently reproduced by the proposed scheme, if the thermal properties of the ground and snow cover are well known. However, the performed sensitivity analysis shows that the largest uncertainty in active layer dynamics are introduced by uncertainties in soil water/ice content whereas the evolution of the permafrost temperatures are mostly affected by uncertainties in the evolution of snow depth and the snow thermal properties. The results of this study clearly demonstrate that multi-satellite and weather reanalysis data can be joint to a forcing and initialization dataset which features reasonable accuracy for the operational use in permafrost monitoring. However, the parameterization of the thermal properties of soil and snow are still subject to large uncertainties which strongly limit the accuracy of permafrost monitoring. The assimilation of further satellite products such as surface moisture from SAR might help to overcome some of the actual limitations of parameter dataset.

Arctic Coastal erosion: A review

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Instructions

Arctic permafrost coasts are known to make up a third of the coasts of the Earth and to undergo large erosion rates [*Lantuit et al., 2011a*]. This erosion bears considerable threats for Arctic coastal infrastructure, planned or existing, and could result in the alteration of the coastal food web through the release of large quantities of organic carbon and nutrients to the nearshore zone [*Forbes et al., 2011*].

Our knowledge of Arctic coastal erosion is often constrained by the capacity of research teams to collect information over several decades at the same location, which is necessary to capture the inter-annual variability of the process and establish significant trends. Lantuit et al. [*2011a*] published a database with data on coastal erosion for close to 100 000 km of coast in the Arctic (25% of the total length of the Arctic permafrost coastline), but the rates of erosion were generally computed for one time period only, which limits the use of the dataset to look at temporal trends of erosion. In this paper, we look at publications released over the past six years on coastal erosion to provide a circum-Arctic update on rates of erosion and on process knowledge.

Methods

We collected, inventoried and analyzed all publications on Arctic coastal erosion published since 2007. The goal was to encapsulate the knowledge gained on the topic since the last international conference on Permafrost in Fairbanks, in June 2008.

We focused our analysis on two main aspects:

1. Temporal trends of coastal erosion
2. Process knowledge

Temporal trends were retrieved from publications computing coastal erosion rates over long periods of time, either through the means of remote sensing imagery [*e.g. Jones et al. 2009*] or through the means of field surveys.

Process understanding was subdivided in several themes that were explored over the pas six years (including link between erosion and environmental forcing; role of subsea permafrost; role of sea ice and water temperature; release of organic carbon and nutrients to the nearshore zone)

Results and conclusion

Coastal erosion rates

The number of publications of the topic increased dramatically during the period of study compared to the one leading up to the Ninth International Conference on Permafrost in Fairbanks. The trends have described very different patterns, depending on the location along the Arctic rim, highlighting the local nature of erosion, as highlighted by Lantuit et al. [*2011a*]. While some section of coasts have seen dramatic increases in the rate of erosion, possibly coupled to the loss of summer sea ice [*Jones et al., 2009; Overeem et al., 2011*], some other locations have not yet seen these kind of increase [*et al., 2011b*]. Despite the increasing availability of very high resolution remote sensing, the number of temporal series is still too small to produce a representative subset of coastline and create temporal trends at the Arctic level.

Headings

Over the same time period, several authors have made breakthroughs in the study of the erosion process, either by linking it to environmental forcing [*e.g. Overeem et al., 2011*] or by looking at specific processes, such as block failure [*Hoque & Pollard, 2008*]. The coordination of activities in the International Permafrost Association and the level of awareness prompted by the release of the State of the Arctic Coast 2010 report [*Forbes et al., 2011*] will without a doubt help to gain new knowledge on coastal erosion processes over the next five years.

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Disturbance Recovery Monitoring of Tundra Vegetation by Saline Incursion from an Oceanic Storm Surge within a Freshwater Arctic Delta using Landsat

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Oceanic storm surge impacts on coastal Arctic ecosystems

Coastal freshwater deltas are unique ecosystems found within the Circumpolar Arctic. These features are important transition and exchange sites for terrestrial, oceanic, and atmospheric biospheres. They are also environments predicted to be largely at risk to climate change. Sea level rise and increased storminess are two change agents predicted to have significant impacts along Arctic coastlines [*Manson & Solomon 2007*]. These events are of great concern because they pose major risk to both human and ecological systems.

Oceanic storm surges present the greatest ecological threat by means of saline water inundation. The incursion of seawater onto a terrestrial ecosystem dominated by freshwater plant species severely disturbs the surrounding vegetation communities and creates abrupt changes in the chemical and biotic structure of neighboring waterbodies.Vegetation recovery largely depends on the capability of the system to expel enough salt to restore pre-disturbance soil concentrations. These events become severe when post-disturbance regeneration of impacted areas take decades to millennia to occur, causing the region to become a prolonged ecological dead zone. As destructive as these events can be, the ecological impacts associated with oceanic storm surges are some which few have investigated.

Storm surges within the outer Mackenzie Delta, NWT Canada

The Mackenzie Delta, NWT Canada is one of the most ecologically important deltaic systems within the Circumpolar Arctic (Figure 1). The warm nutrient rich waters of the Mackenzie River have evolved the delta into a freshwater tundra wetland comprised of vegetation found beyond their normal latitudinal limits [*Walker 1998*]. This unique landscape has become key breeding and wintering habitats for ungulate and avian species (e.g. reindeer (*Rangifer tatandus tarandus*) and tundra swans (*Olor columbianus*)), as well as resident fauna like moose (*Alces alces*) and polar bears (*Ursus maritimus*).

An oceanic storm surge occurred within the outer Mackenzie Delta in late September of 1999. The event impacted 350 km^2 of terrestrial vegetation extending as far as 30 km onshore. Over a decade later, tens of square kilometers continue to scar the landscape with vast and persistent vegetation mortality. For a region as ecologically significant as the Mackenzie Delta, the loss of essential food, migration and nesting resources for local and migrating species will be of a momentous consequence.

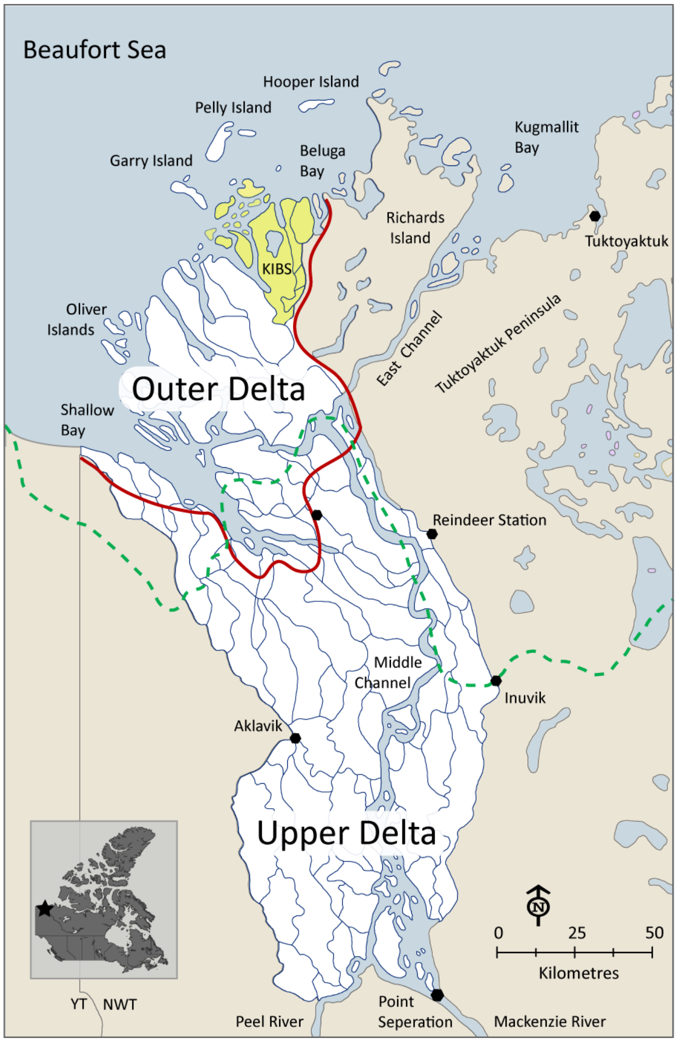

Figure 1. Mackenzie Delta, NWT Canada. The 1999 oceanic storm surge extent boundary is outlined in a solid line. The Low Arctic ecozone treeline boundary is outlined in a dashed line and is defined as the geographical limit of black and white spruce (*Picea mariana* and *P. glauca*). Kendall Island Bird Sanctuary (KIBS) national ecological preserve was not included in this assessment.

Landsat use in Arctic ecological studies

Satellite-based Remote Sensing (RS) has proven to be an invaluable tool for the characterization and monitoring of vegetation changes within the Arctic. Landsat is an optical satellite RS system with instrumentation specific to assessing various aspects of terrestrial vegetation. The release of the Landsat archive by the U.S. Geological Survey in 2009 has allowed the scientific community to perform multi-temporal ecological studies throughout the world at no cost to the user.

Optical satellite imagery from Landsat was used to map and quantify changes in vegetation within the outer Mackenzie

Delta from 1972 to 2010. Normalised difference vegetation index (NDVI) was used as the biophysical indicator to calculate temporal and spatial changes within the study area. Temporal changes in NDVI were identified using a newly developed spectral trajectory algorithm called LandTrendr [Kennedy et al. 2010]. These trajectories were then characterised into a disturbance or vegetation growth event of either a short or long-term duration. Spatial changes were assessed through the recreation of past land cover classification maps. The establishment of 39 consecutive land cover maps for the region was completed through the creation of a backdated time series.

Vegetation monitoring and recovery from storm surges

Both the land cover map time series and LandTrendr found only one event that produced a broad extent, high magnitude change in vegetation within the outer Mackenzie Delta between 1972 and 2010. Apart from the 1999 disturbance event, landscape-level vegetation changes seen to have occurred throughout this assessment were largely found in small patches of ± 10 pixels (9,000 m^2), had no temporal pattern and were concentrated around water bodies. Although changes were identified in NDVI throughout the entire study area each year, a majority of the detected change was determined to be of a magnitude too small to cause a shift in the main vegetation community composition (i.e. land cover type conversions). The small amount of land cover conversion observed within the outer delta prior to the 1999 storm surge event indicates the ecological stability of the region on a landscape scale.

Just over 50% of the area impacted by the 1999 storm event was found to have returned back into a land cover similar to that before the disturbance occurred. These areas had a strong correlation with the proximity of water bodies connected to active water channels. Over 200 km^2 of the area still remains dead or in a state of low vegetation productivity. Within areas identified by Landsat as dead, field surveys conducted in 2010 found limited amounts of revegetation to be occurring. However an estimated recovery time back into an ecologically functional land cover is still unknown. There is the possibility that areas of persistently low recoverability could maintain this habitat modification permanently.

This research provides a foundation in the evaluation of oceanic storm surge impacts on freshwater vegetation in Arctic coastal deltaic systems. It also shows how Landsat digital satellite imagery can be applied to create annual change assessments for use in long term ecological studies. With sea ice free Arctic summers predicted as early as 2040 [*Holland et al. 2006*], larger and more frequent storm surges are becoming a great possibility within the western Beaufort Sea. If the ecological impact observed within the outer Mackenzie Delta is an indication of future landscape changes resulting from oceanic storm surge events, there needs to be a strong effort placed into the complete understanding of these change agents.

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Latest Pleistocene permafrost structures in the southwestern West Siberian Plain

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Abstract

Numerous zones of polygonal pattern have been revealed in deciphered satellite images of southwestern West Siberia within 57°12' to 53°55' N and 62°56' to 75°20' E. The polygonal pattern is especially prominent in images shot in fall or spring seasons at sites occupied by tillage in the time of observations. The polygonal pattern appears to control the river network in some images.

Keywords: Ice-soil wedge cast; permafrost, polygonal pattern.

Introduction

It has been proven many times, independently by different methods, that permafrost in the northern West Siberian Plain joined the mountain permafrost of Kazakhstan during the last Pleistocene glaciation [*Fotiev 1978, Aubekerov 1990, 1992, Balobaev 1991, Arkhipov & Volkova 1994, Gorbunov et al. 1998, etc.*]. At theta time, permafrost was continuous as far as 47° N and sporadic only south of this latitude. However, the cited publications contain few descriptions of permafrost structures, especially in the southwestern West Siberian Plain. In this respect, traces of permafrost we observed in the summer of 2011 in the Kurgan and Tyumen regions south of 56°40' N may be of interest.

Note first of all that the studied part of southwestern West Siberia is very poorly exposed. Therefore, permafrost can be traced mainly as a polygonal pattern in satellite images. Numerous zones of polygonal pattern are detectable in images of the territory within 57°12' to 53°55' N and 62°56' to 75°20' E (much larger than the area we explored). The polygonal pattern is especially prominent in the images shot in fall or spring seasons at sites occupied by tillage in the time of satellite recording. It appears as patches of polygonal ground with mostly square polygons. The blocks in the polygonal pattern are as large as about 80 m near Gorkoye Lake (southern Kurgan region). The pattern of blocks and depressions (kettles) near Krutali Lake resembles bulge-framed polygons. The depression that currently accommodates the lake may be a remnant of a latest Pleistocene alas. The topography in the northeastern side of the lake consists of elongate blocks. The present lakes in the area occupy depressions between the blocks and possibly follow kettle holes. The blocks reach sizes of 60-70 m in the northwestern side of Krutali Lake. Satellite images of the lake sides, as well as other areas we studied, sometimes show the river networks to follow the polygonal topography features. Note that earlier reports from southwestern West Siberian Plain were of a polygonal pattern with rather small blocks [*Aubekerov & Chelykhyan 1974*] (8-10 m or less often up to 22-40 m). However, Gorbunov et al. [*1998*] described polygons as large as 70 m in the Turgai plateau, about 51°15' N, presumably of a Late Pleistocene age. Therefore, the 80-m or larger polygons we saw in the satellite images in the Tobol catchment and in the Ishim-Tobol interfluve are not unusually large. Because of continuous vegetation, we could find only one cast of an ice-soil (primary soil?) wedge in trenched walls of an abandoned quarry at 55°11'12" N, 64°59'58" E. The cast provides reliable evidence of permafrost in the first terrace above the Tobol River floodplain.

Acknowledgments

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The Consequences of the Non-Presence of Pre-Construction and Construction Stages in the Geotechnical Monitoring System at the Gas Field Facilities of the North

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Gas transmission facilities and accompanying infrastructure facilities of the "Bovanenkovo - Ukhta" pipeline are constructed in geocryological conditions of unprecedented complexity. Experience in the construction of large industrial facilities in such complex engineering and geocryological conditions does not exist in the world practice. In this regard, it becomes especially important to monitor the dynamics of geocryological conditions in foundation grounds and the stability of buildings and structures during construction and operation for the purpose of timely identification of destabilization processes; to develop and implement measures for their prevention as well as to gain experience in the field of construction and operation of bases and foundations in especially difficult geocryological conditions.

The construction and subsequent operation of the pipeline in the cryolithozone will lead to formation and intensification of geocryological processes developing in grounds both in the area of direct interaction with the pipeline, and in the area adjacent to it that was disturbed due to the pipeline construction. These processes may have a significant impact on the performance of a pipeline and cause its accidents. They may also disrupt the ecological sustainability of the natural geocryological environment.

However, the patterns of anthropogenic dynamics of natural and technical systems in different environments are still poorly explored. The knowledge of these patterns is crucial for composing scientific rationale of stabilization prognosis and for restoration of the engineering and geocryological environment. Organization and a constant monitoring system (engineering and geocryological monitoring) are necessary for ensuring the stability and safe operation of gas pipelines in such difficult engineering and geocryological conditions. But the current practice of monitoring usually reduces to the control of the state of the pipe itself, practically ignoring the natural conditions of its laying and their changes during construction and subsequent operation.

The composition, volume, and regime of works conducted within the framework of geotechnical monitoring must ensure completeness of information enabling continuous complex diagnostics of a gas transportation system and enabling timely detection of deviations from the project design, construction norms and regulations that may entail a reduction in operational reliability of the facilities, accidents and a damage to the environment.

Engineering and geocryological monitoring is an integral part of environmental monitoring that aims at a comprehensive assessment of changes in the atmosphere, hydrosphere, biosphere and geological environment.

When creating and maintaining engineering and geocryological monitoring, it is important to consider the main engineering solutions to the specific structures adopted in the project: the principle of using permafrost as a foundation ground; particularities of thermal and mechanical interaction with the foundation grounds; acceptable values of bearing capacity of the foundation and deformation of facilities; environmental requirements, etc.

Engineering and geocryological monitoring should be initiated at the pre-construction stage when monitoring network for the background assessment of the geocryological situation is formed. The results of monitoring during this period serve as source data for assessing the changes that will occur during the construction and operation of a geotechnical system. During the construction period, a monitoring network is organized and observations at the facilities under construction are conducted.

Depending on the particularities of territories development and on varying degrees of impact of technogenic load in time, the operational period can be subdivided into two stages: the initial stage that lasts for 3-5 years and the main stage starting from 3-5 years and lasting up to the end of the facility operation. At the initial operation stage, interaction between the building and the environment is the most active, and therefore significant changes in geocryological situation as well as deformations of structures may occur. After 3-5 years of operation of facilities, there occurs a relative dynamic equilibrium in the "structure – natural environment" system, or the necessary measures for maintaining the stabilization of the natural environment and the structure stability are taken over this period of time [*Ershov 2002*].

In general, gas transportation through an underground pipeline will be carried out at negative temperatures. One of the important features of the "Bovanenkovo-Ukhta" gas main is that it will cross the waters of Baydaratskaya Bay over the area with the width of about 70 km. In order to eliminate the possibility of pipes icing and their ascent from the bottom of the bay, gas transportation in this area is planned to be conducted at positive temperatures. Gas heating and cooling will take place at compressor stations located on both shores at the distance of up to 3 km from the waters of Baydaratskaya Bay. The coast of Baydaratskaya Bay is characterized with complex geocryological conditions.

As a rule, exogenous geological processes in the study area are of cryogenic origin and are developed quite extensively. At the same time, in natural conditions, in terms of the planned construction of pipelines, the degree to which the territory is affected with cryogenic processes and the genetic diversity of these processes are relatively low. However, in the course of technogenic transformation of the territory, rapid activation of many exogenous processes is possible (Fig. 1).

Figure 1. The erosion of sandy silt grounds of the seasonally thawed layer upon removal of the peat layer

On the territory itself the following processes are widespread: frost heaving, frost cracking and polygonal wedge ice development as well as thermokarst and deflation. Poorly distinct forms of thermal erosion and solifluction are observed in some areas. On the adjacent territory of the sea coast, the following processes are added to the ones listed above: wave action thermal abrasion and active formation of developed forms of gully thermal erosion.

Despite its uniqueness, the Bovanenkovo-Ukhta gas pipeline project does not involve the organization of monitoring at the pre-construction and construction stages, which will subsequently make it difficult to operate. The monitoring system of the Bovanenkovo-Ukhta pipeline is created for the operation period. However, despite such widespread development of adverse factors, the following facts are absolutely groundless: the thermometric wells network is not arranged according to the determined conditions, but only mechanically according to a grid; snow survey is not taken into account at all; besides, the pipeline is leveled also according to a "grid". Observations of exogenous geological processes and phenomena are not provided for.

According to the geotechnical monitoring service of Vorkuta linear production management of gas mains, active deve-lopment of exogenous geological processes and phenomena is currently observed along the construction strip, even before the beginning of operation. In the future, this will lead to hazardous situations or accidents similar to those that occur in the pipelines of Western Siberia.

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The Subdepartment of Cryosphere at Russian State Geological Prospecting University

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Abstract

Permafrost occupies more than 65% of the Russian territory, the least explored northern and eastern areas. These are undeveloped or poorly developed lands expected to become prospecting and exploration targets as they store rich mineral and petroleum resources which make the basis of the today's economy of Russia. Currently the production, transportation, and social infra-structure is already being created in those areas, and hydraulic facilities are being built. Thus, specially trained people are wanted for research and engineering, as well as for exploration in hard or often extremely hard geological and mining conditions of permafrost. There is urgent need for a separate university subdepartment which could provide this kind of training, along with background cryological education for students in all geological and mining specialties. This is the reason why a subdepartment of Earth's cryosphere is being founded at the Department of Hydrogeology of Russian State Geological Prospecting University (MGRI-RSGPU).

Keywords: Geocryological education; permafrost; permafrost zone; subdepartment of Earth's cryosphere at MGRI-RSGPU.

Mining has made a large portion of the Russian national economy for the past 30-35 years, while for the two recent decades it has been from the resources explored before 1990. The resources are being very little replenished, mostly from the periphery of the known deposits. Many deposits are almost fully depleted. Rapid recharge of the developed resources has been demanded or will be demanded soon, which means broadening of mineral and petroleum exploration.

Permafrost occupies more than 65% of the Russian territory, its least explored northern and eastern lands. Therefore, most of exploration is expected to be in permafrost, i.e., in undeveloped or poorly developed terrains. Currently the production, transportation, and social infra-structure is already being created there.

Thus, specially trained people are required to run exploration in hard or often extremely hard geological and mining conditions of permafrost. There is urgent need for a separate university subdepartment which could provide this kind of training, but solving the problem is being put off ever farther as a result of significant reduction of prospecting and exploration projects that began in the 1980s and has been only aggravated in the 2000 through 2010s.

Since the amount of explored resources has been diminishing, the necessity for such a subdepartment at Russian State Geological Prospecting University (MGRI-RSGPU) becomes ever more obvious. In 2011, a decision was made to found a subdepartment of Earth's cryosphere, on the initiative of V. Melnikov, director of the Earth Cryosphere Institute SB RAS (ECI SB RAS), V. Lisov, rector of MGRI-RSGPU, and professors E. Kozlovsky, V. Pendin, L. Bobrovnikov, and others. The original idea was to create an inter-department structure where to carry out a large amount of research with participation of undergraduate students and to teach the following disciplines: fundamentals of Earth's cryogenesis; historic geocryology; permafrost-related processes; physicochemical properties of rocks and ground ice; mechanics of frozen soils and groundwater in the permafrost zone; permafrost surveys and prediction; permafrost monitoring; permafrost engineering geology (geo-ecology); global change, responses of permafrost, and consequences for the environment; geophysical methods of exploration in permafrost; permafrost landscapes. It was planned that university professors and even more experts from the Earth Cryosphere Institute SB RAS, *Fundamentproekt* Association, Moscow University, and other academic, R&D, and educational institutions will be giving the lectures. Obviously, to master the courses, students have to be already familiar with tectonics, lithology, Quaternary geology, etc., i.e., the courses are designated to four- or five-year students. Unfortunately, no subdepartment of this kind has been founded yet.

The subdepartment of cryosphere has been formally created but as part of a department rather than as an inter-department body. Hence, the professors have high teaching loads, and neither large research work nor broad involvement of students are possible. Furthermore, one course was given to second-year students without preliminary training, which made unfeasible teaching any of the eleven courses listed above. The course "Fundamentals of Earth's cryosphere" was already given, for one semester, to second-year students but it included only some of the listed disciplines which were severely reduced. On the other hand, it took much time and efforts, to the prejudice of the principal course, to explain the issues of Quaternary geology indispensable for understanding the permafrost issues. Experts from academic institutions had to be recruited even for the reduced courses.

It is hardly feasible to complete setting up all eleven courses in two or three years: preparing the programs takes quite a lot of time and some pilot versions may be needed. The subdepartment of permafrost studies has just begun working and there is still an opportunity to discuss and, possibly, correct the teaching plans, which are not yet rigorous and are open to specifying and updating.

Exploration and mining have been successfully run for many decades in the Russian permafrost zone. The large experience gained through that work is reported in thousands of publications and synthesized in various regulations. However, people have to handle this material without solid educational background. The goal of the subdepartment of Earth's cryosphere is to provide MGRI-RSGPU students with basic knowledge making them ready to face problems related to work in permafrost conditions.

Learning permafrost has been included into curricula of many higher educational institutions of Russia. The courses have practical applications in construction engineering and give a lot of attention to prediction of the permafrost state for the nearest two or three decades (more rarely for longer periods), a span commensurate with the payback time of engineering structures. This approach is important for construction, as well as for mining, though the latter has its specificity. However, exploration concerns more with the present state of frozen ground and the permafrost setting on the regional scale (or locally at the sites and during the period of works), rather than with predictions. Exploration is often run likewise on the periphery of the developed deposits. In these cases, it is important to be aware of changes that result from the effectuated development. This necessity is especially evident in the case of petroleum pipelines. The costs for pipeline maintenance and repairing the permafrost-related deformation amount to 55 billion rubles annually, which is far more expensive than remediation after any natural disaster. This is not because permafrost would be so insidious but rather because the knowledge of it is insufficient, or more often because no due regard is made for its spatial changes and high vulnerability as an environment system.

In the course of drilling, one has to take into account the effect of freezing soil on alien inclusions and elements of engineering structures, including well tubes. Accumulations of gas and condensate in permafrost may be a source of high gas release while drilling and operation of wells. These features of perennially frozen soil, as well as many other exploration-relevant issues, often receive little attention in the courses given at the mentioned educational institutions.

Acknowledgments

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Permafrost in the Community Earth System Model: Present-day and projected permafrost conditions and feedbacks onto global climate

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Earth System Models (ESMs) project that Arctic warming will continue and potentially accelerate during the 21st century under various scenarios of continued anthropogenic greenhouse gas emissions. Ecological model studies suggest that the interplay of snow season length, soil thaw and growing season will govern the carbon balance in high latitudes [*Euskirchen et al. 2006*], yet the present generation ESMs typically fall short of capturing the full range of hydrological, ecological and biogeochemical feedbacks that can occur as soils thaw and permafrost degrades. This is relevant because it is thought that on balance these feedbacks are positive and therefore would act together to amplify Arctic and global climate change [*see McGuire et al. 2006 for review*]. The biggest concern and biggest unknown is the degree of vulnerability of the large and historically inert permafrost soil carbon pool that could be exposed to decomposition as permafrost thaws [*Schuur et al. 2008*] and the role that permafrost thaw will have on local hydrological conditions which strongly control the fate of the freshly thawed carbon.

Consequently, an improved and more expansive representation of permafrost and its vulnerability along with associated feedbacks that could be instigated by permafrost degradation or changes in seasonally frozen ground is an important challenge for climate change science. Until recently however, relatively little specific effort has been made to incorporate permafrost dynamics and permafrost related feedbacks into ESMs [*Riseborough et al. 2008*]. Incorporating and improving permafrost dynamics in ESMs is not only required to improve the fidelity of climate projections in general, but also will provide an additional powerful tool that can be used to increase our understanding of the complex interactions between terrestrial cryospheric change and Arctic and global climate.

CCSM4 and CLM4

The Community Climate System Model (CCSM4/CESM1) is an earth system model consisting of individual models of the atmosphere, land, ocean, and sea ice that are coupled together. An overview of CCSM4 and its performance relative to CCSM3 is provided in Gent et al. [*2011*]. The land component of CCSM4 is CLM4 [*Lawrence et al. 2011*]. Biogeophysical processes simulated by CLM include solar and longwave radiation interactions with vegetation canopy and soil, momentum and turbulent fluxes from canopy and soil, heat transfer in soil and snow, hydrology of canopy, soil, and snow, and stomatal physiology and photosynthesis. CLM4 includes a 5-layer snow model which simulates processes such as accumulation, melt, compaction, snow aging, and water transfer across layers and also considers the radiative impact of aerosol deposition onto snow. Improvements to CLM that were included in CLM4 that were specifically aimed at improving the representation of permafrost in CCSM4 include an extension of the ground column to a depth of ~50 m by adding 5 bedrock layers below the original 10 soil layers [*Lawrence et al. 2008*] and an explicit accounting of the thermal and hydrologic properties of organic soil [*Lawrence & Slater 2008*], which due to the insulating properties of organic soil tended to cool the soils across much of the organic rich Arctic. Heat conduction in the soil is determined by numerically solving the second law of heat conduction equation which requires the volumetric heat capacity and the thermal conductivity. The thermal and hydrologic properties of each soil layer are functions of soil liquid and ice water content, soil texture (sand, silt, clay, organic), and soil temperature. The boundary conditions for the solution of the heat conduction equation are the heat flux into the soil/snow at the top and zero heat flux at the bottom of the soil column. Heat advection associated with water infiltrating into and through the soil is not considered.

CMIP5 Experiments

The CCSM4 simulations include five member ensembles of historical (1850 to 2005, referred to as 20th century) and future (2006 to 2100, referred to as 21st century) simulations. The 20th century simulations are described and assessed in Gent et al. [*2011*]. For the 21st century simulation, ensembles were completed for four different Representative Concentration Pathways (RCPs). The atmosphere and land resolution for these simulations is 0.9375° latitude x 1.25° longitude.

Results and Summary

The combined impact of improvements to CLM and a more accurate climate simulation improve the representation of the permafrost in CCSM4 compared to CCSM3. Though evaluation of the permafrost simulation is limited by the availability of observations and the scale mismatch between point measurements and grid cell quantities, comparisons of model data against available observations indicate improvements in the permafrost distribution, active layer thickness, and permafrost temperatures (Figure 1 [*Lawrence et al. 2012*]). The area containing near-surface permafrost is projected decline substantially during the 21st century in CCSM4. The rate of degradation, however, is slower by about 35% during the first half of the 21st century in CCSM4 than it was in CCSM3 due to improved soil physics. Under the highest emission scenario (RCP8.5), the majority of present-day permafrost is projected to undergo significant active layer deepening and permafrost degradation. The total projected loss of near-surface permafrost from the end of the 20th century to the end of the 21st century is

9.0 million km^2 . Under the low emissions pathway (RCP2.6), the projected near-surface permafrost area contraction is much less severe (loss of 4.1 million km^2) and the permafrost state effectively stabilizes by 2100 in response to a stabilizing climate. This result implies that the permafrost-carbon feedback could be largely constrained if a low enough emissions pathway is followed.

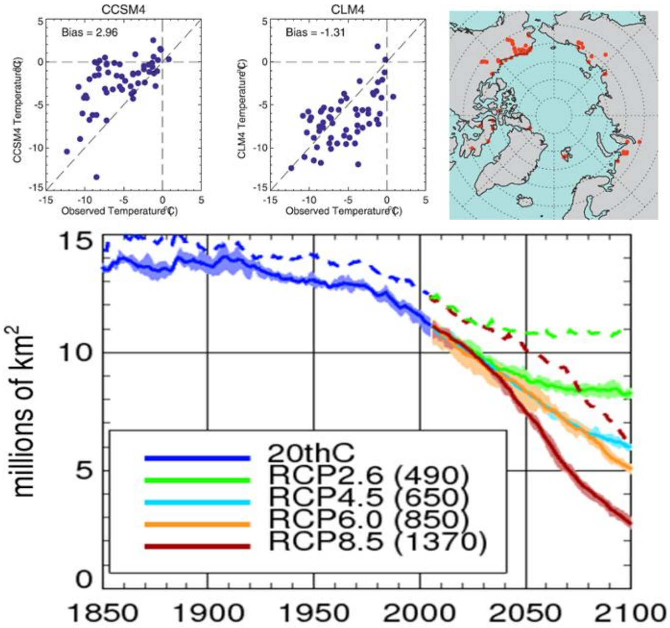

Figure 1: Upper panels: Scatter plot of deep ground temperature for borehole sites (observed) versus model for CCSM4 and CLM4. Lower panels: Time series of Northern hemisphere near-surface permafrost extent for CCSM4 for historical and projection periods. Near-surface permafrost extent is the integrated area of grid cells with at least one soil layer within the top 3.8m that remains frozen throughout the year. Frozen ground underneath glaciers is not included. The greenhouse gas concentration in CO_2-equivalents (ppm) for the year 2100 are listed in parentheses for each SRES and RCP scenario. Shading indicates the ensemble spread. Dashed lines show near-surface permafrost area from an offline CLM4 simulation forced with bias-corrected (for T, P, solar radiation) CCSM4 data from a single ensemble member.

Although there is a general improvement in the simulated terrestrial Arctic climate in CCSM4, the remaining biases are substantial and these biases degrade the permafrost simulation, as evidenced by the poorer agreement with observations of permafrost distribution, active layer thickness, and permafrost temperature in coupled CCSM4 versus offline CLM4 simulations. When CLM4 is forced with CCSM4 data that has been corrected to remove the CCSM4 climate bias, the present-day permafrost temperatures are cooler, better matching borehole data. For the RCP8.5 emissions scenario, the bias correction leads to ~29% less contraction of near-surface permafrost extent than in the corresponding CCSM4 simulation. The substantial difference in permafrost projections in the biased and de-biased simulations suggests that a further reduction of Arctic climate biases should be a high priority for the CCSM development community.

Permafrost degradation of the magnitude simulated in CCSM4 is likely to initiate several hydrological, biogeochemical, and ecological feedbacks in the Arctic system that remain poorly represented in CLM and CCSM specifically and global land and Earth System models in general. The broad scientific challenge is to increase our understanding and representation of the complex hydrological, biogeophysical, and biogeochemical feedbacks that are anticipated in the Arctic. Progress on several of these fronts is being made. The CLM and CCSM development community are focusing on advances in land model biogeophysics (e.g., prognostic wetland distribution, dynamic vegetation, cold region hydrology, sub-grid scale permafrost, thermokarst) and biogeochemistry (vertically resolved soil biogeochemistry, aerobic versus anoxic decomposition, CH_4 emissions) as well as the CCSM representation of Arctic climate, all of which are required to better represent the impact of climate change on permafrost and the feedbacks of permafrost degradation on regional and global climate.

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Modeling Permafrost Thaw Effects And Thermokarst Parameterization In The Community Land Model

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Introduction

In the past century, high latitude ecosystems have undergone drastic changes due to global scale warming. Earth System Models project that Arctic warming will continue and potentially accelerate during the 21st century. Recent advances in the Earth System Models put an effort into accurately representing permafrost, thermal and hydrologic properties of organic soil, biogeochemical cycles, and Arctic vegetation succession [*Lawrence et al., 2008*], the current representation of cold region hydrology is inadequate to predicting the ecological changes in the Arctic in regards to permafrost [*Lawrence et al., 2011*].

One aspect of Arctic warming lies in thawing of permafrost and carbon stored in permafrost. Recent estimates suggest about 1672 Pg C exists within the 300 cm depth, including the deeper yedoma soils [*Schuur et al., 2008*]. This new estimate of permafrost carbon compares to approximately 33-44% of the total global soil carbon stock and over twice more carbon stored in the atmosphere. In ice-rich permafrost areas, permafrost thaw can be followed by subsiding of land surface due to melting of ice wedges and lenses that formerly sustained the ground surface known as thermokarst. Thermokarst and permafrost thaw effects can create large alteration of surface hydrology and ecosystem function including ecosystem carbon cycling. When it occurs on a large scale, thermokarst can expose stable old carbon buried in the permafrost zone and change previously known carbon sink permafrost zone to a large carbon source [*Schuur et al., 2009*]. Therefore, in order to accurately predict the fate of permafrost carbon under future projections of climate warming, adequate representation of permafrost thaw effects need to be included in the Earth System Models.

Here, we report an improvement to the Community Land Model that expanded the model's capacity of capturing permafrost thaw and thermokarst effects on the arctic land surface to improve hydrology and biogeochemistry in the arctic system. We also show details of how we parameterized permafrost thaw and thermokarst in the model.

Methods

Model description

The Community Land Model version 4 (CLM4; [*Oleson et al., 2010*]) is the land component of the CESM (Community Earth System Model). Biogeophysical processes simulated by CLM include solar and longwave radiation interactions with vegetation canopy and soil, momentum and turbulent fluxes from canopy and soil, heat transfer in soil and snow, hydrology of canopy, soil, and snow, and stomatal physiology and photosynthesis. CLM4 includes a 5-layer snow model, which simulates processes such as accumulation, melt, compaction, snow aging, and water transfer across layers and also considers the radiative impact of aerosol deposition onto snow. Improvements to CLM that were include in CLM4 include an extension of the ground column to a depth of ~50 m by adding 5 bedrock layers below the original 10 soil layers and an explicit accounting of the thermal and hydrologic properties of organic soil, which due to the insulating properties of organic soil tended to cool the soils across much of the organic rich Arctic. Heat conduction in the soil is determined by numerically solving the second law of heat conduction equation, which requires the volumetric heat capacity and the thermal conductivity. The thermal and hydrologic properties of each soil layer are functions of soil liquid and ice water content, soil texture, and soil temperature. The boundary conditions for the solution of the heat conduction equation are the heat flux into the soil/snow at the top and zero heat flux at the bottom of the soil column.

Thermokarst parameterization

In order to accurately simulate thermokarst development, we included 'excess ice' in the soil thermal properties calculations, as the probability of land surface subsidence occurrence increases in the ice-rich permafrost areas. By including excess ice the soil temperature would increase via increased thermal conductivity. The model was initialized with estimates of the current excess ice distribution and amount that are based on the International Permafrost Association (IPA) map. In current stage, the excess ice is evenly distributed in soil layers. In addition, excess ice was included in the calculation of relative total water content of soil. We also increased the heat capacity to 150% to understand what affects the soil properties by including the excess ice in soil thermal property. The excess ice component was then inserted for a long-term model run to understand the future projections of arctic climate change associated with accurately parameterizing soil properties within the permafrost zone.

Results

Excess ice and energy balance

Inclusion of excess ice in CLM affected the patterns of seasonal heat flux in soil via increasing thermal conductivity and temperature of soils. The net radiation was similar for the control and excess ice inclusion; however, the magnitude of variability in ground heat flux throughout the season varied in the control and excess ice inclusion (Figure 1) and latent heat flux and sensible heat flux was similar for the two cases.

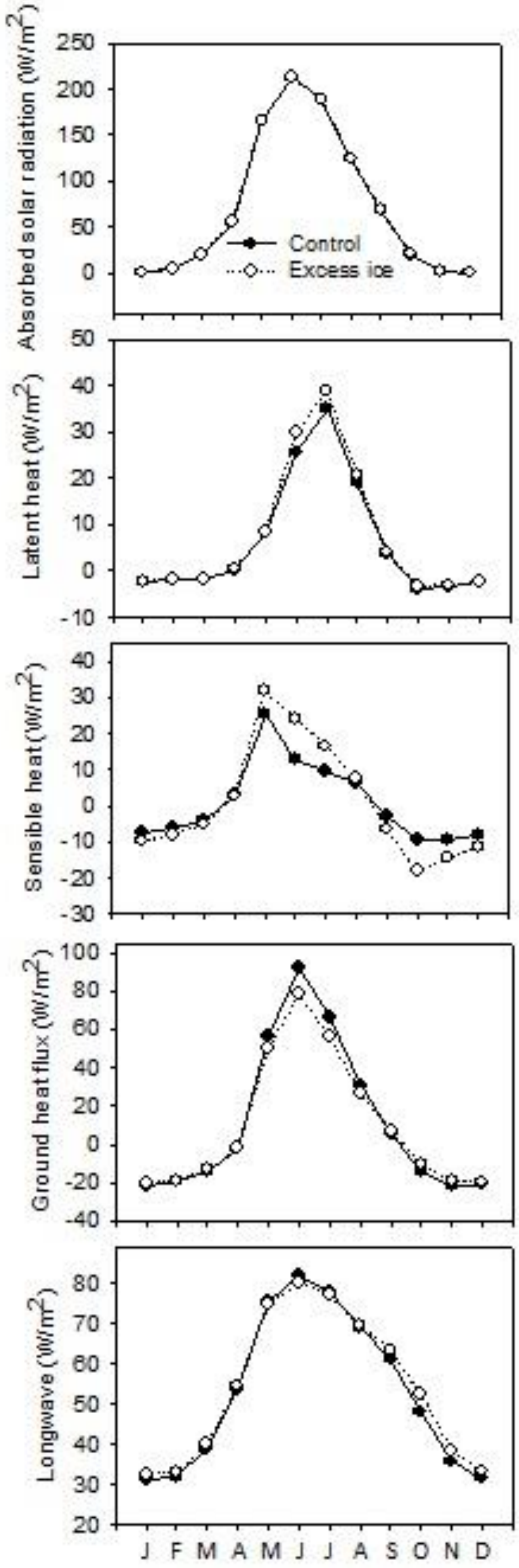

Figure 1. Monthly climatology of Energy balance components (total incoming radiation, latent heat, sensible heat, ground heat flux, and longwave radiation) in the first and second layer of soil for Control and 100% Excess ice from 1948-2004.

Future research

The suit of future research includes statistical parameterization to capture the sub-grid scale variability in surface water and thaw depth using the bases of excess ice inclusion in the CLM. The basis of the wetland parameterization will be a statistical representation of surface microtopography. The representation of sub-grid scale permafrost will be performed closely with that of wetland parameterization as some factors are co-dependent. The soil carbon model will also be adapted so that the rates of soil carbon degradation are functionally dependent on the sub-grid frozen and unfrozen ground distribution. Using the new model with mode realistic two-way interactions between permafrost and hydrology, we will reexamine this potential acceleration in the permafrost degradation rate and access how vulnerable permafrost may be on decadal time scales in greater detail.

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Model Hypothesis for the Formation of Ice Lenses in Saturated Freezing Soil

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Instructions

Temperature, water and stress interact in freezing soil. Under the effect of temperature gradient in the soil, the unfrozen water migrates from the high temperature area to the low temperature area and gathers at the freezing front, so that soil becomes deformed and frost heave happens. The stress field also changes when unfrozen water migrates in freezing soil. Because of the phase change during soil freezing, water migration affect heat transfer in return. At the same time, stress change makes the change of void ratio and pore pressure, and then affects the process of water migration.

Derivation of mathematical model

Equation of state balance and basic conceptions

Fig. 1 is a three phase diagram of saturated freezing soil. In the figure, e is void ratio, S_i is the ratio of the volume of pore ice to the volume of pore. The relative volume is with respect to the soil grain, so in the diagram the relative volume of soil grain is 1.

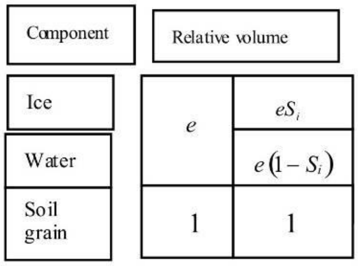

Fig. 1. Three phase diagram of saturated freezing soil

In freezing soil, S_i is a function of temperature (Tice et al., 1976), which can be written as

$$S_i = \begin{cases} 1-\left[1-\left(T-T_0\right)\right]^{\alpha} & T \le T_0 \\ 0 & T > T_0 \end{cases} \qquad (1)$$

where T is temperature; α is experimental parameter; T_0 is the freezing temperature of pore water in Celsius temperature. According to Fig. 1, the unit weight of soil can be expressed as

$$\gamma = \frac{g}{1+e}\left[\rho_s + eS_i\rho_i + e\left(1-S_i\right)\rho_w\right] \qquad (2)$$

where γ is the unit weight of soil; g is the gravity acceleration; ρ_s, ρ_i and ρ_w are the density of soil grain, ice and water respectively. At the beginning of freezing, $T > 0$, $S_i = 0$, $e = e_0$, so the initial unit weight of soil γ_0 is

$$\gamma_0 = \frac{g}{1+e}\left(\rho_s + e_0\rho_w\right) \qquad (3)$$

The equation of static balance (one-dimensional) is

$$\frac{\mathrm{d}\sigma}{\mathrm{d}x} + \gamma = 0 \qquad (4)$$

where σ is the total stress of soil; x is the height of a certain point in soil mass. The height of soil mass is l, and the bottom of the soil mass is defined as origin. There is a load of P^* at the top of the soil mass, so the boundary condition of stress is

$$\sigma\big|_{x=l} = P^* \qquad (5)$$

Solving equation (4) and the boundary condition (5), we obtain

$$\sigma = P^* + \int_x^l \gamma \mathrm{d}x_0 \qquad (6)$$

The initial total stress is σ_0. According to equation (6), σ_0 can be expressed as

$$\sigma_0 = P^* + \int_x^l \gamma_0 \mathrm{d}x_0 \qquad (7)$$

The compression curve of soil gives

$$\mathrm{d}\sigma' = -E_s \mathrm{d}\varepsilon \qquad (8)$$

where σ' is effective stress; E_s is modulus of compression; ε is strain. At the beginning of freezing, the strain is zero, and the effective stress equals to the initial total stress σ_0, so we can obtain effective stress by solving equation (8)

$$\sigma' = -E_s\varepsilon + \sigma_0 \qquad (9)$$

In the undeformed status, the unit height of soil is $1+e_0$, and that in the deformed status is $1+e$. The relationship between strain and void ratio is

$$\varepsilon = \frac{e-e_0}{1+e_0} \qquad (10)$$

Pore pressure, ice lens and new hypothesis of the separating void ratio

P_{por} is pore pressure, which can be expressed as

$$P_{por} = \sigma - \sigma' \qquad (11)$$

Consequently, we can express P_{por} in another way uniting equations (6), (7), (9), (10) and (11)

$$P_{por} = \int_x^l \left(\gamma - \gamma_0\right)\mathrm{d}x_0 + E_s\frac{e-e_0}{1+e_0} \qquad (12)$$

$P_{por}\left(\max\right)$ is the maximum value of P_{por}, which equals to the total stress.

$$P_{por}\left(\max\right) = \sigma \qquad (13)$$

On the basis of equations (12) and (13), we can obtain e_s, which refers to the void ratio matching $P_{por}\left(\max\right)$

$$e_s = \frac{1}{E_s}\left(1+e_0\right)\left[\sigma - \int_x^l \left(\gamma-\gamma_0\right)\mathrm{d}x_0\right] + e_0 \qquad (14)$$

From the above, pore pressure can be expressed as

$$P_{por}=\begin{cases}\int_x^l(\gamma-\gamma_0)\mathrm{d}x_0+E_s\dfrac{e-e_0}{1+e_0} & e<e_s\\ \sigma & e\geq e_s\end{cases} \qquad (15)$$

There have been some scholars who studied the formation of ice lenses. Konrad and Morgenstern [*1980*] thought that when temperature lowers to θ_{sf} an ice lens begins to form, and when temperature lowers to θ_{sm}, the ice lens stops growing. This judge criterion for the formation of ice lenses can be expressed as

$$\theta_{sm}\leq T\leq\theta_{sf} \qquad (16)$$

O'Neill [*1983*] thought when the pore pressure exceeds the total pressure, the ice lens forms.

$$P_{por}\geq\sigma \qquad (17)$$

According to equation (15) and inequality (17), a judge criterion for the formation of ice lenses in terms of void ratio can be expressed as

$$e\geq e_s \qquad (18)$$

Another opinion was that an ice lens forms when the pore pressure exceeds the sum of the total stress and the separation strength [*Nixon 1991*].

$$P_{por}\geq\sigma+P_{sep} \qquad (19)$$

where P_{sep} is separation strength. According to equations (12), (14) and inequality (19), we can obtain

$$e\geq e_s+\frac{P_{sep}}{E_s}\left(1+e_0\right) \qquad (20)$$

Comparing inequalities (18) and (20), the difference of them is that inequality (20) introduces the separation strength which leads inequality (20) to gain the term:

$$\frac{P_{sep}}{E_s}\left(1+e_0\right)$$

To be able to judge the formation of ice lenses by void ratio directly, we propose a concept of separating void ratio e_{sep}, i.e. the hypothesis of separating void ratio e_{sep} [*Zhou & Li 2012*]. When the void ratio is less than e_{sep}, the pore ice grains can not connect each other, even if the soil grains are separated, as is shown in Fig. 2(Left). As the void ratio is greater than or equals to e_{sep}, ice grains connect each other to become integrated and ice lenses begin to form, as is shown in Fig. 2(Right). As for silt which is liable to form ice lenses, the separating void ratio is approximately equal to the maximum void ratio when it is in the most incompact status. From the above the judge criterion for the formation of ice lenses can be expressed as

$$e\geq e_{sep} \qquad (21)$$

Because e_{sep} is greater than e_s, inequality (21) can be expressed in another way

$$e\geq e_s+\left(e_{sep}-e_s\right) \qquad (22)$$

Comparing inequalities (20) and (22), the term $e_{sep}-e_s$ in inequality (22) can be viewed as the result of the separation strength P_{sep} enlarging the separating void ratio e_{sep} in inequality (19).

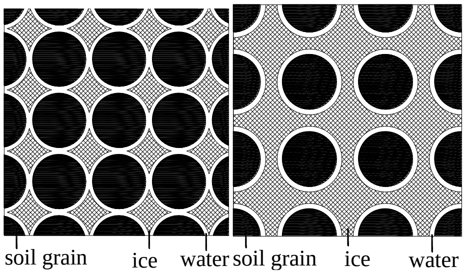

Fig. 2. Diagram of freezing soil whose void ratio is less than e_{sep} (Left) and greater than or equals to e_{sep} (Right).

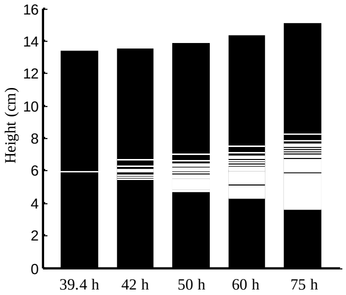

Fig. 3. Histogram of ice lenses distribution at different times with the initial soil column height of 12cm (The white parts are ice lenses).

Recently, the model hypothesis of separating void ratio which proposes the separating void ratio as a judge criterion for the formation of ice lenses, had been used to derive a mathematical model of coupled water, heat and stress, and predict the formation of ice lenses and to calculate the amount of soil's frost heave, the equivalent water content, the pore pressure and et al. by adjusting the hydraulic conductivity in the model. Fig. 3 shows the distribution of ice lenses at different times. Ice lenses are distributed discontinuously layer by layer, which are confirmed in laboratory. At the time of 39.4h, an ice lens begins to form, and with time goes by, more ice lenses form and grow to increase the frost heave. [*Zhou & Li 2012*].

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The deformation characteristics in circumpolar latitude permafrost regions along Mohe-Beiicun Highway

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Abstract

In order to explore and discuss the causes of embankment and pavement in circumpolar latitude patchy permafrost regions of Northeast of China, the uneven settlement of embankment was analyzed along the Mohe - Beijicun Highway. Based on the deformation condition of each soil layer under the different of permafrost conditions and engineering measures, the mainly soil layer occurred the deformation, and the causes of damage were explored and discussed along the Mohe - Beijicun Highway. The result showed that the initially deformations of embankment was large as a result of post-construction uneven settlement of the season activities layer under the original natural ground. The settlement of embankment occurred mainly in the warmer season, the roadbed kept stability and the deformation was small in the colder season (November-next June). The deformation of embankment had to do with the ice contents, the temperature of permafrost. The deformation of embankment was larger in High temperature permafrost regions than that in low temperature permafrost regions.

Late-Pleistocene and Holocene Glacier-Permafrost Interaction in Norway

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Introduction

Following the last glaciation, cryogenic processes related to valley and cirque glaciers, permafrost and seasonal frost have dominated Norwegian landscape development in high-mountain areas. This is evident by different landscape and landform features, like rock glaciers, block fields, palsas, ice-wedge polygons and ice-cored moraines, in addition to the varying presence of glaciers. A recently developed inventory of permafrost-related landforms both clearly demonstrates a spatial pattern which is attributed to different climate conditions during Holocene, and that the currently active permafrost landforms are mostly related to glacial activity [*Lilleøren & Etzelmüller 2011*].

For Scandinavia in general and Norway in particular the present regional distribution of mountain permafrost is reasonably well known, both through ground temperature measurements in boreholes, geophysical soundings and spatial modelling exercises. An important question in this context is the dynamics of permafrost during the Holocene, as a major factor for landscape development and geomorphological processes in high mountain areas of Scandinavia.

Methods

In the present study two mean annual air temperature deviation curves through Holocene have been compiled to drive a 1D heat flow model over the last 10 ka period for several mountain sites in Norway. At each site temperature-monitored boreholes, which were used to calibrate the model, exist. Both an annual run and a seasonal run including monthly temperature variations were performed for each site. In addition the spatial distribution of permafrost during selected time periods of the Holocene were addressed using a newly implemented version of an equilibrium permafrost model [*TTOP; Gisnås 2011*].

Results

An important result of this study indicate an altitudinal zonation of relative permafrost age in Norway, where permafrost has existed continuously since the deglaciation in the highest areas, while large areas that is presently underlain by permafrost were degraded during the Holocene Thermal Maximum (HTM). In all boreholes the deepest simulated permafrost occurred during the Little Ice Age (LIA), and also the largest areal distribution of Holocene permafrost in Norway is connected to the LIA (Figure 1). In addition, there exist a clear connection between the distribution of permafrost and presence of blockfields.

Holocene glacier-permafrost interaction

On a local scale glacier-permafrost interaction in manifested by the development of large and stable ice-cored moraines and by moraine-derived rock glaciers. In general, the currently active permafrost landforms in Norway are connected to glacial activity [*Lilleøren & Etzelmüller 2011*]. In other cases the lack of typical glacier-marginal landforms might represent areas of cold-based glaciers terminating in permafrost environments.

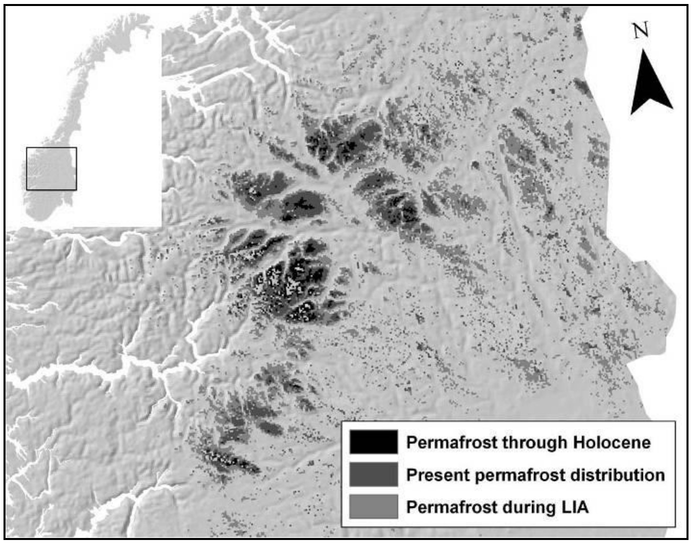

Figure 1. Map of relative permafrost ages in Southern Norway.

Implications

Subglacial temperature regime

If permafrost has existed continuously since the deglaciation, permafrost was presumably present also below the late-Pleistocene glaciations. During the onset of the Scandinavian glaciations, the climate was more severe than e.g. during the LIA. However, cold-based ice is often interpreted as a deglaciation phenomenon in Norway when considering landforms such as lateral meltwater channels and the lack of for example eskers within certain areas, but an ice-sheet transgression into permafrost areas is just as likely. One can expect most of the build-up areas of the ice sheets to have been underlain by permafrost at the time, and only areas where we positively find evidence of large-scale erosional landforms (hence U-shaped valleys and fjord systems) to have been permafrost free during the glaciations. Aggrading permafrost during interstadials must also have been important for the subglacial thermal regime while new ice-sheet transgressions took place.

Blockfields and permafrost

Blockfields cover large areas of the so-called ‘paleic surface’ in Scandinavia, and their presence represent a ground thermal anomaly. The openwork blocks efficiently trap cold air, and permafrost might occur in blockfields in an otherwise marginal permafrost environment. In addition, blockfields appear very little affected by glacial erosion. However, lateral melt-water channels and erratics prove glacier presence during the glaciations. It has been hypothesized that the blockfields represent a ‘self-preserving’ surface [*Berthling & Etzelmüller 2011*]. As glaciers aggrade into blockfield areas prone to permafrost presence, these may attain cold-based conditions and hence rather preserve than erode its substrata.

Conclusions

The interaction between permafrost and glaciers has played a major part in the landscape evolution of Norway, both during the last glaciations and during Holocene in high-mountain environments.

On a local scale, the geomorphic expression of such interactions is often manifested in the development of stable ice-cored moraines and moraine-derived rock glaciers. Also the lack of prominent landforms in glacier marginal areas in certain cases can be attributed to glacier-permafrost interaction.

The “self-preserving” properties of block fields are presumably decisive of where permafrost first develops and where aggrading glaciers remain cold-based.

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Assessing Snow-Measurement Methods for Managing Arctic Transportation on the North Slope, Alaska

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Introduction

Arctic transportation networks are extensively used by the oil and gas industry for supporting drilling and maintenance activities. These seasonal networks include snow and ice roads, runways, working pads, ice bridges across streams, rivers and lakes. Their use prevents or minimizes adverse impacts to the tundra. The Alaska Department of Natural Resources (ADNR) is the agency currently responsible for authorizing winter tundra travel on Alaska state lands. This includes activities for ice-road construction. The criteria in the coastal plain region, a snow depth greater than 15 cm, and in the foothills region a snow depth greater than 23 cm [*Bader 2005a, Bader 2005b*].

The number of days available for tundra travel, and thus the winter-work season, has been steadily decreasing and is currently about half of the days of the 1970 season. The year-to-year variation appears to be increasing at the same time.

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Analysis of Alpine Vegetation and Its Effect on Active Layer Thermal-Water Process in Frozen Ground in Source Area of Yellow River, China

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Introduction

The source area of Yellow River (SAYR) lies in the central of Qinghai-Tibet, which is the main body of the Tibet. The area is mainly covered by alpine vegetation: alpine meadow and alpine steppe, where the biodiversity is various and the ecosystem is sensitive as well as playing a vital role in water conservation and maintaining biodiversity. Global warming has been causing worldwide ecosystem changes. Within the last century the mean global surface temperature has increased by 0.67±0.2 °C. For the 21st century, an increase in mean global temperature between 1.8-4.0 °C over the next 100 years is predicted [*IPCC 2007*]. Arctic and alpine regions are likely to be affected by the climate warming because observed temperature increase in these area are higher than anywhere else [*IPCC 2007*]. The active layer, defined as "the top layer of ground subject to annual thawing and freezing in areas underlain by permafrost" [*Permafrost Subcommittee 1988*], plays an important role in cold regions because most ecological, hydrological, biogeochemical, and pedogenic activity takes place within it [*Hinzman et al. 1991; Kane et al. 1991*]. The thickness of the active layer is influenced by many factors including surface temperature, thermal properties of the surface cover and substrate, soil moisture, and the duration and thickness of snow cover [*Hinkel et al. 1997; JIN et al. 2010*]. Under the condition of global change and its threaten on ecosystem in SAYR, the relationship between vegetation and the processes conduct in active layer has been highlighted [*CAO et al. 2006; Hou et al. 2009*]. In order to understand the effects of vegetation on the water-thermal process in active layer in SAYR, our study seeks to examine what happens to the water-thermal process when the vegetation is different in coverage, diversity and biomass and so on.

Methods

Soil moisture contents were determined in situ using the time-domain reflectometer (TDR). Soil temperature was measured by thermistors every hour. As for the battery in degraded meadow for sustaining the electricity of the memory device was stolen by local people, the data ended at August 2011.Soil and plant samples were taken during the growing season (June-September). Five replicate soil samples were taken from each sampling point. Based on the soil layer depth believed to be affected by land cover changes, soil samples were collected from the 0-0.4m horizon, split up into four intervals: 0-0.1m, 0.1-0.2m, 0.2-0.3m, 0.3-0.4m [*Wang et al.2009; Wang et al. 2011*]. All soil samples were analyzed for nutrient condition, and mean values were calculated for each site. Five 1.0 m×1.0 m sampling quadrats were investigated in degraded meadow and two were surveyed in swamp meadow which was highly homogeneous. All the plants were clipped from the quadrats and placed in paper bags. Then the plants were dried in temperature 75 until reaching constant weight which was aboveground biomass.

Preliminary Results and Discussion

1 Vegetation

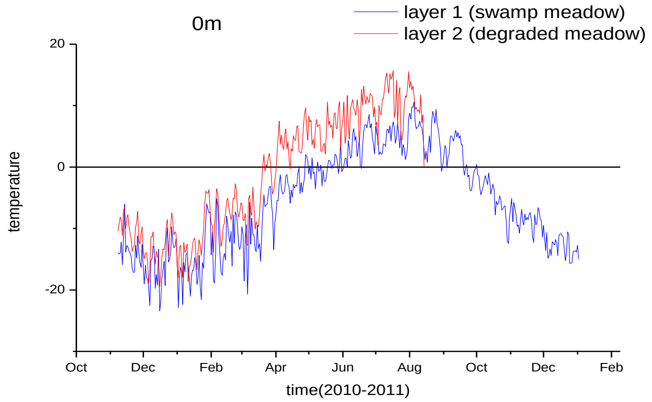
The coverage, abundance and diversity indexes of the community in non-degraded swamp meadow were significantly higher than the ones in degraded meadow;

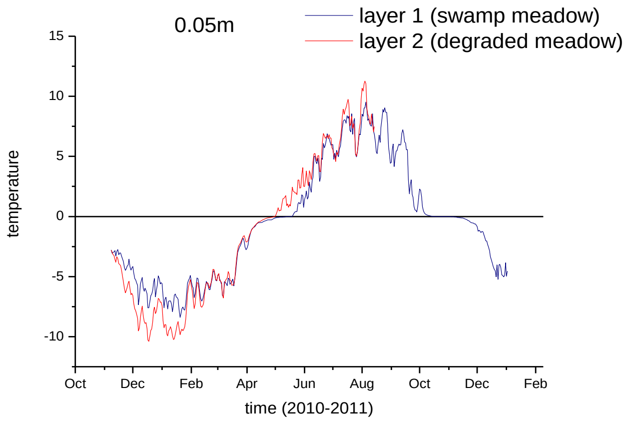
2 Soil

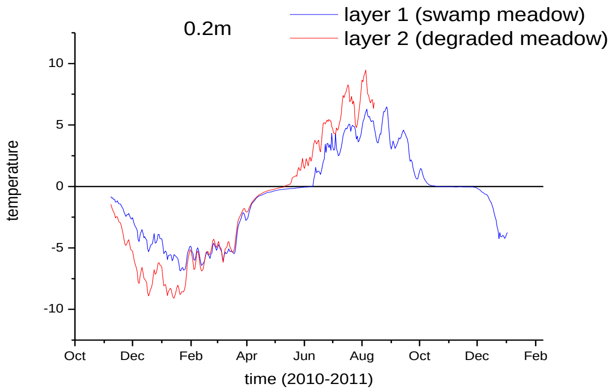
In degraded meadow the soil nutrition dropped and the pH climbs as the depth went deeper while in swamp meadow they exhibited a contrary tendency;

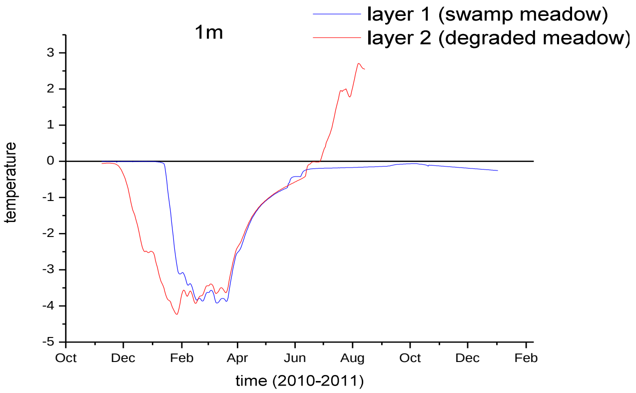
3 Active layer thermal-water processes

Degenerated meadow’s active layer thickness was about 2m; swamp meadow’s was approximately 0.8m. Degraded meadow got frozen earlier than the swamp meadow; degraded meadow also got thawing earlier than the swamp meadow. The degraded meadow’s average annual ground surface temperature was higher than the swamp meadow. As for the other depths, the degraded meadow can reach a lower temperature at the low point and higher at the high point. For both meadows, the temperature went more smoothly when the depth went deeper. The volumetric soil water content in both swamp and degraded meadow was about 0.4 in summer, but underground volumetric soil water content 20cm and 40cm in swamp meadow reached almost 0.7 while 0.3-0.4 in degenerated meadow.









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Expansion of a thermokarst lake in Beiluhe Basin, on Qinghai-Tibetan Plateau

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Abstract

The expansion of thermokarst lakes in ice-rich permafrost in Beiluhe Basin has been documented through the field surveys and examination of aerial photographs. The monitoring data from a trpical lake shows that the lakeshore has been retrogressing at 0.5 to 0.8 m/a rate during the past six years, and the max total retrogression was over 4 m. The surface area increased had increased about 55% from 2000 to 2010. Especially since 2006, the expansion was very quickly.

Keywords: thermokarst lake, expansion, Beiluhe Basin, Qinghai-Tibetan Plateau

Introduction

Landscape on the permafrost regions has been modified due to the disturbances of the anthropogenic activities and the warming climate conditions [*Harry & French, 1983; French, 1996; Lin et al., 2011a, 2011b*]. The covered vegetation and the surface soils have been completely eradicated, or destroyed, and have led to the thawing of ice-rich permafrost or the melting of underground ice [*Jin et al., 2008; Lin et al., 2011c*]. Such disturbance may cause a reduction in soil strength and in soil volume (consolidation), even can create the significantly increased water area to develop into related lakes. A thermokarst lake (also called thaw lake) occupies a depression formed by thaw settlement [*Kääb & Haeberli 2001*]. After the lake occurs on the surface, the ground temperature beneath the lake is higher than that of the surrounding permafrost because the year-round temperature at the lake bottom is equal to or higher than 0ºC, except in that too shallow lakes [*Niu et al., 2011*]. Most of the lakes may expand and deepen with the thermokarst forming processes [*Williams & Smith 1989*] and promote geomorphic and sedimentary processes [*Julian B.Murton 2009*]. Therefore, the objectives of this paper are to describe the expansion of a thermokarst lakes in Beiluhe Basin on the Qinghai-Tibet Plateau.

Regional condition and study lake

The Beiluhe Basin, a main part of the Hoh Xil Nature Reserve Region with an altitude of 4,600 m in elevation, lies in the interior of the Qinghai-Tibet Plateau (QTP). The basin is 350 km away from Golmud city and is surrounded by Chumarhe High Plain in the north and Fenghuo Mountainous in the south (Fig.1). This region is under cold and arid climate condition. The mean annual air temperature in the basin is 3.8 °C, with the highest value of 21.3 °C in mid-July and lowest value of -21.4 °C later January. Permafrost, characterized by high ice-content is continuous in the basin. The mean annual ground temperature ranges from -1.8 to -0.5 °C. The permafrost thickness ranges from 20 to 80 m, with an active layer of 1.8 to 3.0 m in thickness.

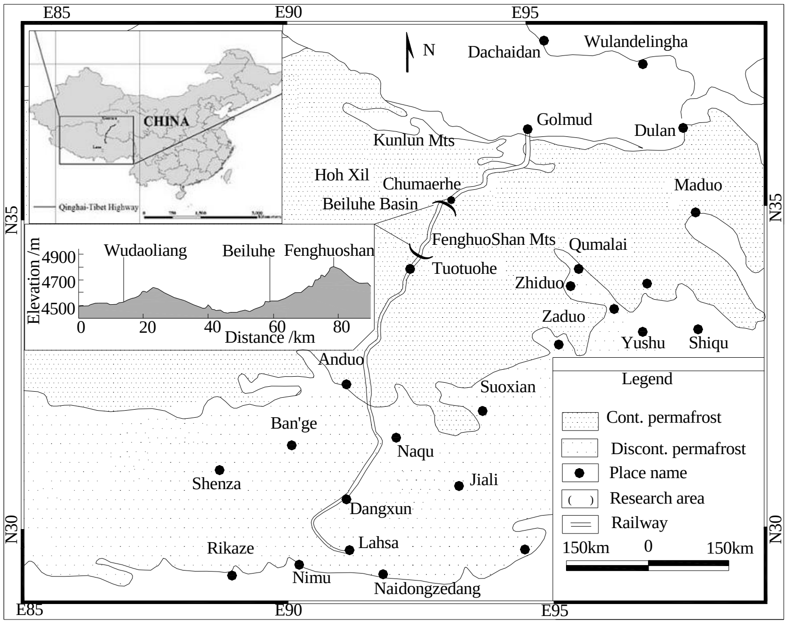

Fig.1. Location of the study area in the Qinghai-Tibet Plateau. Permafrost underlies 75% of the total area of the plateau and is relatively warm and in places, ice-rich. The study site is within the continuous permafrost zone.

Many thermokarst lakes can be found within the basin. The mean area is 8500 m^2, the biggest one is over 60,000 m^2, and the smallest is 1200 m^2. The water depth varies from 0.5 to 2.5 m. The expansion of a particular thermokarst lake has been studied in detail from the aerial photographic record (2000 to 2010) and by field surveys (2006 to 2011). This lake is located on the west side of the Qinghai-Tibet Railway (QTR) (Fig.2). The major axis was about 150 m and 120 m of the minor axis in 2006. It belongs to the closed perennial type and has water depths up to 2 m. It is viewed as typical of thermokarst lakes in the Beiluhe Basin.

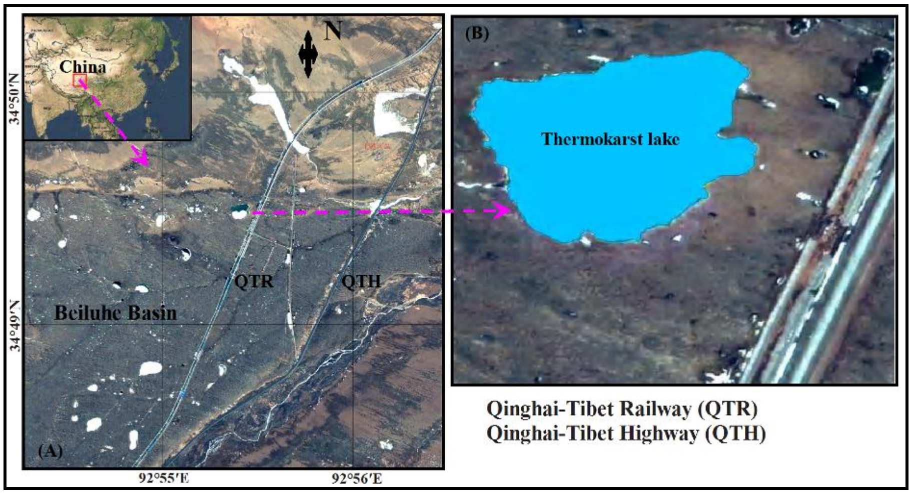

Fig.2 Location of study sites and thermokarst lake in Beiluhe Basin. (A) a portion image of landscape which was taken by QuickBird, Nov 15, 2006; (B) an amplified typically thermokarst lakes.

Lakeshore retrogression

The surface area of lake at various times since 2000 was obtained from the field surveys and examination of aerial photographs (Fig.3 (A)). Thermokarst lake expansion is one of the important characteristics during the period of evolvement and is achieved through lakeshore retrogression (Fig.3 (B) and (C)). Therefore, indexes of lake area and lakeshore retrogression were computed to describe the development of lake. The surface area of lake had increased continually from 2000 to 2010 according to the aerial photographs. The value of area was about 1.22×10^4 in 2000, 1.35×10^4 m^2 in 2006, and 1.89×10^4 m^2 in 2010 by QuickBird aerial photographs. Especially since 2006, the increase of surface area was very quickly.

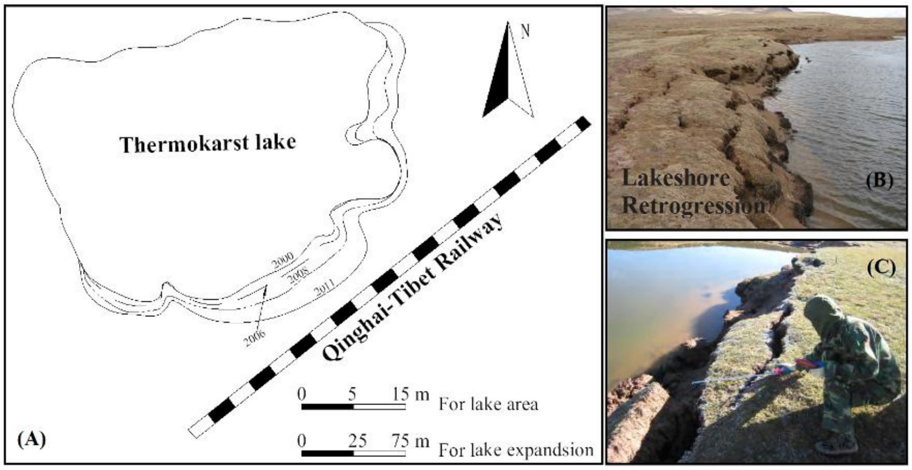

Fig.3 Thermokarst lake expansion since 2000. (A) the outline of lakeshore retrogressed; (B) active collapse of the lakeshore in August 2008; and (C) a scene of monitoring the lakeshore retrogression.

The observation to lakeshore retrogression began in 2006. Nine profiles to manually monitor lakeshore retrogression were laid out along the seriously collapsing lakeshore (Fig.3 (A)). Each profile was made up of two steel bars inserted to depths of 50cm and set 10m apart. Lakeshore retrogression was measured by the change of distance from the edge to the monitoring stakes (Fig.3 (C)). The measured data from 2006 to 2011 were listed in Table 1.

As is shown in Table 1, the total lakeshore retrogression among the profiles varied between 2.25m and 4.25m, with a mean value of 2.91 m and the mean annual retreat varied between 0.45m and 0.85m from 2006 to 2011, with a mean value of 0.58 m/a. In 2007, the increment rate of mean retrogression was 0.46 m, 0.59 m in 2008, 0.33 m in 2009, 0.66 m in 2010, and 0.86 m in 2011. It in generally showed the gradually upward trend.

Some negative growth in retrogression can be found in Table 1, for example at profile 3 in 2010 to 2011, at profile 5 in 2006 to 2011, and at profile 7 in 2007 to 2009, etc., meaning that the ground fissures widened and tilt towards the lake as a prelude to future collapse. After the expansion of the fissures, the collapse blocks cut by the cracks and collapse into the water when the bottom ice-rich frozen soil thawed or the massive ice melted. Waves help break up the blocks in the water and the remnants constitute the lake-bottom sediments. In additional, several no growths in retrogression can be also found at profile 2 in 2008 to 2009, at profile 3 in 2008 to 2009, and at profile 8 in 2007 to 2008, etc., meaning that the lakeshore was in stable period. Therefore, one retrogression cycle involves three phases: a crack-formed, a crack widen, and a collapse [*Lin et al., 2010; Niu et al., 2011*].

Table 1. Index lakeshore retrogression from 2006 to 2011. Assume the value in 2006 was zero.

Years	Measured profiles									Mean retro-gression /m	Rate of increase /m.a^{-1}
	1	2	3	4	5	6	7	8	9		
2006	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	—	—
2007	0.33	0.95	0.73	0.45	-0.14	0.27	0.80	0.76	0.00	0.46	0.46
2008	1.17	1.60	0.88	1.05	0.90	0.95	0.72	0.76	1.47	1.05	0.59
2009	2.83	1.60	0.88	1.91	0.90	1.33	0.68	0.80	1.50	1.38	0.33
2010	2.78	2.40	3.18	2.75	2.50	1.70	1.40	0.60	1.10	2.05	0.66
2011	2.90	3.05	3.10	4.25	3.08	2.90	2.25	2.35	2.28	2.91	086
Mean rate of increment /m.a^{-1} (2006-2011)	0.58	0.61	0.62	0.85	0.62	0.58	0.45	0.47	0.46	0.58	

Generally speaking, lakeshore retrogression happens mainly in warm seasons, especially from August to October with the ice melt and active-layer thaw. The retreat stops abruptly when the lakeshore is frozen from the middle of October to the middle of May. Despite this temporal concentration of retrogression in the warm season, lake expansion over the long term relates to permafrost conditions (such as ice content and thermal regime) and likely has little correlation with climatic variations [*Burn & Smith, 1988, 1990*], because no retrogression has been found in the north and west lakeshore with ice-poor permafrost. The climatic condition provides only an external environment; it does not become an important, climatically driven condition.

Conclusions

The field surveys and examination of aerial photographs for a typical thermokarst lakes in the Beiluhe Basin show that the increase of lake area was very quickly during the past decade years. The lakeshore retrogression is one of the important characteristics. The mean retreat was about 0.6m from 2006 to 2011.

Acknowledgements

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Preconstruction Thawing of Frozen Grounds with the Use of Low-Voltage Ohmic Electric Heaters at the Facilities of the Yurubcheno-Tokhomskoye Field

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Abstract

This article is devoted to the issues related to preconstruction preparation of permafrost at the facilities of the Yurubcheno-Tokhomskoye field by method of electric heating for the subsequent usage of this permafrost as foundation grounds for buildings and structures designed according to principle II (in the thawed state).

Keywords: electric heater; ohmic; preconstruction thawing; principle II.

When developing working documentation of "Complex infrastructure development of the top-priority site of the Yurubcheno-Tokhomskoye field with oil export line" according to code 1982/5, we encountered a necessity to take measures for preconstruction thawing of permafrost at the base of buildings and structures.

Preconstruction thawing of frozen grounds is aimed at acceleration of their transition into the thawed state and their compaction for maximum stabilization of deformations and for reduction of ground settlements caused by degradation and anthropogenic defrosting impacts; and it is aimed at subsequent usage of these grounds as foundation grounds for buildings and structures.

The region of the designed construction is located within the Yurubcheno-Tokhomskoye field in Evenkiysky Municipal District of Krasnoyarsk Krai. The climate is equated to the conditions of the Far North regions. Frozen grounds occupy more than 50% of the area and are spread discontinuously with islands of thawed grounds.

Economic development of the territory and construction of facilities are accompanied by disturbance of natural covers, which leads to the change of the thermal regime of grounds' upper layers and to the increase in the seasonal thawing depth.

It is known that when erecting buildings and structures on permafrost, 2 principles of usage of grounds as foundation grounds are considered in the regulatory documentation:

principle I consists in the frozen state during the entire service period of a building (structure);

principle II consists in the thawed state (i.e. after preconstruction thawing) or in the thawing state (i.e. with permitted thawing during the use of a building (structure)).

In case of discontinuous frozen grounds of the Yurubcheno-Tokhomskoye field and their unstable thermodynamic state, the grounds should be used as foundation grounds according to principle II – in the thawed state, with due consideration of frozen grounds' deformations that will evolve in the process of transition of such grounds into the thawed state. According to the geotechnical site investigations, most of frozen grounds on this territory become highly compressible after thawing, which gives evidence of significant settlements.

Preconstruction thawing of grounds is performed for buildings and structures that thermally affect the ground, thereby maintaining its positive temperature after thawing, i.e. for buildings and structures designed according to principle II. These are buildings with floors on the ground, vertical reservoirs or buildings with a warm technical cellar.

When selecting a method of heating, a lot of options were analyzed, for example: injection thawing with steam or hot water, heating with high voltage current, electrode heating with alternating current, heating with electric heaters (tubular electric heaters, electrolythic and ohmic heaters).

Taking into account the engineering and geological conditions of construction sites, the most reasonable method for preconstruction thawing of permafrost at the Yurubcheno-Tokhomskoye field is heating with low voltage ohmic electric heaters. The principle of the method is very simple: the temperature of frozen grounds is increased by means of warmth emitted from a heater in the process of transformation of electric energy into thermal one.

By comparison with other methods, this one is the simplest and the least time-consuming, as heaters can be made directly on a construction site and, besides, the most common type of energy – electric energy – is used. But this method has a few drawbacks the major of which is an increased hazard of work. Besides, this method features significant energy consumption and a relatively low average thawing speed. In other words, at the initial stage of the process the speed is several times higher than that at the final stage. This is due to the growth of thermal resistance of baked ground occurring with time around the heater, as shown in the diagram.

Two most important parameters for development of efficient design solutions to preconstruction thawing of grounds are as follows: the estimated depth and the optimal radius of thawing.

In order to prevent nonuniform deformations and additional settlements resulting from thawing of excessive volume of frozen ground, the estimated depth of preliminary thawing should be determined on the basis of maximum permissible settlement of a building foundation: as a sum of the depth of foundation and the position of the lower surface of compressible ground mass or based on the depth of ground natural thawing by heat emitted from a building during its entire service period.

Determination of the thawing radius comes down to a task of searching the best balance between the cost of electric energy supplied to electric heaters during a thawing period and the expenses related to drilling wells for installation of such heaters with the given time of heating.

The calculation of the heater itself consists in the determination of a diameter of a heating branch on the basis of the required heat input, provided that the heater does not fail during its operation. The required heat input of the heater is determined on the basis of specific physical and mechanical characteristics of ground at a construction site.

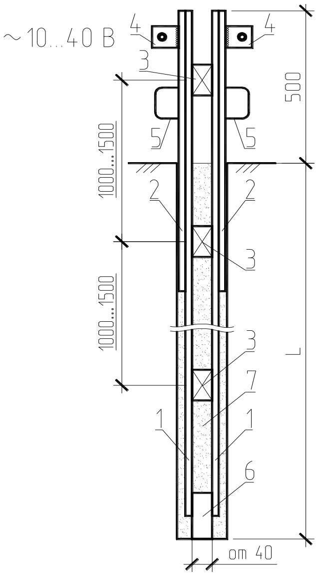

Figure 1. Ohmic heater construction

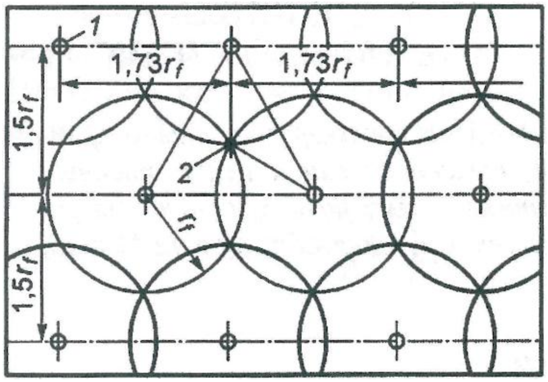

Figure 2. Layout of electric heaters:
1 - heater, 2 – thermometric well

Ohmic heater (Fig. 1) is made from two reinforced bars with the diameter of 10-36 mm serving as heating elements (1) that are connected with each other at the bottom by metal connecting insert (6). The upper part of the heater serves as a conductor and is fitted with additional bars (2). Insulators (3) are placed over the heater length at an interval of 1.0-1.5 m and can be made of asbestos cement or porcelain. The contacts of ohmic heater (4) are made in the form of metal plates with holes for attaching current leads. If necessary, the heater is fitted with slinging elements (5). The heaters are installed into the pre-drilled wells that are subsequently filled with sand (7) for improvement of heat transfer. In order to avoid well casing, well construction works should be preferably performed at the end of winter – beginning of spring, when the seasonal freezing - thawing layer is still in the frozen state. Ohmic heaters are supplied with alternating or constant current with the voltage of 10-40 V.

At a construction site the heaters are arranged chequer-wise (Fig. 2), which ensures uniform heating of grounds with a minimum number of heaters. A heater is lowered down to the depth (L) that is 1.0 m less than the estimated depth of thawing.

The thawing process of grounds is controlled by periodical measurements of electric parameters of heaters and of grounds' temperature in thermometric wells the depth of which is determined to be 1.0 m more than the estimated depth of thawing. Thermometric wells should be located at the sites with the most unfavorable engineering and geological conditions – in the center of an equiangular triangle composed by the heaters.

The experience in preconstruction thawing in the Komi Republic shows that the heating process will be accompanied by ground settlement caused by pressing-out of the generated water and by compaction of ground particles under the weight of the ground mass, while the water will be distributed over hydrophilic layers, due to their natural slope, almost without running out to the surface. The thawing period is expected to have 60-70 % of settlements and the rest of the settlements will presumably occur within 2-3 years.

The supply of electric power is cut off when the ground temperature reaches + 2° C. In order to confirm the fact of thawing and determine physical and mechanical characteristics of thawed grounds, we perform the control drilling operations with sampling for laboratory research. The control wells are made at the points with maximum initial ice content, at the points where the heaters functioned with deviations from the estimated regime and so on.

Conclusions

Thus, heating of permafrost at the base of the facilities of the Yurubcheno-Tokhomskoye field with the help of ohmic electric heaters is the most suitable method of preconstruction preparation of foundation grounds composed of frozen clayey silts and rubbly grounds with clayey silt filler.

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Geocryological Conditions of the Grounds of the "Ice Complex" and Their Impact on the Berkakit - Tommot - Yakutsk Railway of the Amur-Yakutsk Mainline

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Introduction

The report presents the characteristics of the geocryological conditions of an "ice complex" of the most difficult section (688 km - 734 km) of the Amur-Yakutsk mainline construction. The methodology of studying the ground temperatures in the annual cycle of their changes to the depth of 10 m is discussed. The changes in geocryological conditions on the territory of the ice complex in the course of the natural climate change and under the influence of different types of technical pressure are shown. The characteristics of the roadbed designs that are used for railroad construction in accordance with Principle I (preservation of permafrost in the foundation of a linear structure during its construction and operation) are given. A set of activities aimed at the quality control of the selected structures to ensure effective operation of the railway in the section located within the ice complex is proposed.

An ice complex is usually understood as a blanket-like horizon of deposits of different genesis, composition, structure and properties with a high ice content.

During the last decades, the Melnikov Permafrost Institute SB RAS conducts comprehensive fundamental and applied research of the geocryological conditions within the territory of the Amur-Yakutsk Mainline construction. Among the research participants were N.P. Bosikov, I.S. Vasilev, S.P. Varlamov, M.N. Zheleznyak, I.P. Konstantinov, P.N. Skryabin, A.N. Fedorov, N.I. Shender and many others. As a result, additional data on the patterns of geocryological conditions formation in the "ice complex" were obtained. The peculiarities of their changes caused by the technical pressure on the landscapes were brought to the attention. It was demonstrated that the natural climate change will not have a significant impact on the "ice complex".

Study methods

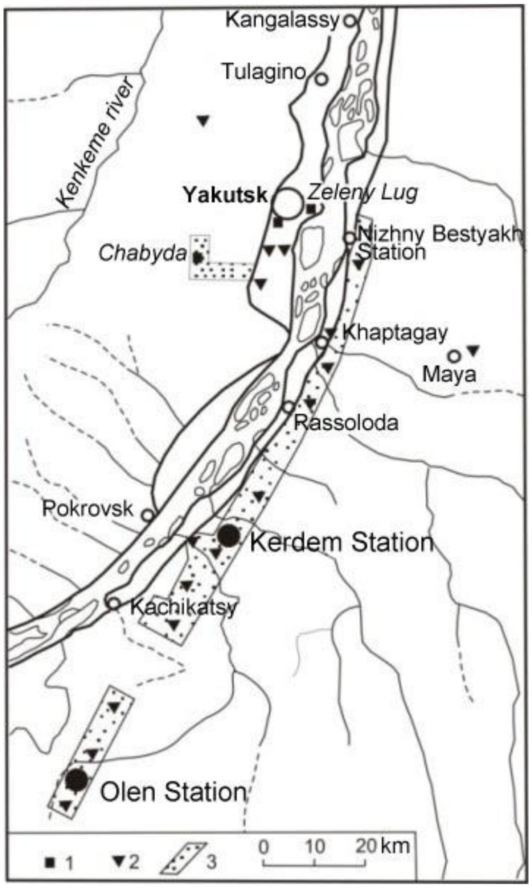
The study of the ice complex geocryological conditions was conducted in monitoring mode since 1987, in connection with the transformation of the cryogenic environment under the influence of the technogenic pressure [*Shesternev 2011*].

The landscape zoning of the territory performed at the initial stage made it possible to establish the borders of study areas and to equip them (Fig. 1).

The first site is located between the settlements of Kachikatsy and Nizhniy Bestyakh Station, while the second one is located in the Olen Station area. Both sites are equipped with monitoring grounds and stationary units that study the temperatures of grounds at the depth of down to 10 m.

The changes in the main climatic characteristics are monitored based on the data of the Yakutsk weather station. To establish the formation patterns of the snow cover parameters, snow survey is conducted annually at the end of winter.

Exploratory drilling is carried out at the territory of the sites in order to study the composition, structure and characteristics of grounds in changing environmental conditions of the Amur-Yakutsk Mainline route.



1 – stationary units, 2 – monitoring grounds, 3 – areas of landscape mapping.

In 2009-2010 further equipping of the key areas of the monitoring geodetic and geothermal network was carried out with consideration of the roadbed designs used by the construction workers. The engineering-geocryological investigations included the following types of activities:

- excavation in the areas of high temperature permafrost distribution, in maris, water-saturated, frozen and icy grounds;
- installation of geothermal wells and benchmarks with the depth of not less than 10 m and installation of geodetic marks.

The objects of the "ice complex" study were: cryogenic environment - the layer of seasonal thawing and freezing of grounds as well as permafrost down to the depth of the annual temperature fluctuations;

- snow cover as the thickest heat-insulating factor that influences the formation of the upper boundary conditions for the existence of the cryogenic environment;

- temperature field of foundation grounds and roadbed in the areas of the mainline construction in accordance with Principle I that provides for preservation of permafrost during the construction and operation of the mainline.

The investigation types mentioned were carried out in accordance with the requirements of normative documents (GOST (State Standard), SNIP (the Building Code) and departmental regulations).

Research results

Central Yakutia is the region where we can observe one of the highest trends of the increase in the mean annual air temperature in Russia in the last 30 years (0.08 °C/year). While in the 60s and 70s of the previous century the climate warming was not so noticeable, in the 80s it was manifested rather clearly. The last two decades of the XX century and the first decade of the XXI century were the warmest in the history of meteorological observations in Central Yakutia (5). During this period the mean annual air temperature was below normal (equaling -10 °C) only twice. According to the works of Yu.B. Skachkov, the increase in the mean annual air temperature in Yakutia is primarily associated with the increase in the number of anomalously warm winters formed as a result of the transformation of air circulation in the atmosphere.

Similar studies that were carried out within the "ice complex" along the route of the Amur-Yakutsk Mainline showed that temperature changes, increasing depth of the layer of seasonal thawing and deformation of thawing grounds strongly depend on the types of disturbance of soil and vegetation covers (Fig. 2).

The set of activities that determine the possibility of using Principle I include: 1) vertical vapor-liquid seasonal cooling systems in conjunction with a heat insulator – foam polystyrene at 39 sites (693 – 710 km, 730 km) with the total length of 4.9 km (grounds of subsidence category IV); 2) thermal insulation of extruded foam polystyrene with the thickness of 5 cm on the slopes and berms (within the section at 709 km with the length of 129 m); 3) installation of cantilever sun protection roofs on the slopes (within the section at 709 km with the length of 100 m); 4) installation of seasonal cooling systems (within the section at 709 km with the length of 100 m). Measures 2, 3 and 4 were used at the test site where geocryological conditions were roughly the same.

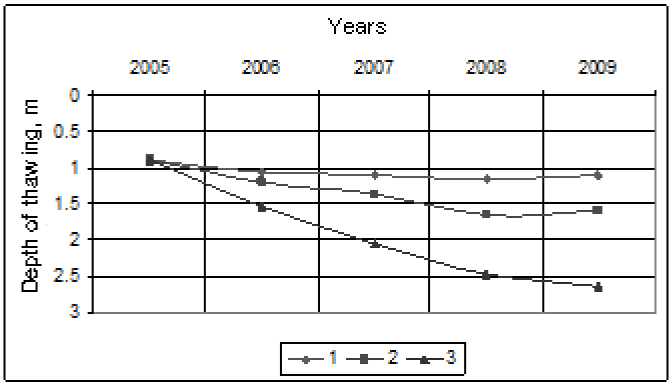


Figure 2 The change in the depth of seasonal thawing in the grounds of the "ice complex"
1 - surface with natural vegetation; 2 – surface with the removed forest vegetation cover (deforestation); 3 – surface with the removed soil cover (10-20 cm thick) and forest vegetation cover.

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Experimental and Numerical Investigation on Temperature Characteristics of High-Speed Railway's Embankment in Seasonal Freezing Regions

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Abstract

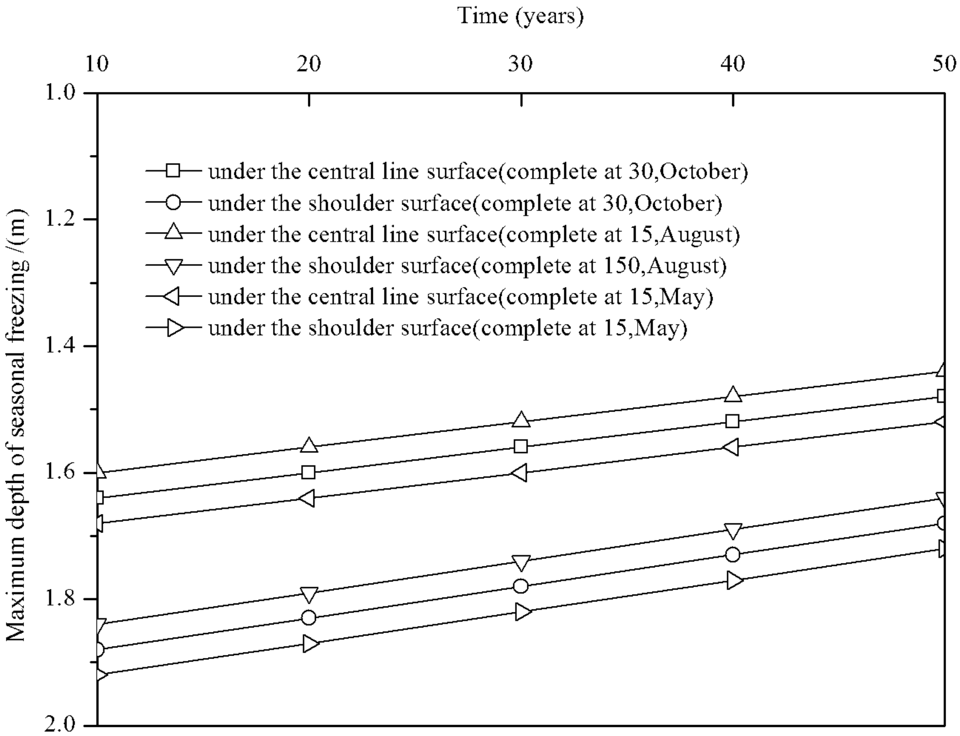
Harbin to Dalian passenger dedicated lines (HDPDL) is the first design and construction of high-speed railway in deep seasonal freezing regions at the same latitude in CHINA. Because of the complicated geographical and geological conditions on Northeast Plateau, all kinds of engineering structures, e.g. embankment, cutting, tunnel, bridge, are often used alternately in the construction of HDPDL. The depth of seasonal freezing along the railway is 0.88m~2.90m from south to north of the lines. The temperature characteristics of the embankment are the most important factor for the design and performance of the measures for anti-freezing. The experimental sections (D3K692+840~D3K692+860) are located in Changchun (capital of Jilin province) along HDPDL. The study site is a semi-humid monsoon climate region of Northeast Piedmont, where the freezing period is from November to March of the next year which accounts for 5months and the thawing period sustained about one month. Engineering geological investigations at the site indicate that the maximum depth of seasonal freezing in nature ground is about 1.3~1.4m.

By analyzing the temperature characteristics of the embankment at Changchun site. We find that temperature changing process in different parts of roadbed and foundation under the seasonal freezing-thawing cycles. In cold season, the temperature which under the reinforced concrete component is higher than which under the shoulder at the same depth. This difference decreased with the depth of roadbed. In warm season, these phenomenons appear contrary trend but decreased as usual except the freezing and thawing influence depth. This difference is almost 5°C when the roadbed surface temperature reach the lowest at late January, 2011. In different parts of embankment, the maximum depths of seasonal freezing are all higher than in natural ground 20~50cm at least for the material of roadbed changing the heat exchanging process with air and surface. It should be multiplied by an appropriate correction coefficient to the standard depth of seasonal freezing on setting the anti-frost layer thickness of roadbed. The soil temperature distribution figure shows that in the first freezing-thawing period after roadbed completion (November.2010～June.2011) on the test sections. It can be seen that the maximum depth of seasonal freezing were 1.7m~1.9m under the shoulder and 1.5m~1.6m under the left central of roadbed. At the day of maximum depth of seasonal freezing, the depth of freezing under the shoulder is higher about 10~20cm than which under the left central roadbed surface. Because of heat conduction process and conditions in the roadbed are changed by the track plate, the reinforced concrete base, and the fills of roadbed, which their effects are directly shown by the changing in the soil temperature and heat flux. The comparing of accumulated cool energy under the embankment surface indicated that the reinforced base and the track plate were enough to keep warm the roadbed and to produce a local high temperature filed in the winter. At the same time, the lowest exothermic of heat in the freezing period and the lowest absorption of heat in the thawing period were present under the reinforced concrete base were no coincidence. It indicated that the reinforced concrete component express the fine insulation for the roadbed and reducing the exchange of heat energy between roadbed and environment. So the ratio of track plate's width and roadbed surface's width is a most important design parameter.

The numerical analyses indicate that, by changing the materials fills, a series of computer simulations were carried out. The simulated thermal states of roadbed which using CRTS-I track plate and reinforced concrete base for the following 50 years with climate warming are presented and discussed. It indicated that the modified-common A/B group fills by using cement doesn't make the thermal state better obviously. The maximum depth of seasonal freezing are 1.5~1.6m under the track plate and 1.7~1.8m under the shoulder. The reinforced concrete component makes the isothermals appearing the saddle shape which will be flatter with the decreasing of depth of roadbed. The isothermals figure shows that the maximum depth of seasonal freezing is under the shoulder on the March when the absolute value of negative air-accumulated temperature is at the maximum. After that, the subgrade is appearing two-way thawing. It can be seen that the temperature gradient changing (TGC) is shown different law: TGC under the toe of side slope> TGC under the shoulder> TGC under the roadbed surface. The changing mechanism is discussed that in the toe of side slope, the material and the geometric curve gradient are changing together which dual influence the TGC. The geometric curve of roadbed surface is flat and the material is consistent which make the TGC is the smallest of all. The geometric curve of shoulder is mutation and the material is consistent which make the TGC is between them. As a result of it, it better not uses different materials on the mutation part of geometric curve.

From figure 1 we also find that the comparison of the maximum depth of seasonal freezing in different construction completes time. It can be seen that maximum depth of seasonal freezing under the shoulder surface is higher than that under the central line surface at same complete time. Respectively, the same position of different complete time has a slightly difference. The maximum depth of seasonal freezing which construction complete at 15, May is the largest one and at 15, August is the smallest, the complete time which at 30, October is between them. Because of the "cooling energy storage" which make this difference. In warm season, the thermal energy storage is the peak of a year which makes the annual

heat budget of roadbed is higher than in cold season, although this difference isn't obvious.



Figuer1 The comparison of the maximum depth of seasonal freezing in different parts of different complete time

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Environmental Management of Thermal Erosion and Gullying in the Cryolithozone

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Abstract

The structure and content of the system of the environmental management of thermal erosion and gullying under the cryolithozone conditions are discussed.

Keywords: database; engineering management decisions; environmental management; geotechnical system; gullying; thermal erosion.

Introduction

According to ISO-14001, a corporate environmental management system comprises a wide range of activities: planning, monitoring, practical aspect of development and implementation of an environmental policy. As to the practical aspect of the economic activity in the cryolithozone, the most important component of the environmental management is the monitoring and control of exogenous geocryological processes.

Thermal erosion and gullying are the most prominent processes of destructive technogenesis in the geotechnical systems of the deposits in the Far North. These processes reduce the stability of geotechnical systems and endanger the safety of engineering facilities operation.

Today, this problem is taking place at the UKPG-1V complex gas treatment plant of the Yamburg oil and gas condensate field. Intensive formation of gully systems and thermal erosion of collectors are also taking place at the area of GP-2V, GP-5, GP-8, GP-9 and GP-10. Elimination of six gully systems is a part of the "Reconstruction and Engineering Upgrade of the Facilities of the Yamburg Oil and Gas Condensate Field. The Second Reconstruction Stage" project. According to the project documentation, the expenditures for the elimination of a medium-sized gully (with the length of 200 m and the volume of 6700 m^3) are about 17 mln roubles. This sum includes the cost of geotechnical site investigations, the development of project solutions and elimination works.

The research carried out by Bashkir State University indicates that the volume of the gully systems at the Yamburg oil and gas condensate field is increasing and depends nonlinearly on time in accordance with the logistic equation. According to the developed express-method of local numerical prediction of gully thermoerosion, the dependence of the coefficient of the annual increase in the volumetric gully damages on age is described in terms of the log-normal distribution with an error of 10-15%. The volume of the damages on the initial stage (1-2 years after the development of gully systems has started) is on average less than 1/5 of the volume of the damages on the late development stage (10-15 years) when operation of the facilities is really endangered, and one starts to undertake measures to prevent gullying.

Hence, the expenditures for the prevention of gullying can be decreased by 5-6 times thanks to preventive engineering management decisions.

The Structure of the Environmental Management System

Organization of an environmental management system is necessary for the implementation of the measures optimal from the viewpoint of deadlines and content and undertaken to prevent hazardous thermal erosion and gullying. At the same time, legal regulations of the environmental management system shall be substantiated in compliance with the ISO 14000 standards that constitute the environmental policy vector.

The environmental management system being developed will be underlain by methods of geotechnical monitoring of slope processes including thermal erosion and gullying and by a system of informational and analytical support including databases and software for forecasting thermophysical and hydrological regimes and slope stability.

The structure of the environmental management system includes two components:

— the Informational and Analytical Component
— the Control Component

The Informational and Analytical Component

The Informational and Analytical Component as such is a geotechnical monitoring component. This is a system of complex control and forecast of the state of geotechnical systems that includes:

— a database and software for forecasting temperature fields within the active layer of the cryolithozone;

— a database and software for the calculation of stability coefficient of slopes composed of permafrost during seasonal ground thawing;

— a database and software for forecasting surface runoff at watersheds of gully systems;

— a database and software for forecasting the development dynamics of gully systems and for the assessment of thermoerosion hazard.

The software has been developed to implement physical and mathematical models that describe thermophysical, hydrodynamical and mechanical processes as well as to study the processes of thermal erosion and gullying. These models take into account numerous factors. Their treatment requires ordered data storage and the presentation of the data in the way that enables its processing. A special database for data support of the software shall be created.

Acquisition and treatment of thermal erosion research data consist of three stages: data acquisition by means of in-situ investigations; laboratory investigations; data structuring and systematization performed using the database. The data stored in the database is sorted and placed in the 3 sections, namely, the meteorological section, the geophysical section and the thermophysical section. The first section contains the hydrometeorological and actinometric data on the region. The second section contains the morphometric parameters, the topography and hydrology data and the data on the lithography of the composing grounds. The geocryological data is stored in the third section (thermophysical and mechanical properties of grounds).

The storage of the research results and the access to them are performed by means of the database. The access to the data occurs via the user interface depending on the results of the corresponding queries to the database control system. The user interface provides data reading and writing, as well as the analysis of the research data.

Results of in-situ investigations, geotechnical site investigations, scientific publications and reference and regulatory literature are the sources of the information stored in the databases.

The Control Component

The Control Component includes a procedure for determining the content and the time of implementation of engineering management decisions designed to stabilize thermal erosion and prevent gullying. According to STO Gazprom 2-3.1-072-2006, the engineering management decisions are a method, an approach and a technology that was not planned in the original project for the facilities at the field or for the erection of an engineering structure. They are designed and implemented as a part of the production process in order to ensure operational reliability of structures.

The experience of gullying prevention under the cryolithozone conditions is taken into account. According to the data of Bashkir State University, there have been implemented measures of different scales and success to eliminate 25 gully systems since the start of the Yamburg oil and gas condensate field development in 1986. These measures have been underlain by methodological recommendations and projects developed by YuzhNIIGiprogaz OJSC, PNIIIS, NIIOSP, Bashkir State University and Gazpromdobycha Yamburg LLC.

Due to the special natural conditions of the cryolithozone, the elimination of gullies and the prevention of thermal erosion constitute a rather challenging engineering and technical problem. The engineering management decisions implemented shall be comprehensive and include groups of methods [*Ananenkov, Stavkin, Lobastova, Khabibullin 2000*]:

— adjustment of mechanical and thermal effects of water flow on permafrost grounds;

— adjustment of geocryological medium of development of thermal erosion, composition and properties of grounds;

— adjustment of man-caused impact on the surface layer of the cryolithozone.

Engineering management decisions concerning the prevention of thermal erosion development are preceded by the assessment of thermoerosion hazard and environmental (engineering) hazard. A number of factors governing the state of geotechnical systems are taken into account when the methodology of this assessment is developed, namely:

— current change speed (in annual cycles) and absolute values of the main characteristics of gully systems (area, length, depth and volume);

— possible values of these characteristics;

— engineering significance and balance cost of engineering structures located in the gullying area, etc.

These factors are assessed considering the data of the Informational and Analytical Component.

Conclusions

Implementation of the environmental management system in question will provide both the managerial effect due to the reduction of expenditures for the measures undertaken to eliminate man-caused gullying, and the environmental effect due to the reduction of industrial safety hazard.

The managerial effect manifests itself when measures preventing and eliminating gullying are implemented thanks to taking the optimal engineering management decisions. Besides, the planning and implementation of environment protection measures will enable uniform document management when organizing prospecting works and geotechnical monitoring, as well as the reduction of time and efforts necessary to develop, discuss and approve a project, engineering and cost estimate documentation, layouts and plans for the measures to prevent and eliminate gullying.

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Geocryological Processes and Phenomena at the Engineering Facilities of the Zapolyarnoe Oil and Gas Condensate Field

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During the geotechnical monitoring at the facilities of the Zapolyarnoe field, various geocryological processes and phenomena are observed. The following types of processes and phenomena were distinguished based on the monitoring data.

The degradation of permafrost at the foundation of buildings due to changes in conditions of snow accumulation

As a rule, during the development of the plan for the layout of engineering structures on-site, favorable conditions for snow accumulation are not taken into account. Many low trestles of on-site utilities (up to 3 m high) are located in close proximity to the guard. Such a layout leads to excessive snow accumulation at the base of the trestles. The snow cover thickness here can reach 1.0 – 1.5 m. Excessive snow accumulation hinders the seasonal cooling of grounds and acts as a catalyst for permafrost degradation, which may result in the loss of foundation bed stability (Fig. 1).

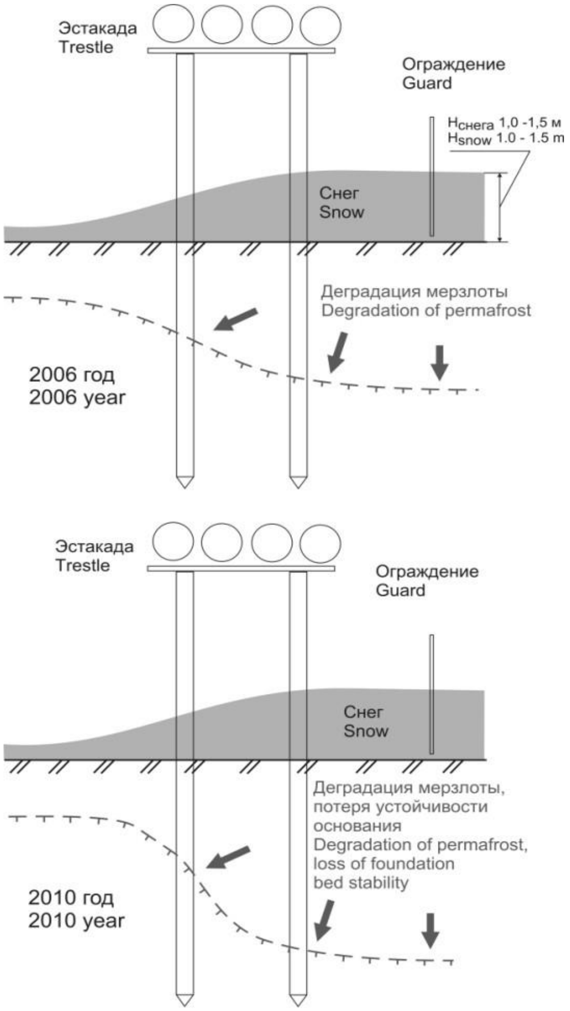

Figure 1. Change in the position of the permafrost table.

Based on the geothermal observations, the permafrost degradation process at the Zapolyarnoe field is activated when the snow cover depth is 0.6 – 0.7 m and above. In the future we propose to provide for a 5 m clearance between the guard and the structures when creating the project design. First of all, this will enable reduction in snow drifting, and secondly, it will provide a possibility to carry out the mechanical snow removal works in the area adjacent to the building territory.

Development of adverse geocryological processes in the body of the site fill (formation of seasonal frost heaves)

The composition of fine sands enriched with silty fraction, irregularities of impermeable relief and different freezing rates of the fill were the main factors for the formation of a local or areal trapping of ground water in the fill of the sites of engineering complexes. As a result of seasonal freezing of such areas, heaving reliefs in the form of frost heaves and ground heaving areas that were formed by injection are frequently observed. The height of a frost heave may reach 0.4-0.5 m and its diameter – up to 6 m. Therefore, heaving may lead to the destruction of buildings with structural elements located close to the ground. The adopted standard clearance between the day surface of the fill and the closest structural element (that is 0.15 m) does not guarantee operational reliability of the structure.

From the operating experience of the Zapolyarnoe field, the clearance between the horizontal element of the foundation structure and the surface of the foundation ground shall be not less than 0.5 m.

Technogenic thermokarst development

At present there still exists the practice of operating engineering structures with heating units recessed into the ground (pump and drain tanks) in accordance with principle I of permafrost use in construction. The practice shows that operation of such structures is always associated with the risk of permafrost degradation development in the surrounding area.

During project designing, such structures should be positioned above ground. If this solution is impossible to implement, then based on the results of thermotechnical calculations with obligatory consideration of the existing operating experience, it is necessary to provide for additional measures to ensure the specified thermal regime of grounds.

Adverse processes development inside the pile

As a rule, pile works process includes filling of the central hole and the pilot hole with the sand and cement mortar. Some authors mention that at low winter air temperatures, the sand

and cement mortar at the top of the pile and of the pilot hole freezes before it sets, which means that the mortar becomes heaving ground. None of the pile works projects includes the regulations on filling the central hole of the piles with mortar depending on the time of the year when the works are conducted. Figure 2 shows destruction and deformation of the foundation elements, which is caused by heaving forces during freezing of the sand and cement mortar inside the pile to a limited extent. In the situations shown in the photo, the heaving force exceeded the strength of the structures of piles' above-ground part.

Cracking in structures foundation

Under the structure built in 2007/08 in accordance with construction type I, during the winter of 2008/09 cracking occurred in the tiled floor of the crawl space with the crack width of up to 10 cm and the depth of up to 1 m and with deviation from the vertical position of the piling (Fig. 3).

In natural conditions foundation grounds of the structure were composed of thawed, mainly clayey silty grounds. The thickness of the sandbed of fine sand was 1.7 – 2.0 m. According to the research data, the permafrost table was located at the depth from 4.0 to 8.0 m. Due to the fact that a large amount of thawed grounds was to be frozen, the project provided for installation of approximately 400 seasonal cooling devices at intervals of 2×2 m and less, both along the axes of the pile field and between them.

Significant cooling of grounds in the winter of 2008/09 resulted in the appearance of pressure in the ground during the freezing of thawed masses. As a result, ground cracking occurred in the center of the structure along the longitudinal axis.

Figure 2. The uplifting of the pile head due to heaving of the sand and cement mortar inside the pile with the diameter of 159 mm.

When using seasonal cooling devices, the thermal calculations should be based on the determination of their sufficient quantity, with consideration of the conditions of heat exchange on the surface of the foundation, moisture transfer during the freezing and the state of ground conditions, especially in case of high moisture content in thawed grounds.

Maintenance of areas allocated for construction

At the stage of field infrastructure development after filling of the sites for construction, these territories are often conserved for several years due to various reasons. At the Zapolyarnoe field, such territories are used for the installation of booster compressor stations.

In order to extract maximum benefit from the period of conservation of the designated areas, it is advisable to include specifications in the project for the maintenance of such areas during the period of their inactivity. Snow cover removal should be reflected in these specifications. This will enable a natural and cost-effective increase in the bearing capacity of frozen grounds by the beginning of the construction process.

In general, the geocryological processes and phenomena discussed result in the decrease in reliability of structures or emergency condition thereof during the operation. Development and implementation of engineering solutions aimed at preventing the described problems at the design stage are reasonable and cost-effective.

Figure 3. Ground cracking along the longitudinal axis in the vented crawl space.

Antarctic Soils in the Areas of Russian Research Stations Location: Effects of Anthropogenic Impacts and Remediation Possibilities

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Introduction

Extremely small distribution area of antarctic soils, their invaluable significance in terms of ensuring of ecosystems functioning and also their extreme vulnerability towards anthropogenic impacts define the main goal of the studies – prevention of an-tarctic soils liquidation and disappearance of the entire ecological niche in already extreme conditions of the 6th continent.

Objects of research

The soils of antarctic oases were studied at 8 key areas in the course of the 55-57 Russian Antarctic Expedition (2009-2012) – Novolazarevskaya, Molodezhnaya, Soyuz, Druzhnaya-4, Progress, Mirny, Oazis (Bangera), Leningradskaya, Russkaya and Bellingshausen stations (Fig. 1).

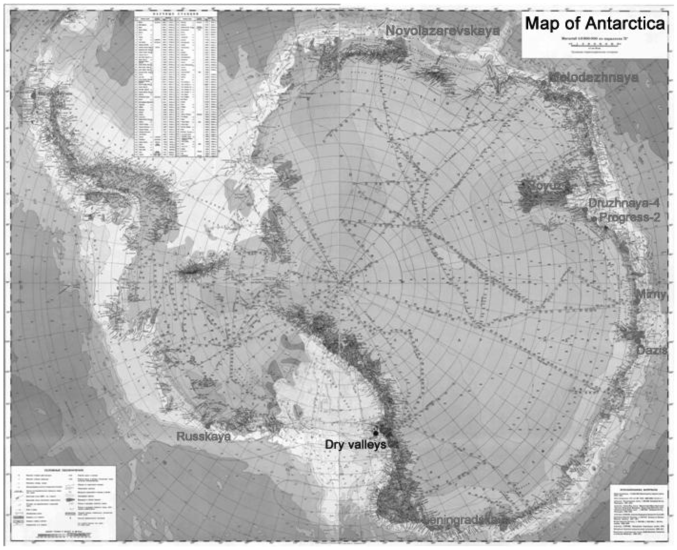

Figure 1. Location plan of research objects in Antarctica: Russian research stations and a prospective research object within the framework of the Russian-New Zealand inter-governmental agreement (Dry Valleys).

Results and discussion

Anthropogenic facilities and structures occupy from 10-15% (Progress Station, Novolazarevskaya Station) to 80% (Mirny observatory) of the territory free of ice, and the zone of active human impact often covers the whole area. The intensity of anthropogenic impact is a very good example of the generally accepted "population density" indicator: in conversion to the area of oases and nunataks it can be in the range from 24 people/sq.km (Progress-2 station) to 300 people/sq.km (Mirny observatory) during certain summer periods, which is comparable to the population density of the USA, China and Western Europe countries, and this only accounts for the manpower of Russian stations (on the territory of one oasis there can be from 2-4 (Larsemann Hills oasis, Schirmacher oasis) up to 7 (King George island) research stations operated by various countries).

Deep and significant differences between natural and anthropogenically transformed soils were revealed. The content of fine soil (<1 mm) in undisturbed soils varies from 5-10 to 30%. In this case pollutant substances intensively migrate vertically, from the day surface into the deep layers of soils and deposits, and then they also migrate laterally – along the surface of monolithic hard rocks or along the upper permafrost boundary. The soils that are subject to anthropogenic impacts contain 40-50% and sometimes up to 70% of fine soil. Despite the poor conditioning and aggregation of the material, pollutant substances can accumulate on the surface of individual particles and grains, where secondary minerals coatings are widespread (the hydroscopic moisture index reaches 3-7%, unlike 0.5-1% in undisturbed soils). The soils that were subject to anthropogenic impact contain 3-10 times more As Pb, Cd and Cs than their background analogues. Soils and grounds under linear structures and in close proximity to petroleum bases also accumulate oil products – from 150 to 600, and in local cases 2200 mg/kg and more, which corresponds to the medium and high level of pollution (background concentration – 40-60 mg/kg).

Antarctic soils represent the only available habitat for a large number of living organisms, the regulator of biogeochemical cycles of elements-biogenes and pollutant substances, the source of emission and gases discharge reservoir as well as the zone of accumulation and transformation of organic matter and they require detailed study, restoration and protection. The studies conducted by the authors and the work results of international environmental commissions show that modern ecological condition of the Russian antarctic stations can be called critical, and individual cases of pollution (primarily by oil products and solid wastes) indicate a need to conduct comprehensive assessment of the ecological damage and to start taking measures aimed at remediation of soils and grounds of the an-tarctic oases as soon as possible. At the moment the team of authors is conducting works aimed at identifying aboriginal consortium of oil destructor microorganisms and, ultimately, creating a biopreparation for remediation of antarctic soils in the areas of Russian research stations location.

Acknowledgements

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Gas-Hydrate Formation in Frozen and Thawing Gas-saturated Sediments

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Introduction

Natural gas hydrates (mainly methane hydrates) commonly originate at depths below 250-300 meters in bottom sediments of seas and oceans, as well as in permafrost areas below the frost penetration, i.e., at positive Centigrade temperatures. However, gas hydrates may occasionally form in shallower subsurface as well (above 250 m), in frozen ground, i.e., at t <0 °C. Gas-hydrate formation at shallow depths is possible in gas pockets within freezing sediments and at related high pressures, by crystallization of pore fluid (crystallization factor) or under external loading (pressure factor) upon localized gas pools in frozen sediments [*Chuvilin et al. 1998*].

Pressure responsible for formation of gas hydrates in the pore space of sediments is associated either with transgression of Arctic seas or with ice waxing during continental glaciations [*Romanovsky 1993; Trofimuk et al. 1986*] whereby within-permafrost gas at relatively shallow depths can fall into the zone of hydrate stability.

Being aware that gas-hydrate formation in porous sediments has been insufficiently understood yet, we developed a special technique for physical modeling of the conditions of the process in frozen and thawing rocks.

Method

The physical modeling of gas-hydrate formation in frozen and thawing sediments followed an original integrate procedure. It included measurements and calculations of parameters that represent the PT conditions of the phase change and the kinetics of hydrate formation in frozen and thawing gas-saturated disperse media.

Formation of gas hydrates in frozen sediments was modeled using a special system consisting of a pressure chamber (about 420 cm^3) with a sample container (4.6 cm in diameter and about 10 cm long), a thermostat for maintaining a required temperature, an ADC, and a PC for recording PT changes in the sample in the course of the experiment [*Chuvilin & Kozlova 2010*].

The tested samples were loamy sand sediments, including those sampled from gas-bearing formations in West Siberian high-latitude permafrost.

The temperature was maintained negative between -2 ^{o}C and -9 ^{o}C. The hydrate-forming gases were methane (99.98%) and carbon dioxide (99.99%). The pressure chamber charged with a sediment sample was first frozen at -8 ^{o}C and then saturated with cold gas. The initial pressure was 4-6 MPa for CH_4 and 2.5-3 MPa for CO_2. After the pressure was applied, a negative temperature was set and maintained constant for the whole experiment duration (10 to 15 days).

The parameters of phase transition in the samples were inferred from PT changes in the pressure chamber in the course of hydrate formation [*Chuvilin et al. 2011*]. Namely, hydrate saturation (Sh), volumetric hydrate content (Hv), and hydrate coefficient (Kh, share of pore water transformed into hydrate) were derived from measured pressures and temperatures, with compressibility according to a gas law recommended by the State Standard of Russia, with regard to gas solubility in pore water.

Results and discussion

As the experiments show, gas hydrates can accumulate in the pore space in both cold (at positive temperatures) and frozen (at negative temperatures, to -8 °C) samples. As the temperature drops from -3.7 to -8°C in the beginning of the test, the hydrate saturation rate decays more rapidly than later, at colder (-8 °C) negative temperatures (Fig. 1).

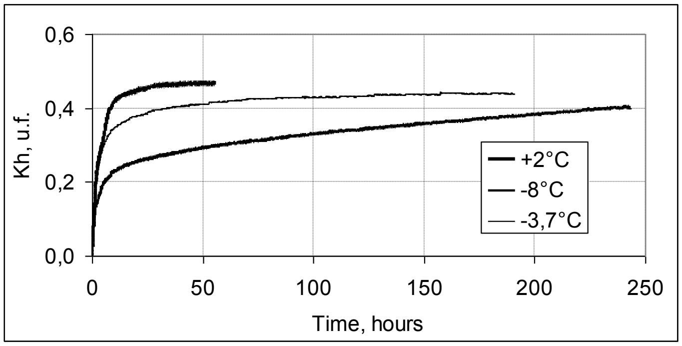

Fig. 1. Kinetics of methane hydrate formation in the pore space of loamy sand (Si = 69%) at different temperatures.

The greatest hydrate saturation correspond to the optimal ice saturation (Fig. 2).

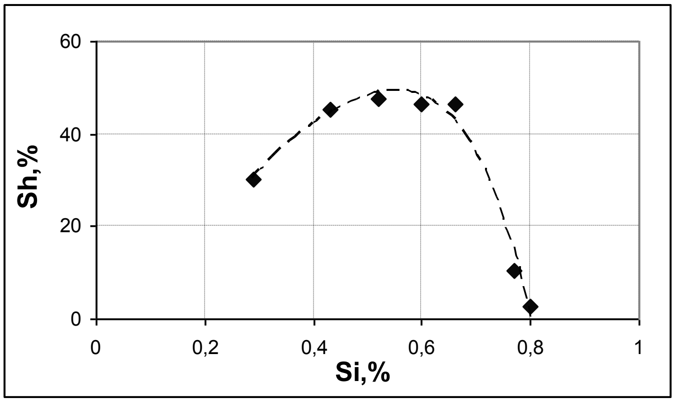

Fig. 2. Initial ice saturation (Si) vs. methane hydrate saturation (Sh) in loamy sand sample 2 at -2.9 °C.

The most favorable conditions for hydrate saturation are at ice saturation between 45 and 65%. At higher ice contents in porous sediments, less hydrates form because the surface of gas-ice contact reduces. When more than 80% of pores are filled with ice, hydrate saturation inside the sample almost stops for the shortage of hydrate-forming gas and a major decrease in gas permeability.

The shares of pore ice transformed into hydrate are lower in finer grained sediments. For instance, 30 % more pore ice transforms into hydrate at -8°C in sand than in loamy sand.

We compared samples saturated with methane and carbon dioxide as to the kinetics of gas hydrate formation in the pores. The formation rate of CO_2 hydrate and the amount of gas accumulated in frozen sand (W=17%) at -3.8 °C is 1.5 times as high as for CH_4 hydrate. The reason may be that CO_2 is much more active than CH_4 and that the formation of CO_2 hydrate has a notable energy gain over the methane hydrate formation process.

Another implication of the experiments is that active hydrate saturation may resume after attenuation of the process in frozen sediments, due to thawing of residual pore ice that has not transformed into hydrate before. A sample of heavy loamy sand (Si=66%), for example, reached only 17% hydrate saturation after 270 hours of experiment at a constant negative temperature of -3°C, but 54% of all stored hydrate formed for 17 hours on warming from -3 °C to +4.1 °C, and the total hydrate saturation was 43% by the end of the experiment (Fig. 3).

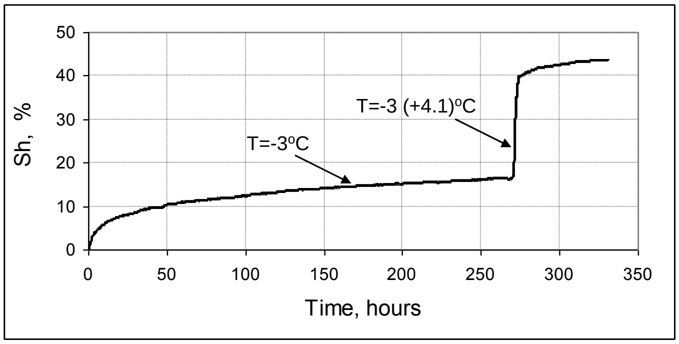

Fig. 3. Kinetics of methane hydrate saturation in loamy sand sample (Si=66%) at constant temperature -3 °C and at warming from -3 to +4.1 °C.

The higher the initial ice saturation, the more hydrate forms as pore ice is thawing. The reason may be that thawing of pore ice leads to changes in structure and texture whereby new gas-water interfaces appear in the pore space of sediments. Thus, thawing of pore ice gives rise to secondary hydrate formation.

Proceeding from the reported experiments and published evidence, models were suggested for formation of gas hydrates at relatively shallow depths in permafrost associated with transgression of Arctic seas or with continental ice sheets.

Generally, the experimental results show that significant amounts of gas hydrates may form in permafrost at favorable conditions (high gas saturation, presence of gas hydrate stability zones, etc.).

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Summer Fluxes and Sources of CO_2 and CH_4 in High Arctic Tundra Under Current and Simulated, Future Climate

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Introduction

Arctic tundra soils store vast amounts of organic carbon (C) [*496 Pg in the top 1 m, Tarnocai et al. 2009*] ranging in age from modern to ancient. These C pools, which have have accumulated over millennia due to the prevailing cold temperatures, may become available to decomposition as climate warms. Loss of arctic soil C to the atmosphere would provide a strong positive feedback to climate warming. Temperatures at the top of the permafrost layer have generally increased since the 1980s in the Arctic by up to 3°C and global models predict increase in air temperature of up to 4°C by 2050 [*IPCC 2007*]. Furthermore, increase in precipitation in the North Polar Region is likely to occur in the future [*IPCC 2007*].

Understanding how rapidly these organic C pools in permafrost can be mineralized as a consequence of warming and changes in precipitation patterns is a major uncertainty in predicting future levels of atmospheric CO_2 and arctic and global temperatures. Our study tries to assess two main questions for high arctic tundra:

a) To what extent do long-term experimental increases in temperature and changes in precipitation alter the magnitude and seasonal pattern of ecosystem-atmosphere CO_2 fluxes?

b) How much do different sources of ecosystem CO_2 emissions (plant respiration, microbial decomposition of recently fixed C or old C pools) contribute to total ecosystem CO_2 emissions under current and simulated, future climate conditions?

Material & Methods

Fieldsite & Experimental Set-Up

The field site is located in the high Arctic of NW Greenland near Thule Air Base (76°31′52″N, 68°42′12″W). Mean annual air temperature is -11.6°C and has increased by 0.5°C per decade from 1971 to 2000 [*Sullivan et al. 2008*]. Mean annual precipitation is 112 mm.

The experiment is established in prostrate dwarf-shrub tundra (polar semi-desert) on patterned ground. At the ecosystem-scale, vascular plants (*Salix arctica, Dryas integrifolia, Carex rupestris*) and bare soil/cryptogamic crust each cover 50% of the ground surface.

Measurements were conducted at a long-term experiment (established in 20??) with 5 treatments: (T1) +2°C warming, (T2) +4°C warming, (W) +50% summer precipitation, (T2W) +4°C × +50% summer precipitation, and (C) control.

Measurements

In a 2-year study (2010-2011), we monitored (1) net ecosystem exchange (NEE) of CO_2 and CH_4 between high arctic tundra and the atmosphere, (2) rates and sources of ecosystem-emitted CO_2 (ER) and (3) concentration and sources of soil pore space CO_2 under current and simulated, future climate conditions. Measurements were taken from May to August.

NEE of CO_2 and CH_4 were measured continuously with clear, automated chambers using cavity ring-down spectroscopy (Picarro 1301). ER and soil CO_2 concentrations (at 20, 30, 60 and 90 cm depth) were monitored daily with opaque chambers or wells, respectively, via infrared spectroscopy (LI-COR 800 & 840).

We used radiocarbon (^{14}C) analysis as a proxy for age to assess the sources ('age') of ER and soil CO_2. Samples were taken monthly. Ecosystem respiration was sampled by trapping CO_2 on molecular sieve traps, soil CO_2 from wells with evacuated canisters through a capillary system. Plant- and microbially-respired CO_2 was sampled using *in situ* or laboratory incubations. In the laboratory, CO_2 was purified cryogenically on a vacuum line and converted to graphite targets using zinc reduction. The ^{14}C content of graphite targets was measured using accelerator mass spectrometry at the W.M. Keck AMS laboratory of UC Irvine.

Results & Discussion

Ecosystem-Atmosphere C Exchange

Initial results indicate that vegetated areas are a net CO_2 sink under both current (C) and warmer and wetter (T2W) climate; with T2W conditions increasing CO_2 sequestration 5-fold (- 11 compared to - 2 μmol m^{-2} s^{-1} during mid summer). Bare soils are a net source of CO_2 at all times. After snowmelt, the ecosystem is a sink for CH_4 under all conditions.

Highest ER rates are observed on vegetated ground with a maximum in mid summer, while ER rates from bare ground remain constant throughout the summer. On the landscape scale, vegetated areas emit 85 ±4.5% of the total ER flux.

Both, additional soil moisture (administered and natural precipitation) and warming enhances ER from both vegetated and bare ground. In vegetated areas for 2011, average ER was 98.9 mmol C m^{-2} day^{-1} in the (C) treatment compared to 123.1 in (T2), 188.6 in (T2W) and 141.8 in the (W) treatment.

Comparing the two years, 2011 ER fluxes were about 3 times higher than 2010 - likely due to higher summer temperatures (Table 1).

The sources of ER in rocky areas were older CO_2 than in vegetated areas. In both years we generally observed a large variability in ER ages (= sources), with older C dominating ER during the snowmelt and before leaf-out, and younger C dominating ER as summer progresses. However, sporadic emissions of old C were recorded throughout the summer and seem to be correlated with rain events or strong increases in temperature in the 24 hrs before the sampling.

While no differences were detected in the ^{14}C content of ER between treatments, we did observe a significant difference in ER sources between the two sampling years. In all treatments, sources of ER were older in 2011 (warmer summer) than in 2010 (wetter and colder summer (Table 1).

Table 1. Temperature and Precipitation records for 2010-11

Month	Average T °C		Precipitation mm	
	2010	2011	2010	2011
May	-1.9	-4.7	5.8	9.9
June	**2.9**	3.6	**5.1**	0.3
July	**6.6**	8.7	**48.0**	19.6
August	6.9	6.0	**25.9**	6.9

Belowground

Well data from all treatments showed a general increase of CO_2 concentrations with depth, during snowmelt and throughout the summer with rocky and vegetated plots showing similar concentrations and patterns.

In a given year, water addition (T2W and W) increased soil CO_2 at depth, especially under vegetation. However, near the permafrost table (90 cm), higher precipitation in 2010 suppressed CO_2 concentrations likely due to a drop in temperature caused by the extra water near the permafrost table at about 1 m depth. Instead, higher temperature (T1 and T2) reduced CO_2 concentations at every depth.

The ^{14}C content (^{14}C-CO_2) at different soil depths showed a general increase in age with depth (in both rocky and vegetated areas). As observed with ER, CO_2 under rocky ground was older under vegetation, presumably due to the lack of fresh C inputs from plants.

The treatments showed that water addition (W, T2W) promoted the release of younger C in the top 60 cm, while higher temperature (T2) stimulated the release of older C (Fig 1). In addition we observed that soil CO_2 was younger in 2010 (wetter) than in 2011 (except at 20 cm).

Conclusions

Our findings indicate that patterned ground landscapes in the high Arctic of NW Greenland have complex C exchange patterns at the fine scale with vegetated areas being CO_2 and CH_4 sinks and bare areas being CO_2 sources. Although our results shows an enhance in C loss in a warmer and wetter climate scenario, the overall future conditions in these regions will likely result in additional C sequestration due to increase in plant C uptake.

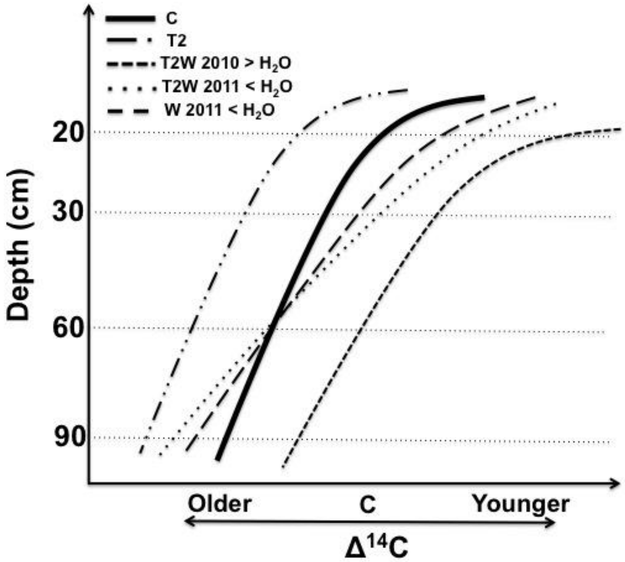

Figure 1. Scheme showing the treatment effect (and years difference in terms of precipitation regime) on ^{14}C-CO_2 at different depth.

Future climate conditions will affect notably the quantity of the different sources of ecosystem CO_2 emissions (plant respiration, microbial decomposition of recently fixed C or old C pools) contributing to total ER. Increasing air temperature will likely boost the release of older C previously trapped in permafrost, making it available to microbial decomposition. While heavy rainfall seems to relocate recently fixed C deeper into soil and slowing down CO_2 diffusion to the atmosphere, light rainfall seems to do the opposite, releasing older C likely creating optimum moisture condition in soil for microbial decomposition.

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Estimating the strength of the permafrost carbon-climate feedback using a coupled global climate model

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Introduction

The contribution of carbon cycle feedbacks to future climate change remains a significant uncertainty in the science of global warming [*Friedlingstein et al. 2006*]. Previous efforts to quantify carbon cycle feedbacks using coupled global climate models have not taken into account the large (only recently quantified [*Tarnocai et al. 2009*]) sequestered pool of carbon held in permafrost soils. Uncoupled ecosystem models have been used to estimate this Permafrost Carbon Feedback (PCF) [*Schaefer et al. 2011 & Koven et al. 2011*] as a release from permafrost soils of 103 (68 to 138) Pg C (Schaefer et al. 2011) or 62 (55 to 69) Pg C [*Koven et al. 2011*] by 2100. However, such models are unable to account for the subsequent feedback that this release of carbon has on further driving permafrost degradation, or to quantify the magnitude of the surface warming as a consequence of the PCF. Here we incorporate the PCF into a global climate model with a fully coupled oceanic and terrestrial carbon cycle. The PCF leads to an additional warming of 0.25 (0.1 to 0.7)°C by the end of the 21st century, independent of emissions pathway followed, with a potential further 1°C by the end of the 23rd century.

Methods

The PCF is estimated using the frozen ground version of the UVic Earth System Climate Model (ESCM), modified using the method of Schaefer et al. [*2011*] to prescribe carbon into perennially frozen soil layers. To estimate a likely range for the strength of the PCF, a suite of sensitivity tests are conducted that explore the estimated range of permafrost carbon density (15.75–26.25 kg m^{-3}) [*Schaefer et al. 2011*] and the likely range of the climate sensitivity to a doubling of CO_2 (2–4.5°C) [*Hegerl et al. 2007*]. For the decade 1990–1999 the simulated frozen permafrost carbon and active layer carbon (overlying permafrost) north of 45°N is 1026 Pg C for the best estimate permafrost carbon density of 21 kg m^{-3}. This simulated carbon pool is close to a recent estimate of 1024 Pg C in the top 3 m of permafrost soils [*Tarnocai et al. 2009*].

The UVic ESCM is integrated under emissions pathways diagnosed from Representative Concentration Pathways (RCP) 2.6, 4.5, 6.0, and 8.5. These Diagnosed Emissions Pathways (DEPs), designated by numbers corresponding to the RCP that each DEP is derived from.

Results

The additional warming created by the PCF by the end of the 21st century (relative to baseline runs with no permafrost carbon) is remarkably consistent between the DEPs; 0.23 (0.09 to 0.73)°C for DEP 2.6, 0.26 (0.11 to 0.75)°C for DEP 4.5, 0.24 (0.10 to 0.69)°C for DEP 6.0, and 0.27 (0.11 to 0.69)°C for DEP 8.5. By the end of the 23rd century, the additional warming from the PCF has diverged between the DEPs, with the highest upper bounds for the lowest two emission pathways; 0.37 (0.13 to 1.62)°C for DEP 2.6, 0.59 (0.22 to 1.69)°C for DEP 4.5, 0.73 (0.28 to 1.31)°C for DEP 6.0, and 0.39 (0.23 to 0.63)°C for DEP 8.5. Under the low emissions pathways reductions in carbon emissions limit the amount of carbon liberated from the permafrost. But the carbon that is transferred to the atmosphere has a higher radiative efficiency than the same unit of carbon released under a high emissions pathway, leading to a strong PCF under low emissions pathways.

After anthropogenic CO_2 emissions cease, the only remaining fast carbon sink is the ocean. The strength of this sink is partially determined by the quantity of CO_2 that has been added to the atmosphere. If the rate at which CO_2 is being released from the terrestrial land surface exceeds the rate at which the oceans can take up CO_2, then CO_2 will continue to build up in the atmosphere, further warming the surface and driving a self-sustaining carbon-cycle feedback. In experiments where DEP 8.5 is followed up to a given date when emissions are instantaneously reduced to zero, all simulations with climate sensitivities above 3.0°C produce a self-sustaining PCF even if emissions are reduced to zero in 2013 (Fig. 1).

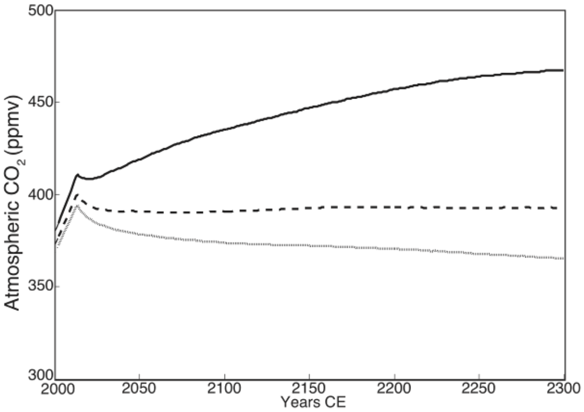

Figure 1. Evolution of atmospheric CO_2 concentration in response to a cessation of anthropogenic CO_2 and sulphate emissions in the year 2013. Dotted line represents the response for a climate sensitivity (to a doubling of CO_2) of 2.0°C, the dashed line a climate sensitivity of 3.0°C and the solid line a climate sensitivity of 4.5°C.

Discussion

The method used here to estimate of the strength of the PCF is in a number of ways conservative. As a coarse resolution climate model, the UVic ESCM is only able to simulate permafrost thaw due to active layer thickening and talik formation. The other two methods that thaw permafrost (water erosion, and thermokarst development) and the effects of fire are not simulated. The UVic ESCM soil component does not presently simulate methanogenesis, therefore all emissions from permafrost are assumed to be in the form of CO_2. We have chosen not to prescribe permafrost carbon below 3.35 m depth to accommodate a globally consistent prognostic simulation of permafrost. As such, we caution that the strength PCF may be stronger than estimated here.

It is troubling to consider the possibility that humanity may have already set in motion a positive climate feedback that is beyond our mitigative capacity through simple reductions in carbon emissions. Our results further suggest that there may be very little that can be done to prevent a hitherto unaccounted for additional 0.25 (0.1 to 0.7)°C of 21st century warming from the PCF. The significance of this result suggests that continued monitoring of carbon fluxes from permafrost soils should both be initiated and sustained to better keep track of this important carbon source within the Earth system.

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Gas Hydrates Formation in the Thermocycling Regime on the Basis of Water-in-Oil Emulsion

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Abstract

The formation and growth of Freon-12 gas hydrates in the water-in-oil emulsion in the sample thermocycling regime with increasing of the sample temperature above the melting point of ice was studied using the the differential thermal analysis (DTA) method.

Keywords: DTA method; emulsion; gas hydrates.

During the process of oil production in the Far North regions the presence of water, dissolved gas and negative temperature of the environment promote the formation of gas hydrates. Gas hydrates lead to a decrease in the capacity of pipelines and wells and even to their complete stoppage. The most probable formation areas are oil wells and pipelines carrying crude oil [*Sloan & Koh 2007, Makogon 1985*].

To improve effectiveness of the existing technologies aimed at preventing and destroying technogenic gas hydrates, it is currently highly important to obtain additional knowledge about the conditions of their formation, growth and dissociation kinetics. A significant shift in this direction is possible with the implementation of unconventional experimental methods in the sphere of gas hydrate studies. One of such methods is differential thermal analysis (DTA). The potential of this method depends on its capabilities for studying the processes of gas hydrates formation and growth.

Considering the high probability of gas hydrates formation in water-in-oil emulsions, in this research we concentrate on studying the process of hydrate formation in a model dispersion system.

Research materials and methods

The experiments testing the DTA method as applied to the study of hydrate formation processes were performed with the help of the apparatus described in detail in the work [*Vlasov et al. 2011*]. The entire set of the scheduled DTA tests was carried out using water-in-oil emulsion that simulates a real oil-in-water system. The initial emulsion components were distilled water and Castrol oil. Freon-12 (CCl_2F_2) was used as a hydrate forming gas.

Water-in-oil emulsions with 15% water content were produced by intensive stirring of the required amounts of water and Castrol oil using the IKA T10 basic disperser at the rotation speed of 20,450 r/min for 120 seconds. As a result of the initial components dispersion, the emulsion samples with an average water droplet diameter of 1.5 µm were obtained. To determine the average diameter and half-width of the distribution of water droplets in the emulsion samples, the classic method [*Fridrikhsberg 1984*] was used. It involved analyzing the linear dimensions of not less than 300 visually observed emulsion particles.

To increase the effectiveness of hydrate formation in the test samples, the cycling regime of temperature changes including the temperature increase above the melting point of ice was used [*Stern et al. 1996*]. Conditions for realizing the water ↔ ice phase transitions were created in the course of the experiment in accordance with the technology of hydrates preparation and for the purpose of conducting comprehensive DTA measurements. Given the small dimensions of water droplets in the emulsion, the samples temperature was varied in the range from -42 °C to +2 °C and kept at the given boundary values of temperature for 30 and 40 minutes, which guaranteed the completion of the corresponding phase transitions. The total duration of the thermocycle was 158 minutes. In the process of changing the samples temperature at the rate of 0.5 K/min using the DTA method, characteristic thermal peaks indicating water crystallization and ice melting were recorded [*Egunov 1996*].

The initial pressure of the hydrate forming gas at the temperature of +2 °C was ~300 kPa. In the process of obtaining the gas hydrate sample, the pressure drop of the gas above the sample was compensated as often as required at the initial stage of the cycle.

Discussion of results

At the initial stage of preparing the gas hydrate emulsion samples a high absorptivity of Freon-12 by Castrol oil was established. This enabled the correction of the technology of obtaining gas hydrate samples. In particular, for a more rapid saturation of oil with hydrate forming gas, brief liquefying of Freon-12 was performed at the early stages of hydrate formation.

In the process of thermocycling of the emulsion sample under the Freon-12 and air atmosphere by the DTA method, characteristic endothermic peaks of the unreacted ice melting were recorded (Fig. 1). From the analysis of the obtained thermograms, it follows that an increase in cyclicity leads to a significant decrease in the area of melting peaks, which indicates hydrate growth. According to the experiments results, it was also found that the processes of gas liberation and absorption involved in the cycling of the emulsion sample do not affect the basic parameters of the unreacted ice melting peaks recorded with the help of the DTA method.

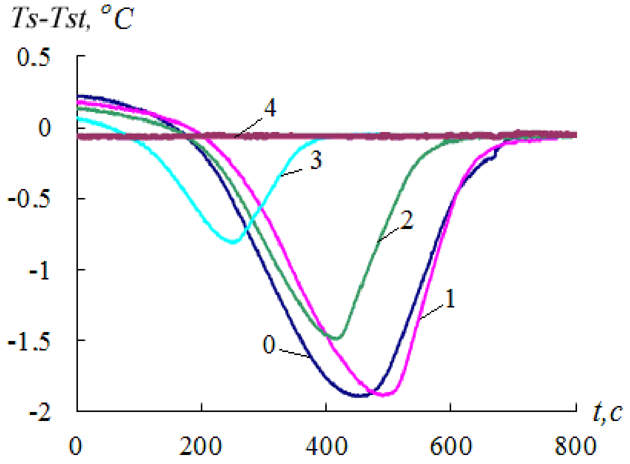

Figure 1. The unreacted ice melting peaks under the Freon-12 atmosphere recorded by DTA in thermocycles 1, 2, 3 and 4, respectively. 0 – ice melting peak under air atmosphere. T_S, T_{St} – sample and standard temperatures, respectively.

According to [*Brown 2001*], the melting peak area is proportional to the amount of ice in the sample. With regard to this fact, the degree of hydrate formation in emulsion samples was calculated according to the formula $P = S_n/S_o \cdot 100\%$, where S_n– the area of the unreacted ice melting peak in the n cycle (n=1,2,3…), S_o – the area of the melting peak of the ice obtained for the initial sample of the water-in-oil emulsion under air atmosphere. As a result, based on the obtained DTA data, a graph of the relationship between values *P* and *n* was plotted (Fig 2).

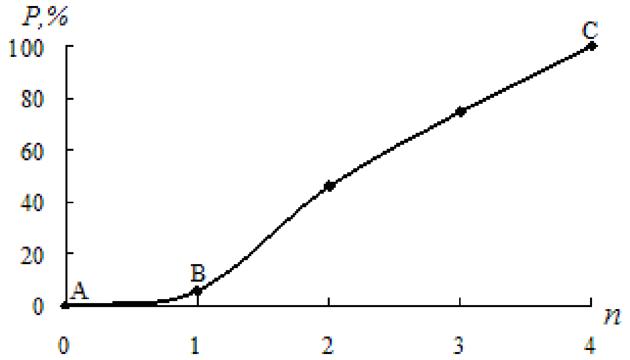

Figure 2. The growth of the degree of hydrate formation in the water-in-oil emulsion sample with an increasing number of freeze/thaw cycles.

In the figure we can observe the anticipated growth of the hydrate under study with an increase in the sample cyclicity. Low rate of hydrate formation in the AB interval is associated with deceleration of diffusion of Freon-12 molecules towards the front of hydrate formation as a result of absorption of the gas by Castrol oil. From then on, oil is saturated with Freon and within the BC interval the hydrate is actively growing at an almost constant speed. We should note that when the initial pressure was raised, the hydrate formation rate in the AB interval significantly increased. It was also established that liquefying of Freon-12 at the initial stage of obtaining the hydrate accelerates the process of hydrate formation.

From the obtained results it follows that the developed method of the DTA analysis of hydrate growth dynamics helps to reliably record the hydrate formation process in water-in-oil emulsion. However, before proceeding to the study of hydrate formation in the real oil-in-water emulsions we plan to evaluate the sensitivity of the DTA method by reducing the water content of the emulsion. In this case, it makes sense to increase the dimensions of water droplets, and to calibrate the melting peaks obtained under air atmosphere according to the known content of ice in them.

Conclusions

A significant result of this work is the developed DTA method of recording the process of hydrate growth in emulsion samples. Preliminary results based on the degree of hydrate formation in emulsion samples are of evaluative nature and require additional research.

Acknowledgements

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Thermal characteristics of mid-latitude high-alpine rockwalls at the Aiguille du Midi (3842 m a.s.l., Mont Blanc massif)

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Introduction

Permafrost degradation has been recently recognized as an essential triggering factor of rock falls/avalanches in high mountains areas. As permafrost in steep rockwalls is presumed highly sensitive to climate forcing, the ongoing global warming would likely impact their frequency and magnitude in the near future. Nevertheless, links between climate, permafrost degradation and rock instabilities are not quantitatively defined and remain misunderstood.

In densely populated areas such as European Alps, risk assessment and geotechnical responses are requiring fundamental understanding of the processes involved. A monitoring network has recently been developed throughout the Alpine range with a growing number of instrumented sites. But because of the difficulty of these *in situ* measurements in harsh and remote areas, statistical and numerical models are important tools to map permafrost distribution and to investigate thermal processes. Located on the French side of the Mont Blanc massif (western European Alps), high-elevated steep rockwalls of the Aiguille du Midi (AdM) have been the first site of such context to be instrumented with 10-m-deep boreholes. This study focuses on the first results of the measurements. It aims to characterize the permafrost at the site, and to discuss the main parameters in relation with our observations.

Site and monitoring system

The Aiguille du Midi area

With its three granitic peaks located on the NW side of the Mont Blanc massif (N45°52'-E6°53'), the AdM has been chosen as a study site for several reasons. First, with its high elevation and with a mean annual air temperatures (MAAT) close to -7.8°C (2007-2011), permafrost occurrence was extremely likely. Then, its topographical settings with varying aspect and slope are representative of the Mont Blanc rockwalls. Some of them have besides displayed a recent and remarkable rockfall activity such as the north side of the Aiguilles de Chamonix which includes the AdM [*Ravanel & Deline, 2010*]. Finally, a cable-car leads to the AdM (half a million of tourists per year), where abseiling is possible for equipment installation, maintenance and data collection.

Instrumentation and monitoring

Two EU-funded projects *PERMAdataROC* (2006-2008) and *PermaNET* (2008-2011) have supported the equipment of the AdM.

Since 2005, a high-resolution DEM of the outer and inner (galleries) rockwalls of the AdM has been realized using terrestrial laser scanning. Between 2007 and 2010, automatic weather stations on the north and south faces of the Piton Central have recorded air temperature near the rock surface, wind speed and direction, short and long incoming, and outgoing solar radiations. Météo France is also recording air temperature and wind speed and direction at the top of the Piton Central since 2007.

Rock temperatures are monitored by ARPA VdA and University of Zurich since 2005 with near-surface sensors (from 3 to 55 cm; Geoprecision M-Log6, resolution: 0.01°C, accuracy: ± 0.05°C) on all aspects, and by EDYTEM Lab with 10-m-long chains of 15 thermistors (Stump YSI 44031; resolution: 0.1°C, accuracy: ± 0.1°C) installed into three boreholes on the NW, NE and SE faces (Table 1) since December 2009 (April 2010 for the NE borehole).

Table 1. The three 10-m-deep boreholes of the AdM

Borehole Code	Elevation (m a.s.l.)	Aspect (°)	Slope angle (°)	MART* (10 m-2011)
ADMNW	3738	345	90	-4.7
ADMSE	3745	135	55	-1.45
ADMNE	3753	50	65	-3.85

*MART: mean annual rock temperature

Five geophysical surveys (Electrical Resistivity Tomography) have also been carried out with the University of Bonn.

Thermal characteristics of the site

Scattered rock temperature data highlight the strong variability of thermal conditions on spatial and on temporal scales.

Spatially, Fig. 1 is displaying the different temperature profiles: NW subsurface temperature is roughly 4 to 5°C colder than the SE one. This difference decreases with depth, and is close to 3°C at 10 m deep. However, the NW profile at around 2.5 m deep is locally distorted and globally cooled. This corresponds to a rock discontinuity pointed out during the drilling.

Temporally, Fig. 1 also shows varying thermal conditions from one year to another at a same location. 2010 was the coldest recorded year since 2007 (MAAT: -9.1°C), and 2011 the warmest one (-6.7°C). SE and NW changing profiles from 2010 to 2011 are in agreement with this climatic parameter. Mean annual temperature was positive at the SE borehole up to 1.4 m deep in 2011, whereas it remained negative during 2010. Active Layer Thicknesses (ALT) on the SE face in 2011 was exceeding the 2010 one for nearly 3 m, reaching up 7.9 m deep in October. A slighter thickening of the active layer has also been observed on the NW borehole: in 2011, the rock thawed on 2.3 m, which is 0.5 m deeper than the previous year.

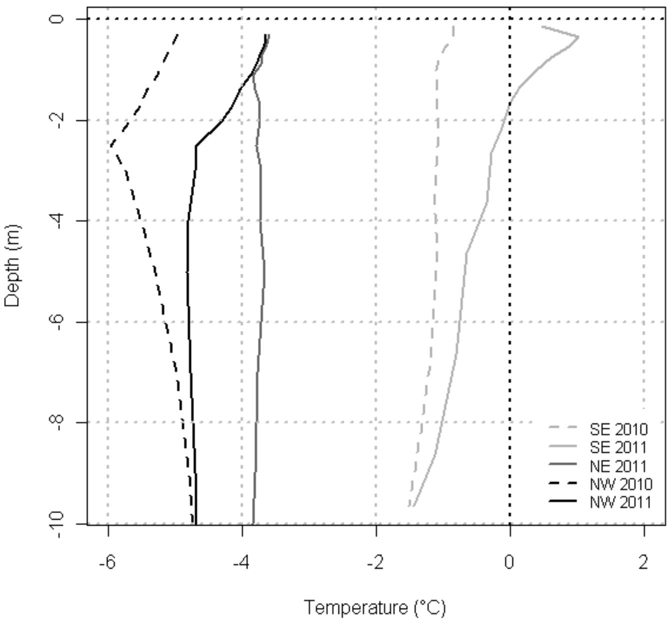

Figure 1. Mean annual temperature profiles at the SE, NW (2010 and 2011), and NE (2011) boreholes.

The NE face is not responding in the same way to the 2011 warm period: its ALT is 0.3 m thinner than in 2010 (3 m deep in 2010). This phenomenon underlines the complexity of thermal behavior of the rock faces controlled by interacting parameters.

Discussion

By comparing boreholes measurements with air temperature data and models outputs, we obtained a qualitative understanding of the interaction of the parameters responsible for observed features.

The warmer profiles in 2011 are illustrating the strong sensitivity of rock faces to climatic signal. Nevertheless, the changing ALT with aspect and time reveal how topography affects the intensity of the signal. Firstly, topography controls the amount of incoming direct radiations. That would explain the temperature and ALT differences in the most exposed to radiation (SE) and shadowed (NW) faces. This phenomenon is also displayed by the recorded maximum temperatures: the 30-cm-deep sensor reached a maximum temperature at least twice warmer on SE than on NW faces: 17.8°C and 8°C in 2011, respectively.

Secondly, the particular response of the NE ALT to the warm summer of 2011 would be induced by a thin snow cover which is partly under topographical control. Indeed, the face is prone to relatively thin snow accumulation, and summer snowfalls could have isolated or cooled the face. The NW near-vertical rockwall, where snow accumulation is only possible on small terraces, is directly controlled by air temperature. The SE face is mainly controlled by direct radiation, and the snow could have melted rapidly. Also, simulated profiles extracted from a 2D numerical model [*temperature fields of an horizontal slice of the Piton Central, Noetzli et al., 2011*] are warmer than the observed ones. That suggests a cooling factor likely due to global effect of snow cover. This assumption is strengthened by studies on steep faces showing that thin snow accumulations on complex morphologies can lead to this effect [*Pogliotti, 2011*].

The distorted NW profile highlights the complexity in the heat transfer processes introduced by rock discontinuities. Heat fluxes calculations indicate a varying impact of the fracture: air ventilation is potentially responsible for cold conditions and remains the most important pattern [*Hasler et al. 2011*], but heat is temporarily brought during summer, perhaps because of water circulation. This non-linear profile indicates that conductivity is not the unique heat transfer way as it is often assumed in massive rock. It is locally interacting with convective transfers (air ventilation) and heat advection (water circulation).

Conclusion and outlooks

The two years of recorded rock temperatures bring out the characteristics of permafrost in steep rockwalls. Variability of thermal regimes is resulting of interacting parameters. Primarily, the atmosphere-rock interface is controlled by imbrications between climatic and topographical factors which regulate the amount of energy received by rockwalls. For heat transfer, even if thermal conductivity is dominant, lithological settings locally involve air ventilation and heat advection which can affect the global thermal regime. These observations provide a conceptual basis for future model development. A quantitative approach will be further required for parameterization of the simulation including snow cover effect and heat transfer interactions. Measured data on distribution, characteristics and evolution of the snow cover during the winter 2011-12 will be available for the TICOP and will support this quantitative analysis. By using potentialities of these field measurements, 3D models of the AdM site simulating steady-state and transient temperature field will be built in the near future.

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Aerovisual Observations as a Source of Geocryological Information

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Introduction

The insufficient quality of geotechnical investigations along with errors in the pipeline systems engineering shift the responsibility for failure-free operation of such systems to operating organizations. The limited funds and swiftly changing geocryological environment caused the need for the methods of operational situation analysis aimed to develop and implement the compensation or protective activities on mitigation of the impact of geocryological processes on the pipelines.

Aerovisual observation is one of the few techniques that allow to obtain, in short time and by relatively low cost, the up-to-date survey information about the spreading and dynamics of the geographic range of geocryological processes observed on the extended linear objects that cross several landscape climatic zones.

Technological and Methodological Peculiarities of Aerovisual Observations

The tasks to be solved in order to obtain information on the distribution and dynamics of the geographic range of geocryological processes include the elaboration of the method of geocryological phenomena detection as well as the determination of their characteristics and distribution limits. Aerovisual works include compilation of a list of morphological processes with regard to their diversity in different landscape climatic zones and the determination of technological requirements to the performance of works. The oblique photographic survey of the pipeline's route is performed with a fixed preset zoom by a team of professional geologists. The choice of the zoom depends on the thoroughness of geocryological phenomena and processes description as well as on the orientation of their geographic ranges on the terrain. The length of the photographed route section should not be less than 100 m, and the setup benchmarks should be necessarily registered. Photographic survey of extended geocryological phenomena (e.g. thermoerosional ravines) must fix the beginning and the end of their occurrence. In addition, oblique photography of the natural landscape is necessary if the development of natural processes in its area can impact the pipeline system. This type of survey has been successfully used before create the Landscape Map of the USSR (scale 1 to 2,500,000), in order to determine the benchmarks for each of previously identified landscape types. It ensures more precise on-site orientation of permafrost phenomena, allows to identify interrelations between the landscape elements and to get images of the phenomena in their natural forms. The resulting photos are representative and easily understandable even by non-professionals.

During aerovisual works the performance of two flights (up and down the oil flow) proved reasonable. Two flights cover the width of the route corridor under survey up to 1 km; so, it becomes possible to compare the disturbed and non-disturbed landscapes. As a result, the probability to miss any cryogenic phenomena is reduced. Within the pipeline's route sections with deep forests, where the trees hide the right-of-way's vision, it is used to increase the flight altitude and the distance from the pipeline's axis in order to improve the vision. Turns and double flights are made over individual sharp bends of the pipeline's route, thus allowing full vision of them.

In addition to photographic survey, video filming and GPS track registration are performed during the full investigation. The identification of the boundaries of extended geological phenomena by photographic materials does not ensure sufficient precision. In this case, it is proposed to fix the boundaries of geographic ranges of the processes using the video filming.

Timing of the navigational and survey equipment is carried out by means of photographing of the computer's display that shows the universal time (UT) value. This timing is carried out twice, before and at the end of a flight.

Precise fixation of the required elements of observation is achieved by electronic maps with maximal detailing that show the layers of technogenic objects, landscape elements, and zones of previously identified geological hazards. These maps are displayed on the GPS receivers of geologists and help to draw their attention to critical route sections.

Aerovisual works are performed twice a year: in spring, after melting of snow cover, and in late summer, during maximal permafrost thawing. The main objective of the spring flights is registration of the distribution and dynamics of geographic ranges of seasonal geocryological processes such as icing formation and heaving.

Processing of Results and the Use of Obtained Information

Affixment of photographing points in the electronic topographic map is made based on the GPS track. This map is developed by means of the MapInfo software used to develop a special program that allows to set and save characteristics of geocrylogical processes' distribution ranges and to form the reporting tabular forms that are necessary for further analysis of the situation changes in time.

Characteristics of geocryological occurrences include information on the development conditions of relevant processes. Registration of the sections where compensation activities have been already performed allows to make conclusions on efficiency of such activities in different geotechnical environments. However, aerovisual observations do not ensure detailed characterization of the terrain and its geocryological processes. Certain characteristics, e.g. extension of a geocryological phenomenon, are determined by experts and should be updated during field land investigations.

Individual examination of each geocryological occurrence is important for the analysis of the process dynamics. Tabular forms and photos obtained as a result of annual flights form the main basis for this analysis.

Conclusions

Extended linear objects are characterized by wide diversity of geocryological, climate, geomorphological, hydrological, and other types of natural conditions. One of promising methods used to analyze the information obtained in the process of aerovisual survey is the comparison of the distribution and intensity of exogenous geological, primarily geocryological, processes and landscape geological characteristics of the terrain (obtained with the use of the existing zoning systems). The comparison is aimed to identify the role of natural and technogenic factors in the activation of those processes within different areas.

Disadvantages of aerovisual observations are as follows:

1. Aerovisual observations cannot ensure precise setup of an object, therefore, they have to be used together with other remote methods (orbital survey, aerophotographic survey).

2. This type of observations provides no detailed information on the object in question and, at particular sites, its results have to be updated in the process of field land investigations.

3. Analysis of the dynamics of some extended cryogenic phenomena, such as thermoerosion, is complicated, since it is not possible to cover them by a single shot. Conclusions on their activation can be made on the basis of indirect signs only.

Advantages of aerovisual observations are as follows:

1. Aerovisual observation is one of the most cost-effective methods that allow to provide, in a short period of time, up-to-date information on the distribution of geocryological and other exogenous processes along extended linear objects.

2. This method allows to assess the development dynamics of geocryological and other exogenous geological processes and to identify the sites that require performance of field works as well as compensation of protective activities. Operating companies can be in advance warned about possible extreme situations.

3. The developed method of aerovisual observations, which is based on uniform descriptions of exogenous geological processes, allows to obtain information on their distribution, orientation in space, intensity and dynamics in various landscape geological environments.

The authors recommend to use aerovisual observations as an operational method to update the information on the presence and location of the geocryological processes that have manifested themselves. This information is used to rank the identified geographical ranges by the chosen criteria in order to determine the scope and sequence of further detailed land investigations.

Temporal and Spatial Variability of Radar Backscatter over a Permafrost Landscape at Kapp Linné, Svalbard

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Introduction

Freeze/thaw cycles in permafrost areas have been studied previously with synthetic aperture radar [*Rignot & Way 1993*] but with limited temporal resolution. Here we describe a five-year very densely sampled time series of Envisat ASAR wide swath backscatter data acquired over a permafrost landscape at Kapp Linné, Svalbard. We use the time sequence to study the freeze and thaw cycles in this unique landscape in order to understand the dominating contributions to C-band backscatter in permafrost regions. Geometry corrections and temporal filtering techniques gave enhanced understanding of the underlying effects. In order to complement the understanding, auxiliary data sets have been used. These consist of in situ air and ground temperature data and MODIS snow cover maps.

Dataset

Study area

The study area of size (16.5 x 20) km covers the Kapp Linné peninsula on western Svalbard 78.0°N, 13.7°E. The area consists of periglacial landscape including an up to 3 km wide strandflat along the western coastline and mountains ranging up to 600 to 800 masl. with several smaller glaciers. For this analysis we are mostly interested in the permafrost of the strandflat along the coast on the west side of the peninsula, where the landscape is relatively flat.

Envisat ASAR data

We have used a densely sampled time series of Envisat ASAR wide swath data over the study area. The spatial and temporal coverage over the study area varies somewhat during the study period from 18 Feb 2005 to 29 Sep 2010. The total number of SAR scenes used in the time series is 1399. We use all available satellite geometries. SAR was geocoded and projected on the same geographical grid (UTM z33N, WGS-84) using 100x100m spatial resolution. The geocoding applies a digital elevation model (DEM) with 20 m spatial resolution. Areas subject to layover and radar shadow due to topography were masked out as invalid samples in each image.

Terra MODIS data

We also use the NASA MODIS/Terra Snow Cover Daily L3 Global 500m Grid, Version 4 (MOD10A1) that provides snow cover fraction [*Hall et al., 2002*]. The product provides masks for areas that are covered by clouds, ocean and polar night darkness. We have resampled the MODIS data into the same projection (UTM z33N, WGS-84) over the study area. We have processed daily data sets for the same period (2005-2010) as we have ASAR data, with the exceptions of the extended polar night period (October 15-March 10) when the solar angle is too low to detect snow. We then developed a time series of snow cover maps that was interpolated between cloud free samples in the temporal dimension. Due to the persistent cloud cover on Svalbard, this yields a coarse product that can be used to get hints about the snow cover over the permafrost landscape and snow climatology on Svalbard [*Malnes et al., 2010*]. Snow cover fraction is set to 100% during the polar night period.

In-situ temperature measuremen.

We use several air and ground temperature stations from the Nordenskioldland Permafrost Observatory network of borehole sites [*Christiansen et al, 2010*]. Several of the stations measures both air temperature (typically 25 cm above the ground) and temperature in the ground at various depths. Most of the sensors provide continuous time series from 2004 to present, but there are also dropouts for certain intervals due to malfunctioning of the instruments.

Methods

Incidence angle correction

Radar backscatter has a strong dependence on the local incidence angle. To use all available SAR images that cover the site we need to correct the backscatter with respect to incidence angle before we can study the temporal development of the backscatter. In this study we use a relative measure for the radar backscatter $\Delta\sigma(t)=\sigma(t)-\sigma(ref)$ where $\sigma(t)$ is radar backscatter and $\sigma(ref)$ is the reference backscatter for the relevant satellite geometry obtained by averaging all available SAR images with the same geometry. Due to the larger variability in the data in the summer season, we use only data for the winter season for averaging. For the study area we use a total of 59 different imaging geometries, A reference image is typical an average over 10-30 SAR scenes.

The above method is analogous to the current state of the art method for wet snow detection using C-band SAR [*Nagler and Rott, 2000*]. It has also been applied to Svalbard snow cover estimation [*Malnes et al., 2010*].

Temporal sampling and filtering

The first step in the temporal filtering is to resample the irregularly sampled time series to a regular daily grid in the time dimension by linear interpolation. In the next step we use a temporal filter to reduce the noise due to speckle and temporal variability in the radar backscatter. The filter is designed to catch the annual cycles in the differential radar backscatter, as well as the abrupt changes caused by snow melting, by combining two median filters with different filter widths.

Results

We can now present the relative backscatter as a time series of maps from study area. Wet snow (sometimes also wet soil) is detected by using the threshold $\Delta\sigma$ <-3dB [*Nagler&Rott, 2000*]. The wet snow map layer is blended with the MODIS snow cover fraction. The resulting maps give a relevant interpretation of the development of freezing/thawing vs. snow cover. Since the area covers several landforms (bog, rocky terrain, steep hills and glaciers) we also observe differences in the annual cycles of the respective relative backscatter for the individual landforms.

We now study the in detail annual cycle of the backscatter at a beach ridge site (KL-M-2-4 in the NORPERM database) on the strandflat area 78.06N,13.68E, were we also have in situ observations of air and ground temperature. Figure 1 shows the annual variability of the relative backscatter for the beach ridge. We also show the temperature and the snow cover fraction for the same point. From the five year time series it is evident that there is an annual sinusoidal cycle of the backscatter at the beach site, where backscatter is high during summer (June-Aug), and decreasing to a minimum in late fall (Oct-Dec). The backscatter increases during the winter. The snow melt period is superimposed on the cycle with abrupt drops for a short period in May-June. The length and magnitude of this period depends on the amount of snow which varies from year to year.

The main reason for the variability in the relative backscatter is the amount of free liquid water in the snow and the top soil layer. Liquid water absorbs radar waves and causes reduced backscatter. During summer the soil moisture drops in this terrain as the active layer develops. In the early winter liquid water seem to be present in the top layer for a significant period after the onset of frost until typically December. This reflects the period of in freezing of the active layer in this relatively warm and wet part of Svalbard. After this period the backscatter increase until the onset of the snow melt period, when the ground surface is frozen and snow or ice covered.

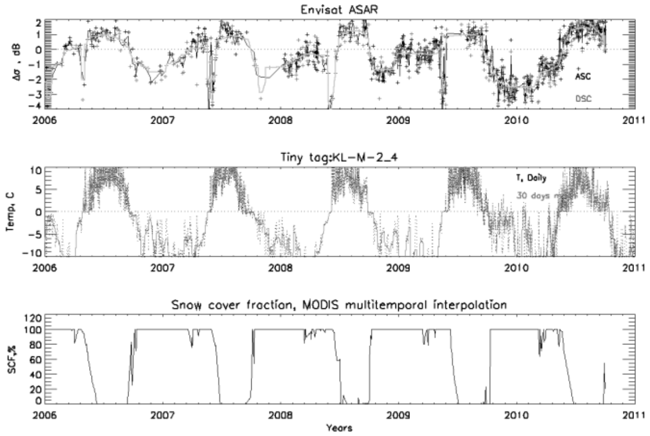

Figure 1. Relative backscatter (top), air temperature (middle) and snow cover fraction (bottom) for site KL-M-2-4

Conclusions

The present study has shown that we can use Envisat ASAR data to obtain detailed spatial and temporal information about the freeze and thaw cycle of the active layer above the permafrost. The relative radar backscatter shows a pronounced annual cycle that can be correlated to the freeze/thaw cycles.

Acknowledgements

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The Potential of the Glaciochemical, Diatomaceous and Palynological Analysis of Glacial Strata

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Core drilling of glacial strata is presently one of the primary ways of obtaining palaeoeclimatic and palaeoecological data with high temporal resolution. It is assumed that the precipitation that fell on the glacier surface, gradually submerges into the depth with the preservation of its isotope-geochemical and gas composition as well as micro-inclusions [*Mikhalenko 2008*]. First and foremost, the horizons of different ages are singled out in the obtained ice cores based on the visual and isotope-geochemical stratification as well as inclusions of biological material and horizons of contamination. Afterwards, glacial strata are dated based on stratigraphic methods, on the use of reference horizons (of high radioactivity and acidity, dust-layers), on methods of absolute geochronology (by the radioactive isotopes ^{10}Be, ^{14}C, ^{36}Cl, ^{39}Ar, ^{81}Kr, ^{210}Pb) and also based on the flow models.

Ice cores contain information on the thermal, moisture and circulation regimes, on gas and chemical composition of the atmosphere, biological productivity, volcanism, solar activity, anthropogenic activities, etc. When interpreting the glaciochemical results for climatic and environmental palaeo-reconstructions, the data obtained are sometimes not enough. Therefore, additional data of palynological and diatomaceous analysis of ice cores are used. But in this case researchers take into account the particularities of interpretation of the data obtained by each method. For example, plants and algae have seasonal cycles in their distribution. Diatoms and cysts are most abundant in March-June and September-November, while the conifers produce most of pollen only in March-April, and the deciduous trees and herbs - in May-July. The range of pollen drift is also taken into account. For example, *Larix* can distribute its pollen only over several hundred meters, while *Picea* and *Betula* – over 250 – 400 km, *Abies* – over 250 – 1300 km, and *Pinus* – already over 500 – 1700 km [*Sladkov 1967*]. The joint use of these three methods for palaeo-reconstructions in the inland areas was first implemented based on the data of the Altai ice core samples.

Ice core from a saddle of Mount Belukha (the Altai, the Katun Ridge, 49°48'26.3" N, 86°34'42.8" E, the altitude is 4062 m) was obtained by the joint Russian-Swiss expedition in 2001. After that, the frozen core was taken to the laboratory of Radiochemistry and Environmental Chemistry of the Paul Scherrer Institute (Switzerland), where it was dated and analyzed, layer by layer, in collaboration with the specialists of IWEP SB RAS. In the same way, a 72 m long ice core from the Tsambagarav Ridge (the Mongolian Altai 48°39.338’ N, 90°50.826’ E, the altitude is 4148 m) was obtained and taken to the laboratory in July 2009. By the present time, most of the core (its surface part) was dated and analyzed layer by layer. Due to the small amount of the data, there were fragmentarily conducted a palynological analysis and a diatomaceous analysis of both cores. As a result of the studies, various biological objects were found in the ice cores. The objects included dia-tomic algae shells, Chrysophyta algae cysts, lower plants spores and higher plants pollen (Fig. 1).

The Tsambagarav ice core

In total, 25 species (29 species, varieties and forms) of diatoms were found in the core samples. The dominant species were bottom-living forms and foulers typical of the littoral area of various types of water bodies or algae population of rocks in mountain rivers. *Hantzschia amphioxys* (Ehr.) Grun. (freshwater plant, ubiquist) was spread throughout the entire core. A distinctive feature of this species, as well as of another diatom, *Pinnularia borealis* (Ehr.), is that they are widespread not only in water but also in dry land habitats in association with bryophytes [*Egorova et al. 2011*]. The significant amount of diatom valves found in the upper layer decreased towards the deep layers of the core and varied from 810 to 8114 thousand valves/m^3, with the average values being 1828±305 thousand valves/m^3. The sharp decrease in the number of diatoms already at some depth from the glacier surface is probably associated with the negative influence of the glacial stratum on the preservation of diatom shells.

The change in the number of cysts, fern spores and pollen of coniferous and deciduous plants from the upper layers of ice towards the underlying layers is not so significant. Given that the samples under analysis cover an almost 70-year long period, we can assume that in the previous century the transfer of pollen from the territories occupied by coniferous forests was significantly higher than at present. Thus, in the Altai the ratio of diatoms (in the upper layers of the glacier), Chrysophyta algae cysts, spores and pollen of plants (over the entire depth of the glacier) can be used as biomarkers for climatic reconstructions based on the data of ice cores.

The Belukha ice core

The Belukha ice core samples that were examined cover the period between 1961 and 2001. In the samples there is a constant presence of the pollen of conifers and cysts or spores of lower plants, while diatoms and pollen of deciduous plants did not occur in some samples at all. A distinctive feature of the ice core examined was a ubiquitous high content of higher plants pollen in the samples. It was primarily the pollen of conifers, its amount varied from 32 to 150 thousand grains/m^3, the average amount being 80±4 thousand grains/m^3. The maximum amount of pollen of conifers was recorded in 1983, while its minimum was registered in 2000. In addition, a certain number of Chrysophyta algae cysts and fern spores that are sometimes very difficult to distinguish visually could be constantly found in the ice. Along the core length their number varied from 5 to 62 thousand units/m^3, the average number being 26±3 thousand units/m^3. The maximum number of cysts was recorded in the layer that was formed in 1999.

Chrysophyta algae cysts and spores of lower plants vary little in composition: most frequently observed forms are smooth spherical forms that are found in almost all investigated layers of both ice cores.

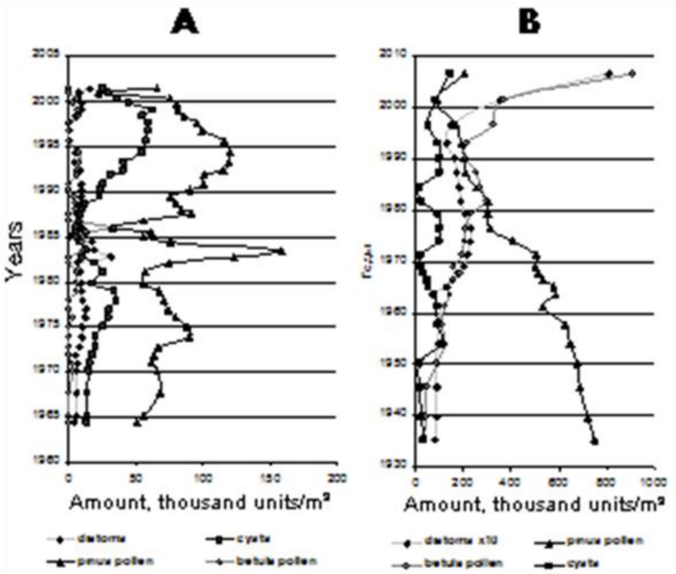

Figure 1. The number of diatoms ("*diatoms*"), Chrysophyta algae cysts and spores of lower plants ("*cysts*"), pollen of conifers ("*pinus pollen*"), pollen of herbs and deciduous ("*betula pollen*") plants in ice cores collected in the Belukha (A) and the Tsambagarav (B) mountain massifs (In Figure B the number of diatoms is x10).

Thus, the conducted study showed that the biological objects detected in the ice cores can be used as biomarkers for palaeoclimatic reconstructions in the Altai region, and for each glacier the most suitable indicators can be singled out. For instance, the pollen of conifers can serve as a marker or bio-indicator for the Belukha glacier, as this glacier is under the influence of the western atmospheric flow some of whose air masses first pass over Western Siberia before passing over Belukha. Considering that the pollen of some coniferous plants can be transported over long distances, we can assume that the pollen grains that are buried in the Belukha glacier may be the "product" of a vast forest area in Western Siberia. On the contrary, diatoms and pollen of birch are more suitable for the analysis and reconstruction of the Tsambagarav glacier located in Mongolia. Knowing that birch pollen is transferred through the air over insignificant distances, we can assume that its presence in the glacial stratum of the Tsambagarav Massif is a local "product" (produced, for example, by high mountain elfin wood forms of birch). The same may be assumed in relation to diatoms that can get to the glacier from the littoral zone of a number of small mountain lakes located on the territory of Mongolia.

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PR-technologies in Promotion of Permafrost Studies and Specialized Higher Education

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Many famous scientists of our time have pronounced and still pronounce the need to promote the science as well as scientific achievements and investigations. Among them are: V.L. Ginzburg, Ph.D. (Physical and Mathematical Sciences), Academician of RAS, Director of the RAS Centre for Photochemistry; V.G. Debabov, Ph.D. (Biology), Director of the State Research Institute for Genetics and Selection of Industrial Microorganisms, Associate Member of RAS; A.I. Akopov, Ph.D. (Philology), Head of Department of Communication Media of Southern Federal University; A.G. Sergeev, Science Editor of the *Vokrug Sveta* ("Around the World") magazine, moderator of the Scientific Journalist Club. Advertisement, public relations (PR) and journalism are called among possible promotional mechanisms. The need to establish press services or at least a staff position of a PR specialist in the research institutions is announced. The supposed functions and operational format of such a service are defined [*Sergeev 2007*]. These theses try to present in a structural form the opportunities provided by PR in terms of popularization of science, in particular, the promotion of the Earth cryosphere studies and the specialized higher education. The tasks that can be solved by means of PR include the engagement of new scientific workers and the persuasion of the public that cryology can help to minimize the risks of man-caused impact on the unique ecosphere.

This approach allows to name six types of target audiences for the specialized higher educational organizations or research institutions in terms of PR arrangement:

1. Mass media. The **objective** is to establish favorable and mutually beneficial relations.
2. The public. The **objective** is to explain the essence of the Earth cryosphere disciplines and to prove the necessity to consider results of research investigations in the industrial development of the North (general popularization).
3. Municipal, regional and federal authorities. The **objective** is to form favorable environment for decision-making concerning research institutes, specialized departments, permafrost studies, and the development of the Russian Far North and the Arctic.
4. Academic community. The **objective** is to facilitate mutual understanding between scientists in various areas and to engage new brainpower (popularization among specialists).
5. Students of specialized higher educational institutions. The **objective** is to stimulate them to stay in the academic world and to strengthen their belief in the significance of their profession.
6. High school students. The **objective** is to form their interest in the Earth cryosphere studies and to attract them to specialized educational institutions.

The modern PR practices allow to divide this field into the informational PR and the organizational (event-driven) PR. One of the latest authoritative works on PR theory names media relations, special events, sponsoring, and friend-rising [*Krivonosov, Filatova & Shishkina 2011*].

Informational PR

Informing the public about the activities, achievements and prospective development of an organization is the main condition of shaping friendly attitude towards it and, consequently, positive behavioral sets. Some research institutions pay significant attention to informational support of their activities. For example, the SB RAS Institute for Earth Cryosphere provides publications in the print media of the regional and international level (*L΄observateur russe*), in the Internet, as well as video plots on the regional TV. Research institutions publish the materials on scientific achievements and future conferences, image articles about their specialists and interviews with them.

Specialized scientific journals cover the limited target audience, that is the academic community (*Kriosfera Zemli* (SB RAS Institute for Earth Cryosphere), *Nauka I Tekhnika Yakutii* (Melnikov Permafrost Institute SB RAS). The popular science editions mostly aim to form stable interest in science among the general public. The SB RAS Institute for Earth Cryosphere publishes the only popular science magazine about cryology in the world (*KholodOK!*). The scientists of the Melnikov Permafrost Institute published the biographies of their colleagues. The book titled "The Geocryological Scientific School of Yakutia" edited by R.V. Dzhan was published in 2010, and the popular science book by V. Alekseev "We Live on Permafrost" was published in 2011.

Research institutions and specialized higher educational institutions use the abilities provided by the Internet. Every institute has its own web-site. The SB RAS Institute for Earth Cryosphere has its group in a social network.

Mass media can initiate popular science plots by themselves. The telecast by A. Gordon "Permafrost" with the participation of V.N. Konishchev, Ph.D. (Geography), Head of the Department of Cryology and Glaciology of Moscow State University [*2002*], and the documentary "Tiksi, the Realm of Permafrost" shown by "*Moya Planeta*" TV channel in 2010, rendered an invaluable service for the popularization of science. Television still holds the first place in the coverage of audience; however, web resources, such as Geowikipedia (all about geology), Geology – Encyclopaedia for All, Oil and Gas Information Agency, and Russian Geographic Society play an important role in the popularization of cryological studies.

There are other forms of informational PR that could be used for the promotion of permafrost studies and specialized education. This is, for example, the publication of a corporate edition designed for the internal as well as the external audience. Public pages or groups in the social networks as wells as blogs of famous scientists will attract the youth oriented at interactive communications.

Media Relations

An effective interaction with mass media results in positive public opinion, optimal informational environment, and efficient and regular publicity (maintenance of attention). Many forms of interaction with mass media are already being used by higher education and research institutions. The SB RAS Institute for Earth Cryology arranged the meetings with journalists where scientists report on their works and demonstrate the miracles of science. The specialists of the Institute give comments on popular science articles. The Institute tracks mass media publications about its activities. The SB RAS Melnikov Permafrost Institute used press releases in the Internet during preparations to the 10th anniversary of the journal.

Effective interaction with mass media requires a dedicated specialist or service that will take responsibility for regular informing mass media on the activities of an organization. Relevant working formats may include: press releases, news releases, journalist events (press conferences, round tables, business dinners, open days, press tours and excursions, workshops, training courses, expeditions), assistance in organization of interviews and lectures of famous scientists, assisting journalists in preparation of popular science texts (consulting, provision of illustrative materials), mass media monitoring. The modern PR practice allows other forms of interaction with mass media, such as club for journalists writing about permafrost, contests of best materials on cryology, informational support of the columns or broadcasts, etc.

Special Events

Such events promote communications between an organization and target audience, as well as the increase of its publicity capital. Since the number of ordinary events in the life of an organization is limited (scientific discovery, anniversaries, award-winning, professional holidays), special events are organized.

In 2010 the SB RAS Melnikov Permafrost Institute, celebrating its 50th anniversary, effectively used the potential of a natural event, covering the festivities in mass media. The Institute staff uses every chance to congratulate the colleagues with anniversaries on the web site and through regional mass media. It should be noted that there are also obituaries that inform the public about the Institute and its experts. The Department of Cryology and Glaciology of the Geographic Faculty of Moscow State University celebrated the 65th anniversary of its establishment, and the Department of Earth Geocryology of the Geological Faculty of Moscow State University celebrated the 40th anniversary of the Zvenigorod practical training.

If covered by mass media, special events that are traditionally arranged by higher education and research institutions also help to attract attention of the scientists and general public to the Earth cryosphere science. They include theoretical and practical conferences (including videoconferences and webinars), scientific readings, symposiums, forums, presentations of scientific developments and monographs, contests of scientific works, and competitions.

Such events may be targeted at academicians as well as students. Specialized departments organize contests for scholarships, students' scientific work days, festivals of science, job fairs for graduates, and open days. The MSU Geological Faculty organizes the Geological School and the Popular Geology group for high school students. It may be interesting to organize such events as the contest of school essays "Holidays in the Arctic", the students' contest "The Best Trainee" with the winner being named by employers. The forms of special events are limited only by imagination and abilities of organizers and may include meetings, round tables, exhibitions, fairs, permanent exhibitions and museums (including virtual ones) of higher education institutions, public lecture centers, e.g. the Geologist Day flashmob, or a road show with the presentation of the fields of study in an educational institution.

Sponsoring or Friend Rising

Friend rising, or search and engagement of event sponsors, includes the following types of work: elaboration of a sponsorship package, elaboration of promotion and PR support of a project, assessment of the interest of business representatives (potential sponsors), activities on engagement of potential sponsors. In spite of the fact that 8 or 9 of 10 proposals are rejected, the money-collecting events by themselves promote the knowledge of the public about the activities of an educational or research institution.

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The Site for Pile Testing in Seasonally Frozen Grounds

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The Melnikov permafrost institute of the Siberian branch of the Russian academy of sciences (MPI SB RAS) in collaboration with Moscow state automobile and road technical university (MADI) conducts tests of piles with adjustable-type design that makes it possible to stabilize the load-bearing capacity during the grounds thermal regime change.

It is a system of boreholes drilled according to the pattern that is presented in Figure 1. The central borehole is designed for temperature measurements. It is assumed that temperature values are the same for all the boreholes at the test site. A circular pattern of these boreholes is chosen to support this assumption, with the lowest possible distance between them. Weights are used to create a pressure-penetration load. Their dimensions limit the distance between adjacent boreholes.

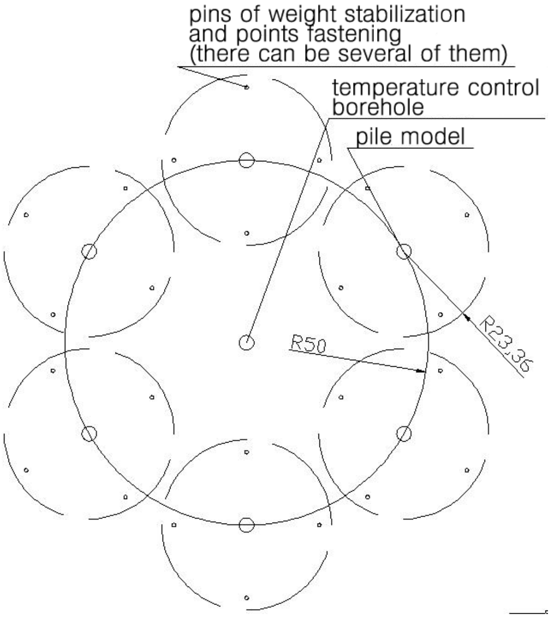

Figure 1. Boreholes pattern.

Figure 2 presents a photograph of drilled boreholes. Boreholes are drilled in thawed ground; the mouths are closed with plugs to isolate from moisture during the period of positive temperatures.

A convertible dome is designed to ensure the ease of access and protect against snow accumulation. It can be clearly seen in Figure 3.

Temperature control is performed using a device with a sensor. The view of the sensor is presented in Figure 4.

The sensor responds to temperature change with the corresponding value of the analog signal. As a result, the device determines the temperature within the sensor location area in three minutes. Measurements at the minimum of three elevation points – at the bottom, in the middle and at the top of the well – have to be performed in order to objectively evaluate the temperatures at various depths.

The pile vertical movement (settlement) control is performed using a dial indicator.

The boreholes have the diameter of 4 cm and the depth of 100 cm, with the use of the scaling parameter of 1/20. This means that a pile with the diameter of 80 cm and the length of 20 m is modeled.

As a result, a testing site that has the smallest possible dimensions is created. It enables evaluation of the load-bearing capacity of scaled-down models of piles of any construction in seasonally frozen grounds without considerable economic and labor costs.

Figure 2. Boreholes

Figure 3. Closed testing site

Figure 4. Temperature measuring device

A Pleistocene-Holocene Section in Terrace IV of Kazantsevo Fluviolacustrine Deposits, Nadym-Pur Interfluve

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Abstract

A quarry outcrop of Pleistocene-Holocene deposits has been studied near Novyi Urengoi city, in northern West Siberia. The section comprises several lithological-genetic units that correspond to main Late Quaternary events and bears abundant ice-wedge casts.

Introduction

The Nadym-Pur watershed areas abound in lake basins (both water-filled and dry called khasyrei) and in polygon systems with ice-wedge casts of Late Pleistocene ages.

There have been four main stages in the history of permafrost in West Siberia [*Baulin et al. 1989*]:

(1) before the end of the Kazantsevo (Mikulino) interglacial (thermochron);

(2) from the Zyryanka glacial to the beginning of the Holocene; (3) Holocene optimum;

(4) from the end of the Holocene optimum to Present.

At the first stage, the West Siberian climate turned to cooling; the second stage consisted of two large cold events with a slightly warmer spell between them; the third stage corresponded to a climate optimum; the colder final stage after the optimum still continues.

Methods

A section of Late Pleistocene-Holocene sediments in the Nadym-Pur watershed was documented during field trips of 2007 through 2009 (under supervision of A.N. Kurchatova), in a quarry outcrop. The exposed sediments are 7 m thick and extend for 14.5 m from west to east. The section was studied at two sites, which allowed a comprehensive idea of the stripped deposits.

Results and Discussion

The outcrop exposes Upper Pleistocene and Holocene sediments in a quarry on the right side of the Sede-Yakha valley, 10 km northeast of Yubileinoye residential district built for development of a gas field 40 km west of Novyi Uregoi city. The quarry is located in terrace IV of the Kazantsevo fluviolacustrine deposits [*Goralchuk et al. 1989*]. The sediments bear abundant geomorphically expressed Late Pleistocene systems of unidirectional tetrahedral polygons. West of the polygons, 150 m away, there are seven ice-wedge casts spaced at 6-8 m, reaching 10-12 m in size. Seven more casts, spaced at 5-7 m, occur 130 m far in the north.

The section documented in the central part of the outcrop (site 1), 7 m from the western edge (Fig. 1), includes five main units (from bottom to top):

1. A thick unit of Kazantsevo laminated cryoturbated alluvial sand;
2. Interbedded fine sand, loamy sand, and loam, with prominent lamination;
3. Cap loam;
4. Podsol sand;

Peat and organic deposits.

The sediments have been stripped and documented to a depth of 6.2 m. The section base (6.2 to 6 m) consists of light-gray to bluish dense and relatively wet sand. Then, from 6 to 3.7 m, there follows light-gray sand, locally reddish due to 2-3 mm to 1.5-2 cm thick nearly horizontal ferric bands locally delineated by cryoturbation features. Furthermore, there exist a few interbeds of channel alluvium (coarse washed sand with minor gravel inclusions). Iron contents increase upsection, especially at 4.4-4.3 m, in a layer pinching out 2-3 cm away from the axis of a wedge cast, i.e., the ferric layer must be related with the wedge.

Fig. 1. Central part of the outcrop.

The interval between 3.7 and 2.6 m is composed of straw-yellow, locally whitish, fine Kazantsevo sand, with color-marked lamination varying from dark-ochre to white depending on iron content. The sediments show a plane-to-cross bedding change (1°-2 ° to 30 °-40 °) at the depths from 3.1 m to the top of the interval. The kink is due to frost cracking whereby the laminated sand experienced folding and bending. In fact, the structure outlines an ice wedge cast.

The next interval, 2.6 to 1.3 m, consists of outsized sand mixed with loam. Above (1.3 – 0.2 m) there lies light-grayish-bluish sand filling a younger ice-wedge cast. The section is topped by peat and biogenic deposits.

Site 2 is located 2.5 m away from the eastern edge of the outcrop, where the stripped section is 4.1 m thick. Sand from the section base to 2.3 m is light-grey to white and includes cross-bedded iron-rich bands, up to 3 cm. This may be a younger generation of wedge ice formed during the colder Sartan glacial (cryochron). The ice veins became more closely spaced as temperature amplitudes increased. This sand is an extension of the Kazantsevo sand in the 3.7 – 2.6 m interval at site 1.

The sediments in the 2.3 m - 0.55 m interval are fine to very fine floodplain sand, loamy sand, and loam, with limonite and manganese nodules. The layers have continuous undulated boundaries. The following interval, 0.5 to 0.2 m below the surface, is sand-bearing loam with sporadic iron nodules. This is cap loam produced by strong frost weathering in the Zyryanka-Sartan glacial. The interval is heavily cryoturbated, with peat and humus filling up intricate features in the upper part. The top of the section consists of peat and biogenic deposits.

We studied in detail a wedge-shaped structure, stripped down to 3.4 m, which is an ice-wedge cast. It dates back to Zyryanka-Sartan time and lies over Kazantsevo laminated sand. The maximum width of the wedge at the 0.5 m depth, is 4.5 m. The wedge formed in three stages:

1. The structure apparently originated and grew during the Zyryanka glacial (cryochron). Then it partly thawed from the top and became filled with soil during the Karga interstadial.

2. The wedge complex thickened up again in Sartan time when the climate was the most severe. As a result of large temperature amplitudes, the ice veins became more closely spaced and new wedges appeared in polygons. This hypothesis is consistent with the kinked ice-wedge cast in the eastern part of the outcrop with its dip increasing upward from 1°-2° to 35°-30 °.

Ice thawing in the Holocene gave rise to ice-wedge casts. The sediments that filled the veins froze again in the late Holocene, which is evident in post-cryogenic textures of loam in the casts (ochre reticulate texture).

Conclusion

Thus, there are three generations of wedge ice in the studied section: the largest wedges formed during the Zyryanka glacial, the slightly smaller and younger Sartan structures, and, finally, the youngest late Holocene ones.

Acknowledgments

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The Use of Simulation Modeling of the Fuel Consumption Process in a Moving Automobile under Low Temperatures

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Base rates of fuel consumption used in automobile transport provide for adjustments, depending on the number of factors designated in this document. One of these factors is climatic conditions. The main characteristic of natural and climatic conditions is environmental temperature. However, the current method offers only marginal values of increments, depending on the region of operation. For Tyumen Oblast the increment added to the base rate is set at 15%. Meanwhile, the mean annual winter temperatures can fluctuate significantly. Even larger deviations from the mean values are observed during the winter period itself (see Fig. 1).

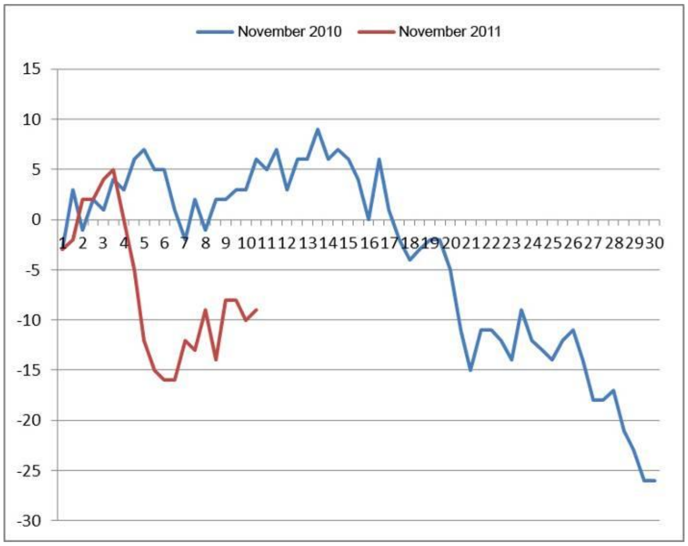


Figure 1. Dynamics of November temperatures in Tyumen over the past two years

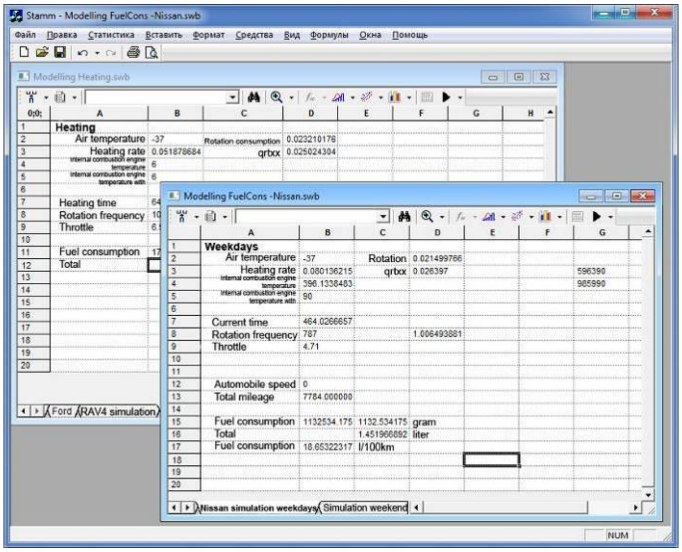
When marginal winter increments are used, as a rule, it does not match the actual fuel requirement and leads to its overuse. To save fuel and reduce harmful emissions, daily adjustments of linear fuel consumption norms are the most effective.

Such adjustments require the use of mathematical models of the relationship between fuel consumption of an automobile and air temperature.

To determine the norm value with regard to low temperature, we propose using a simulation model of automobile fuel consumption by the typical motion cycle.

The same type of regularities in air temperature impact on the parameters and in performance of the automobile engine and fuel consumption was experimentally confirmed for the case of the internal combustion engine with multipoint injection. In order to use mathematical models that describe these patterns for specific automobile makes and models, it is essential to determine the numeric value of their parameters in the course of the experiment for the given make and model of the automobile. This experiment is completely automated. The data are received from the diagnostic outlet of the automobile using BlueTooth of the Check-Engine adapter.

The simulation model is constructed on the basis of the «Stamm» program (Fig. 2). Its features enable obtaining new models for various automobile makes and models without using any programming by simply copying and editing the ones that were already implemented.



0;0;	A	B	C	D	E	F	G	H
1	Heating							
2	Air temperature	-37	Rotation consumption	0.023210176				
3	Heating rate	0.051878684	qrtxx	0.025024304				
4	internal combustion engine temperature	6						
5	internal combustion engine temperature with	6						
6								
7	Heating time	64						
8	Rotation frequency	10						
9	Throttle	6.						
10								
11	Fuel consumption	17						
12	Total							

	A	B	C	D	E	F	G
1	Weekdays						
2	Air temperature	-37	Rotation	0.021499766			
3	Heating rate	0.080136215	qrtxx	0.026397			596390
4	internal combustion engine temperature	396.1338483					965990
5	internal combustion engine temperature with	90					
6							
7	Current time	464.0266657					
8	Rotation frequency	787		1.006493881			
9	Throttle	4.71					
10							
11							
12	Automobile speed	0					
13	Total mileage	7784.000000					
14							
15	Fuel consumption	1132534.175	1132.534175	gram			
16	Total		1.451966892	liter			
17	Fuel consumption	18.65322317	l/100km				

Figure 2. The simulation model of fuel consumption in the process of initial running of engine and in the process of driving.
The «Stamm» System

Using this approach we obtained simulation models for a number of makes and models of automobiles that are equipped with a multipoint injection engine – Ford Focus, Toyota RAV4, Toyota Corolla and Nissan Teana. The obtained models are used both for simulation of fuel consumption during the operation of automobiles in low temperatures, and for determining the time of initial running of automobile engines under different external conditions. The simulation results were used for development of norms of fuel consumption that were differentiated depending on air temperature and conditions of operation and storage of automobiles. These norms are suitable for daily use (see Table 1).

Table 1. Differentiated fuel consumption norms for Nissan Teana, depending on the air temperature and duration of parking with the internal combustion engine turned off (for Tyumen)

Parking duration, min	*Temperatures interval, °C*									
	from 0 to -5	*–5 to -10*	*-10 to -15*	*-15 to -20*	*-20 to -25*	*-25 to -30*	*-30 to -35*	*-35 to -40*	*-40 to -45*	*Below -45*
0	*14.93*	*15.09*	*15.25*	*15.41*	*15.57*	*15.73*	*15.89*	*16.05*	*16.20*	*16.36*
15	*14.94*	*15.12*	*15.31*	*15.50*	*15.70*	*15.91*	*16.13*	*16.36*	*16.60*	*16.84*
30	*15.00*	*15.19*	*15.39*	*15.60*	*15.82*	*16.05*	*16.28*	*16.52*	*18.00*	*17.03*
60	*15.14*	*15.35*	*15.58*	*15.81*	*16.35*	*16.60*	*17.32*	*18.18*	*19.20*	*18.32*
90	*15.26*	*15.49*	*15.73*	*16.27*	*16.87*	*17.54*	*18.30*	*19.19*	*20.24*	*20.49*
120	*15.36*	*15.72*	*16.23*	*16.78*	*17.41*	*18.10*	*18.88*	*19.71*	*20.86*	*22.20*
150	*15.44*	*16.05*	*16.58*	*17.15*	*17.78*	*18.49*	*19.29*	*20.00*	*21.28*	*22.64*
180	*15.83*	*16.32*	*16.86*	*17.44*	*18.08*	*18.80*	*19.61*	*20.53*	*21.63*	*22.99*
210	*16.04*	*16.53*	*17.07*	*17.67*	*18.32*	*19.04*	*19.86*	*20.79*	*21.90*	*23.26*
240	*16.23*	*16.74*	*17.29*	*17.89*	*18.55*	*19.28*	*20.10*	*21.04*	*22.15*	*23.53*

Hydrologic and Thermal Regimes of Coarse Blocky Materials in Tien Shan Mountains, Central Asia

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Abstract

Mountain permafrost and associated periglacial landforms contain large quantities of stored fresh water in the form of ice. The moraines, rock glaciers and other coarse debris and blocky materials have especially high ice content (sometimes more than 30% by volume). We conducted observations on seasonal ground ice accumulation and ablation inside of coarse debris, runoff, precipitation, and temperature dynamics in blocky materials of various genesis and altitudes. The mean annual temperatures inside of coarse debris are typically 3-5°C below the mean annual air temperatures. In such conditions, ice-rich permafrost may develop within coarse debris even in areas with mean annual air temperatures above 0°C. The highest rate of ice accumulation inside of coarse debris occurred during the spring time when air temperature over the daylight cross 0°C threshold and melted and condensed water penetrates into coarse debris, then refreezes and cements the debris. The result is an ice-block mass with ice content as high as 10-30% by volume. Over a warm season, the melted seasonal ice is an important portion in seasonal redistribution of the total river runoff.

Keywords: Active layer, Blocky materials, Ice, Permafrost, River runoff.

Introduction

Central Asia is a water-stressed area where projected climate change could further decrease stream flow and groundwater recharge [*IPCC 2007*]. General circulation models suggest that the increase in summer diurnal temperatures over Central Asia is likely to be higher relative to that in other regions [*IPCC 2007*]. Therefore, we expect a further degradation of glaciers and alpine permafrost and decrease in snow cover. Under continued atmospheric warming the decrease in snowfall will lead to a decline in snow melt contribution to river runoff. Increased glacier melting will compensate this process for some period of time. But eventually, a further decrease in glacial area would lead to a decline in the contribution of glacier melting to the river runoff. Under continuing warming and permafrost degradation in Central Asia, the ground ice could increase future water supply, and the melt waters from permafrost could become an increasingly important source of fresh water in this region in the near future.

Mountain permafrost and associated periglacial landforms contain large quantities of stored fresh water in the form of ice. The moraines, rock glaciers and other coarse blocky materials (Fig 1) have especially high ice content (30-70% by volume). Recent observations indicate a warming of permafrost in many mountain regions with the resulting degradation of ice-rich permafrost. Permafrost temperature has increased by 0.5 to 1.5°C in Tianshan Mountains, Central Asia during the last 35 years [*Marchenko et al., 2007*]. At the same time, the average active-layer thickness increased by 23% in comparison to the early 1970s. Runoff from the active layer contributes a significant amount of water during the summer time, when snowmelt has finished and the ground ice melt starts and intensifies. The thickness of the active layer is one of the dominant factors controlling the subsurface flow conditions. Air temperature, precipitation and ground structure are other components influencing water flow. Blocky materials and other coarse debris, such as taluses, accumulate a significant volume of water in the form of perennial and seasonal ice.

Results and Discussion

We conducted observations on seasonal ground ice accumulation and ablation inside of coarse debris, runoff, precipitation, evaporation, and temperature dynamics in blocky materials of various geneses at elevation 2500 m ASL and 3300 m ASL. The mean annual temperatures inside coarse debris in the Northern Tien Shan Mountains are typically 3-4°C below the mean annual air temperatures [*Harris & Pedersen, 1998, Gorbunov et al., 2004, Marchenko et al., 2007*]. In such conditions, ice-rich permafrost may develop within coarse debris even in areas with mean annual air temperatures above 0°C (case of 2500 m ASL site, MAAT = 1.45°C).

Two sites at 2500 m and 3300 m ASL were examined during the last seven years. Sensors for temperature measurements were installed at the depths of 3 m and 5.5 m inside of blocky material and at 0.3 m depth in silt beneath blocky debris. One sensor was installed at 2 m above blocks for air temperature measurements (Fig 2, a). The perforated aluminum tube (Fig 2, b) was positioned inside of blocks up to bottom of blocky material at 5.5 m depth for dynamics of ice accumulation measurements. Every five days the ice accumulation and snow depth measurements were performed (Fig 3). Additionally, during the melting period the melted water discharge from blocky materials also was measured (Fig 4).

Because the coarse debris has a high surface roughness the snow cover appears as discontinuous or temporally snow cover in comparison with surrounding areas of fine-grained soils. In this situation, the snow cover exists immediately after snowfall but then could quickly disappear during the following 2–3 solar days.

Figure 1. Blocky materials in the Northern Tien Shan Mountains at 2500 m ASL.

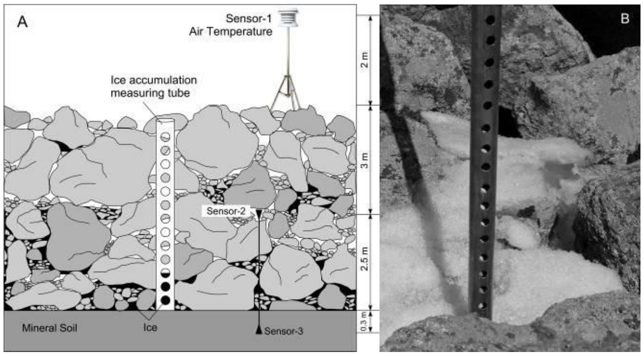

Figure 2. Scheme of sensors location and ice accumulation measuring tube (A), and photo of ice accumulation measuring tube (B) at 3300 m ASL Cosmostation site.

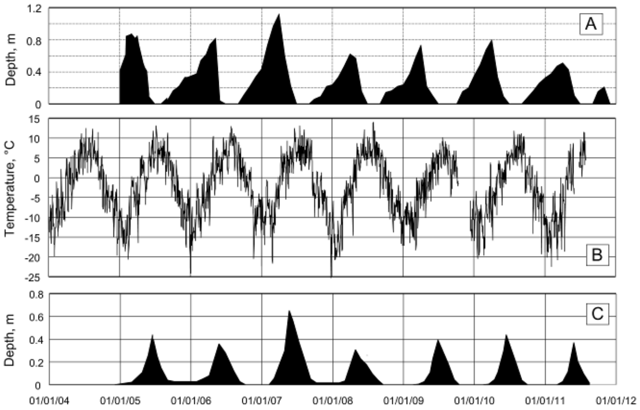

Figure 3. Snow accumulation (A), evolution of daily air temperature (B), and ice accumulation inside of coarse debris (C) at 3300 m ASL, Cosmostation site.

Conclusions

We have found that the highest rate of ice accumulation inside of coarse debris occurred during the spring time when air temperature during the daylight cross 0°C threshold and melted and condensed water penetrates into coarse debris, then freezes and cements the debris. The result is an ice-block mass with ice content as high as 30-50% by volume and sometimes ice survived over the summer season (Fig 3, c). Over the summer season, the water discharge from melting seasonal ice in the upper portion of coarse debris is very important factor in seasonal redistribution of the total river runoff. The rough estimation of the ice volume in such of deposits shown that up to 30% of melted snow, which cover of coarse debris fields could be accumulated in form of ice inside of blocky materials and feed the river runoff during the summer time. This circumstance should be taken into account for hydrologic modeling of individual watersheds.

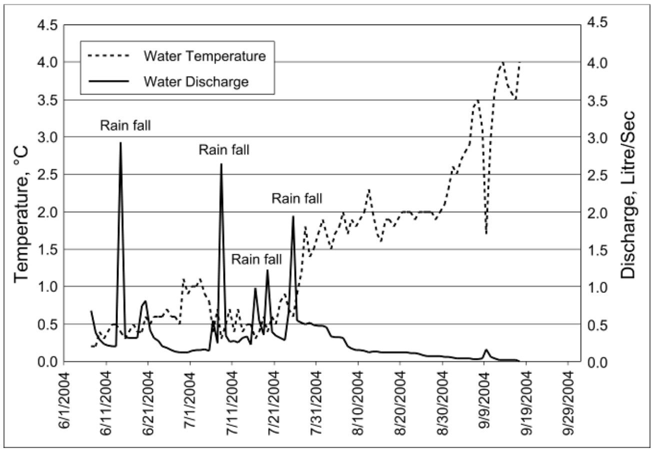

Figure 4. Air temperature and melted water discharge from blocky materials at 2500 m ASL site.

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Development And Location Of Patterned Ground In The Southern Pyrenees (Spain)

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Abstract

Periglacial stone circles from two areas in the Pyrenees (Tucarroya Cirque and Posets Massif) are studied in detail among some other patterned ground. Will be described their characteristics, dynamics, and their emplacement. The flat topographies, fine debris on the surface, snow melt water availability, the high altitude, -more than 2.700 m a.s.l.-, and cold conditions by both atmospheric and ground influence, are the main variables for the development of patterned ground in the high mountain of the Spanish Pyrenees. The active and moderately active processes are related to the relationship with the current periglacial conditions and mountain permafrost, and the Little Ice Age as well.

Keywords: Patterned ground, stone circles, periglacial environments, mountain permafrost, Pyrenees.

Introduction and study site

The presence of periglacial landforms such as patterned ground has a special interest to understand the current day environmental conditions and point out on active periglacial environment in the Pyrenean high mountain, in some cases related to mountain permafrost. The less active or inactive landforms are related to the morphogenetic background of recent cold periods, as Little Ice Age.

In the Pyrenees have been mentioned patterned ground in only fives massifs, Monte Perdido, Neouvielle, Posets, Turbón and Taillón, all of them in the central Pyrenees. In the French Pyrenees have been cited in Neouvielle at altitudes between 2.500-3.000 m a.s.l and Taillon above 2.300 m., while in the Southern Pyrenees (table 1) have been found above 2.400 m a.s.l in Turbón, above 2.600 m. in Taillón and Monte Perdido. Active sorted patterned grounds were observed around 1.900-2.000 m a.s.l. and at 2.300 m [*See García Ruiz et al. 1990; Serrano et al. 2000; Martín, 2006; Feuillet and Sellier 2008*].

The study areas are located in the Central Pyrenees and both culminate above at 3.300 m a.s.l. (Fig. 1). The Monte Perdido Massif (42º40´N-0º0´2´E) is a calcareous mountain with folded structures, and the Tucarroya Cirque is a shallow glacial cirque located at 2.700 m between summits around 3.000 m and below the glacier of Monte Perdido. The Posets Massif (42º39´N-0º26´1´´E) is a high ridge underlain by Palaeozoic slates, limestone and granite rocks. Glacial cirques and troughs contain small glaciers (La Paúl and Llardana) and one ice patches (Posets). Both massifs include moraines from the Late-Glacial to the Little Ice Age, and active periglacial landforms such as protalus lobes, rock glaciers, talus, debris cones, and gelifluction lobes [*Martín, 2006; Serrano et al., 2001*]. In the Central Pyrenees the annual 0ºC isotherm is located at 2.726 m a.s.l. [*Barrio et al., 1990*], while the annual freezing period at 2.600 m a.s.l. has been estimated in 225 days from mid-October to June. Meteorological records show winter temperatures mostly ranged between -5ºC and 0ºC, with very short periods of lower temperatures (-10ºC and -5ºC in January and February). The Spanish Meteorological Agency (AEMET) estimates annual precipitation values in the Central Pyrenees at 1.500-2.000 mm yr^{-1}.

The objective of this research is to understand the distribution and characteristics of patterned ground and the relationship with ground thermal regime at two representative massifs of the Pyrenean high mountain.

Methodology

The geomorphological mapping is an effective tool for the location, distribution and morphostratigraphy of patterned ground study. Detailed maps with periglacial information have been made in Monte Perdido-Tucarroya and Posets areas by mean of field work mainly, completed by aerial photos and satellite images interpretation. We have mapped the extension and altitudinal distribution of each group of patterned ground studied in Tucarroya (2.700-2.780 m a.s.l.), Monte Perdido South side (3.000 m a.s.l.), Collado de La Paúl (3.000-3.050 m a.s.l.) and Posets eastern side (3.000 m a.s.l.). Temperature datalogger have been installed on ground (10 cms depth), one year in Tucarroya and four years in Posets to know the main thermal regime of soils around where the patterned grounds are developed. Field work has permitted us to know the internal structure of patterned ground in Tucarroya and Collado de La Paúl, where also transect measuring texture, clast size, fabric, landforms size, wet slope and lithology composition have been made (table 2).

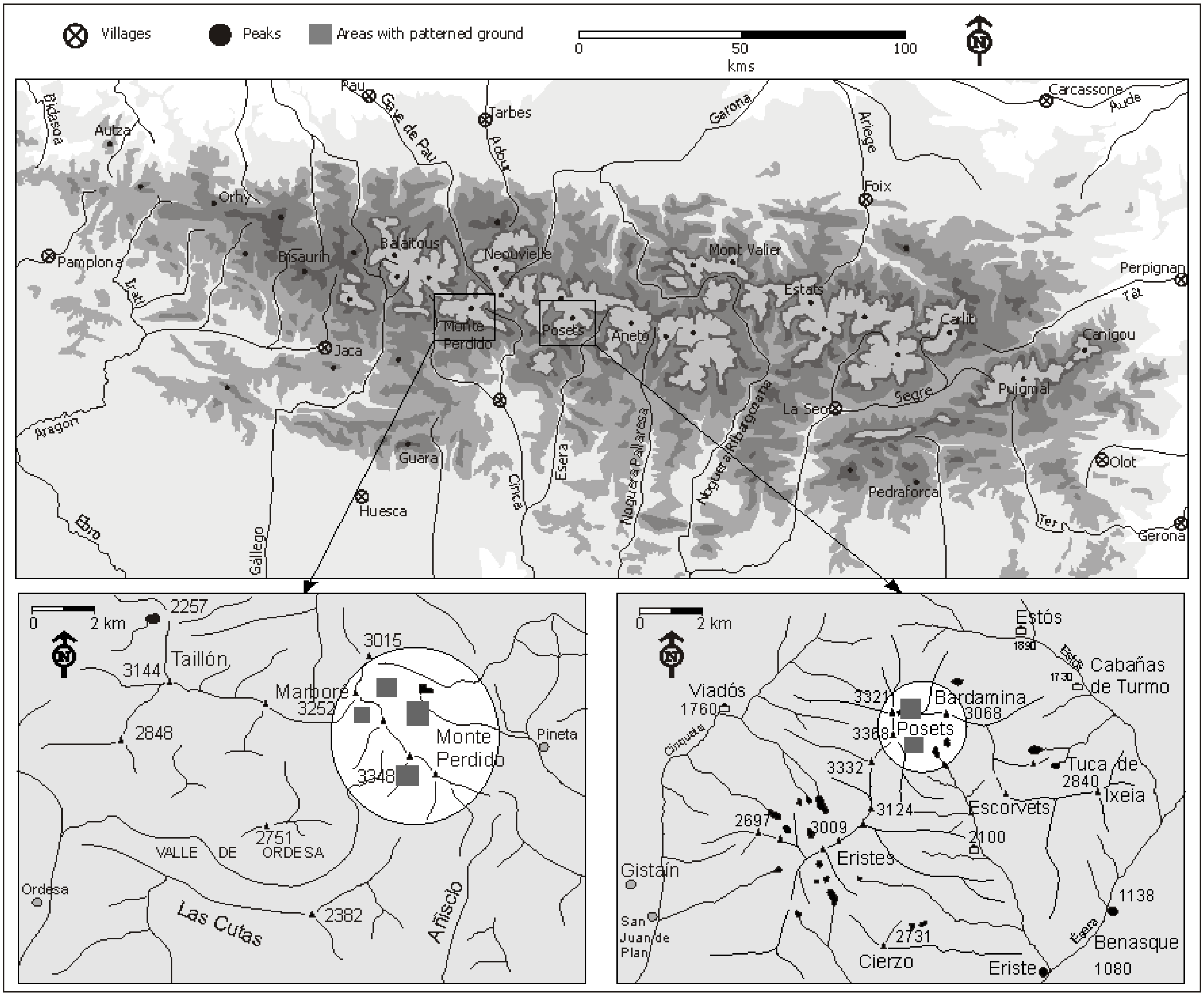

Fig. 1. Location of the studied areas with patterned ground in the Pyrenees.

Results

At the Pyrenees the active patterned ground are always small landforms determined by the location on fine material and the snow melt water availability, always above 2.300 m a.s.l. The most favourable emplacements are characterised by wall and glacier influence, moraine deposits or alteration drifts, flat topographies and high altitude [*Feuillet et al. 2011*]. These authors differentiate three groups of patterned ground: the most dominants are located in glacier foreland with strong glacier influence, moraines presence and wall influence; other one are located on southern slope and at high altitude, without glacier influence and developed on sub-autochthonous drift and without wall influence; finally there are other patterned ground developed in Northern and South eastern slopes.

The patterned ground in Monte Perdido massif

The patterned grounds of Tucarroya are located between 2.500 and 2.900 m a.s.l. They are characterised by flat topographies, location between calcareous crests where cryoclasts and fines deposits are accumulated, shaded conditions by scarps and a favourable location for wet availability feed by snow melt existence, springs or the closeness to the lake. The sizes of landforms are homogeneous, with diameters between 100 and 190 cm. Circles morphologies are dominant. Snow cover melts from June-July and the freeze-thaw cycles are moderates although there is water availability all summer. As Feuillet et al. [*2011*] have shown, vegetal cover has a negative correlation with periglacial features presence and it is an indicator of patterned ground stabilization. Small plants, less than 9 cm diameter, colonize some circles, indicating the existence of inactive landforms and conditions less favourable to patterned grounds development. Martín [*2006*] has differentiated between:

- Active and individualized circles: The structure is defined by more than 75% of clast imbrication, with the size bigger than 10 cm length in the sides, and clast of medium size 4 cm length, scattered by the central portion, all of them overlying fines accumulated by washed. They are forms well and individually defined, not grouped.

Table 2. Patterned ground in Tucarroya and Collado de la Paúl.

Massif	Nº	Altitude	Diameter cm	Lithology	Imbricate Fabric %	Wet	Vegetation
Tucarroya	1	2700	120	Limestone	90	Low	Yes
	2	2700	120	Limestone	90	Low	Yes
	3	2700	120	Limestone	90	Low	Yes
	4	2600	125	Limestone	70	High	No
	5	2600	90	Limestone	70	High	No
	6	2530	100	Limestone	70	High	No
	7	2780	190	Limestone	30	Low	No
	8	2780	190	Limestone	20	Low	No
	9	2780	190	Limestone	20	Low	No
Posets	1	3035	110	68% E, 20% C, 12% G	48	Low	No
	2	3035	143	72% E, 4% C, 24% G	28	Low	No
	3	3035	480	60% E, 12% C, 28% G	20	Low	No
	4	3035	150	80% E, 0% C, 20% G	76	Low	No
	5	3035	51	72% E, 12% C, 16% G	36	Low	No
	6	3035	92	68% E, 4% C, 28% G	76	Low	No
	7	3035	320	72% E, 0% C, 28% G	92	Low	No
	8	3035	122	72% E, 0% C, 28% G	48	Low	No
	9	3035	130	84% E, 0% C, 16% G	60	Low	No
	10	3035	670	80% E, 4% C, 16% G	52	Low	No
	11	3035	188	80% E, 8% C, 12% G	84	Low	No
	12	3035	50	92% E, 0% C, 8% G	16	Low	No
	13	3035	315	72% E, 4% C, 24% G	84	Low	No
	14	3035	152	88% E, 8% C, 4% G	80	Low	No
	15	3045	135	72% E, 0% C, 28% G	92	Low	No
	16	3045	61	80% E, 0% C, 20% G	28	Low	No
	17	3045	206	76% E, 0% C, 24% G	92	Low	No
	18	3045	49	88% E, 4% C, 8% G	32	Low	No
	19	3045	109	84% E, 12% C, 4% G	84	Low	No

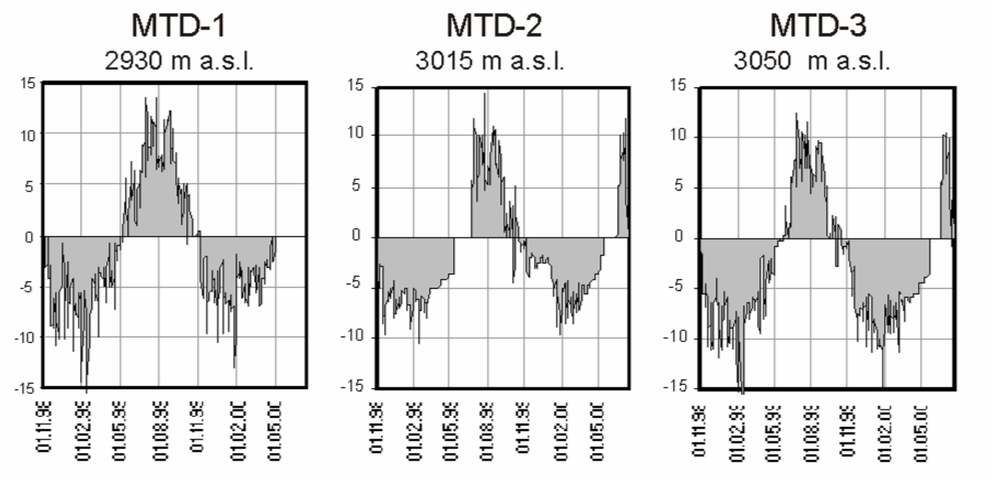

Figure 2. Thermal regime of soils in Collado de La Paúl, Posets massif.

Active circles and polygons: The surface clasts imbrication are less than 75% and are developed in both individually and grouped ways, with shapes less defined than the previous type, but structured.

- Circles and polygons with moderate activity in groups or by themselves: The structure is defined by less than 40% of clast imbrication and not clear shapes, and sometimes with moderate plants colonization. These are the most common circles.

Other active patterned grounds exist in the south side of Monte Perdido and Marboré, at 3.000 m.a.s.l. Small patterned grounds are developed in flat topographies with fines accumulated from slopes and saturated by melting of snowpatches on the slopes. Nival processes and cryoturbation are the joined processes that permit the development of these patterned grounds, located in the mountain permafrost environment.

The patterned ground in the Posets Massif

The active patterned grounds of Posets Massifs are located between 3.000 and 3.050 meters. Two areas with differentiate features can be distinguished. In the upper part of the Collado de La Paúl (3.000-3.050 m a.s.l.), a glacial diffluence area glaciated during the Little Ice Age, active polygons, circles and steps are very common (Table 2). The flat topography and the bedrock, a contact area between schist, limestone and granite support fines from slopes and substrate (Table 2). There is a good drainage and the surface is dominated by blocks. The size of patterned ground is heterogeneous, with diameters between 49 and 670 cm length. The structure is also variable, only in the 48% of studied patterned ground more than 75% of clasts are imbricated. The internal structure shows four units: in surface, in the contour blocks and in the centre planar blocks scarce between fines; a second heterometric level with fines poorly stratified; a third clast-supported level; and finally, a body of massive fines. In this area there is not vegetation cover. The soil thermal regime (figure 2) is defined by winter ground temperature around -4/-6ºC at 2.960 m. a.s.l., -6.6/-6.1ºC at 3.015 and -7.5/-7.2 at 3.050 m, and the medium annual ground surface temperature between -0.5ºC and -1.8ºC. The snow cover melts mainly during the second half of June. Therefore, the patterned grounds are located in the mountain permafrost environment [*Serrano et al. 2001, 2010*].

The Eastern slope (3.000 m a.s.l.) is also characterized by a group of patterned grounds developed on granitic bedrock. The landforms are located on small plains where the fines are accumulated by snow behind the protection of eastern wall. Circles and stone-banked lobes on slopes less than 10° on blocks accumulations from slope and bedrock are developed in a mountain permafrost environment.

Conclusions

The active patterned grounds in the central Spanish Pyrenees are confined to the most favourable sites where there are cold temperatures, fines and moisture availability. The water feeding is due to snow melting mainly, because in all cases the landforms are far from glaciers. The studied patterned ground are located at high altitude, in mountain permafrost environment where cryoturbation processes are commons related to spring, summer and fall activity. The existence of mountain permafrost –sporadic or discontinuous- allows the development of patterned ground, but the nivation processes are very important to fed water and wash the surface formations, accumulating fines in the weathering drifts. The emplacement are linked to the fines production by weathering on schist, granites and limestones, the last one the most favourable to develop patterned ground by the presence of decalcification clays. Several dynamics types have been differentiated, up to 2.700 m a.s.l. there are partially actives patterned ground with small vegetation cover. It could be features inherited from cold periods as Little Ice Age. Above 2.700 m a.s.l. the patterned ground is active, related to mountain permafrost and without vegetal colonization. Several types related to the emplacement and lithology can be distinguished.

Acknowledgments

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The Trends of the Change in the State of Railway Subgrade Based on the Results of Monitoring of the Obskaya-Bovanenkovo Railway Line

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Multi-year observations over the state of the railway subgrade of the Obskaya-Bovanenkovo Railway Line allow us to predict its state and the volume of maintenance works during its operation.

With this purpose within the period of 2008-2011 "Yamaltransstroy" OJSC and Moscow State University of Railway Engineering conduct regular regime observations and measure the ground temperature and geometric subgrade characteristics at experimental site Khralov junction - Sokonto station. The studies conducted allowed us to obtain graphs of changes in ground temperatures at different depths along the mound height. The graphs were processed and analyzed using the intellectual system of monitoring of a subgrade on permafrost. The intellectual system of monitoring was developed in Moscow State University of Railway Engineering earlier. The results obtained allowed us to give recommendations on providing for a safe subgrade operation in the cryolithozone using databases processed with the help of the system of an artificial intellect that is a component of the monitoring system.

The Impact of Anthropogenic Factors on the Hydrogeological Field of the North of Western Siberia

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Over the past half of the century more than 10 billion tons of oil and 11 trillion cubic meters of gas were produced from the depths of Western Siberia, hundreds of thousands of prospecting, exploration and development wells were drilled, dozens of new cities, hundreds of oil-field villages and thousands of kilometers of various pipelines were built.

The removal of an enormous amount of natural hydrocarbons from the geofluidal systems of the West Siberian Megabasin (WSMB) required restoration of the dropping reservoir pressures and injection of even larger amounts of "foreign waters" (water of Aptian-Albian-Cenomanian, Oligocene-Quaternary complexes and surface water) into the productive strata [*Matusevich et al. 2005*]. Naturally, it was never possible and will never be possible to fully restore the natural reservoir pressures in the subsurface. Irreparable subsidence of the earth's surface is currently taking place. It is confirmed by both instrumental measurements and interpretation of aerospace data (increase in wetland areas).

The ever growing process of permafrost degradation should also be added to the list. According to the data of oil companies, over the past half of the century of intensive development of hydrocarbon fields the boundary of the continuous permafrost moved in the north and northeasterly direction for more than a hundred kilometers. This fact is an additional stimulant of the sharp deterioration in environmental conditions that already assume geological scale, greatly disturbing the natural course of the processes of mass transfer of matter and energy in the depths of the basin up to the surface.

According to V.I. Vernadskiy, the planetary transfer of matter and energy is realized through functioning of the components of the equilibrium system: solid body ↔ water ↔ gases ↔ organic (living and fossilized) matter. This system is manifested in the categories of *natural* physical fields. They include gravitational, geothermal, geohydrodynamic, electrical, magnetic and concentration fields. One of the features of all natural physical fields is their autonomous nature and a distinctive parameter typical of the given field (temperature, hydrostatic and geostatic pressure, substance concentration etc.). However, the experience of intensive development of the Earth's subsurface over the past half of the century demonstrated that its consequences resulted in technogenic transformation of natural fields that was displayed in the formation of a new – ***technogenic*** – field. One of its features that distinguishes it from the physical fields mentioned above is heterogeneity and polymorphism. This means that a technogenic field possesses all the features of the existing physical fields, depending on the kind of anthropogenic impact on the subsurface and, consequently, on the transformation of natural fields.

Out of all the physical fields that were sufficiently studied, in the context of this conference, we can speak about the technogenic field as the one that had the most significant impact on the transformation of geothermal and gravitational fields as well as of hydrogeodynamic field associated with the previous two fields and of concentration field.

The geothermal field is transformed, on the one hand, by the cooling of the subsurface through addition of various drilling fluids during the drilling of oil wells as well as through injection of water that has a lower temperature; and on the other hand, it is transformed by the increasing temperature of near-surface horizons during the operation of wells and various pipelines heated by deep fluids (oil, gas and formation water). In addition to other adverse effects, the latter factor leads to the intensification of permafrost degradation.

The hydrogeodynamic field as the field of geofiltration of geofluidal systems is closely connected with the gravitational field and is represented in the WSMB by the water drive systems that we studied previously [*Matusevich et al. 1986, Kartsev et al. 1986*]. It is determined by the parameters of filtration-volumetric characteristics of grounds (porosity, permeability and water transmissibility). Here, technogenic transformation is in most cases associated with the processes of decreasing flexibility of productive strata and aquifers that occur due to incorrect approaches to the development and exploitation of hydrocarbon deposits (increasing of fluid selections under the flush regime of operation is the first stage of operation). Apart from filtration processes, capillary pressures also have a great influence on the field nature. They develop in productive strata as a result of anthropogenic impact (systems of reservoir pressure maintenance, disposal of industrial waste water etc.) and are determined mainly by the characteristics of the lithology of sediments in the WSMB. The presence of polymict (quartz-feldspar with clay material rather than pure quartz) reservoirs divides the latter into two main groups – hydrophilic and hydrophobic. Hydrophilicity and hydrophobicity of the surface of pore channels determine whether the capillary pressure in contacting aqueous and hydrocarbon phases is positive or negative. If the ground is hydrophilic, the capillary pressure is positive, and if it is hydrophobic, the pressure is negative. The wettability nature has a significant influence on the electrical properties of the porous medium (natural electric field), as the reservoir wettability controls the distribution of formation water and hydrocarbons in the reservoir that possess a sharply different electrical conductivity. Energetically, it is more advantageous for oil to occupy relatively large pores, and for water – the small ones. The opposite pattern is observed in the hydrophobic reservoirs, where the injected water is rejected by the surface forces of the solid phase and is filtered under the influence of hydraulic forces only through the largest pore channels and cracks, lugging away a random amount of oil. Concurrently, it destroys the solidity of the reservoir, breaking through the displacement front in a "dagger" manner. This is how flooding of many major oil fields in Western Siberia

(Samotlorskoe, Fedorovskoe and others) and a sharp decline in oil production of the productive strata occur.

The natural concentration field is the reflection of the geologically long-term processes of lithogenesis manifested in the formation of hydrogeochemical zoning based on mineralization and ion-salt composition (classical for infiltration water drive systems and inversion for elision water drive systems); and in the reflection of the stages of oil and gas generation based on microelements and water-dissolved organic matter [*Vassoevich 1968*]. The latter particularity is distinctive due to the fact that the main stage of oil generation is characterized by maximum concentrations of organophylic microelements (nickel, cobalt, vanadium, germanium etc.) and water-dissolved organic microcomponents (organic acids, benzene, toluene, phenols etc.). High concentrations of these components show a clear link with the intervals of inversion hydrogeochemical zoning. This concerns the natural concentration field. The transformation of this field under the influence of technogenesis is expressed primarily in the contamination of the hydrogeological section intervals, which occurs as a result of drilling, operation of the systems of reservoir pressure maintenance and disposal of industrial waste water. The technogenic field here has an impact not only on the concentration field (through the concentration field, to be more exact) but also on the geohydrodynamic field by clogging reservoir grounds as a result of the interaction of "foreign waters" with formation waters, which leads to deterioration of the parameters of their filtration-volumetric characteristics.

This brings up the question about the depth of penetration of the technogenic field into the geological medium. The average depth of wells in the WSMB is 2500-3000 m. However, over the last years we could observe a steady increase in their depth. There are currently 211 wells whose depth exceeds 4 km, including 165 in Yamalo-Nenets Autonomous Okrug and 19 in Khanty-Mansi Autonomous Okrug. In the next few years, the number of such wells will increase, which means that the impact of the technogenic field on the transformation of natural fields will also increase, causing a change in the geological environment. The consequences of this change are unpredictable and, most probably, they bode no good, unless new technological approaches to the development of the West Siberian Megabasin are adopted.

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Use of RADARSAT-2 Data for Permafrost Terrain Analysis in Nunavut, Canada

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Introduction

In order to better assess risks to land development due to climate change, the Government of Nunavut (GN) initiated a desktop study to evaluate utilizing Synthetic Aperture Radar (SAR) satellite images to determine terrain suitability for future development in 14 communities in Nunavut, Canada (figure 1). GN, in partnership with the Aboriginal and Northern Development Canada (AANDC), provided SARimages to the project from the RADARSAT-2 satellite. In addition, aerial photos of the communities, optical satellite images, and other data such as Digital Elevation Models (DEMs) were made available. Visits were carried out at three sites, which provided valuable information used in the detailed analysis of each community.

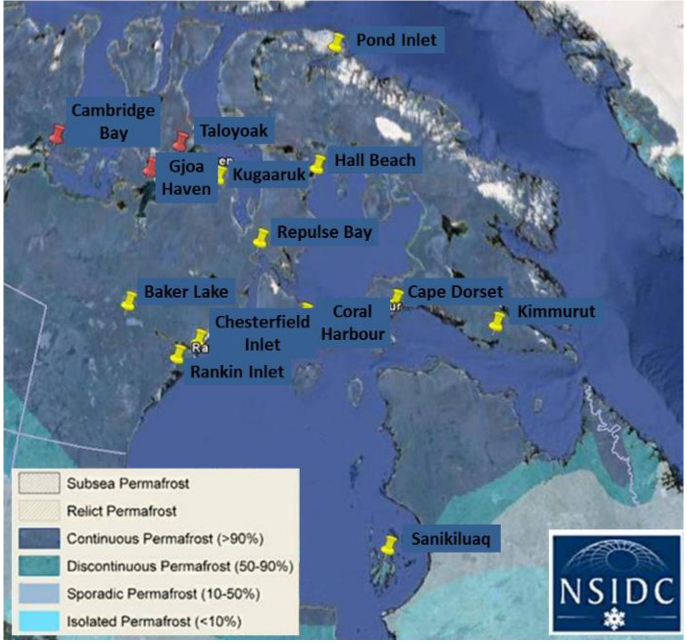

Figure 1. Overview of the communities investigated and the permafrost distribution. Red sites indicate the communities visited in Fall 2010 (Permafrost distribution from NSDIC, 2011).

Methodology

At least two RADARSAT-2 images were acquired over each community and advanced interferometric image processing techniques were applied. These were complemented by geotechnical analysis to produce the following for each community:

- motion layers;
- permafrost features;
- low areas;
- slope/aspect; and
- land cover classification.

Layers depicting this information were generated within a Geographical Information System (GIS). Based on this, permafrost and ground ice conditions were inferred and development suitability maps created, which were divided into the following classification (figure 2):

- no data;
- suitable for development (green);
- possibly suitable for development (light green);
- marginally suitable for development (yellow);
- unsuitable for development (red); and
- built-up (pink)

Discussion

The major limitation on the quality of the results of this study was the volume and timing of the SARimages. In order to get good ground motion information from SAR images, several images over the same area are required; ideally more than 10. In the Nunavut environment, these images need to be acquired when there is no snow cover.

The suitability maps created can assist in high level development planning, but should not be used for a detailed assessment of the foundation conditions. The remote sensing techniques employed for this project can only provide information on the ground surface characteristics, not the ground ice content, which is an important parameter in any northern foundation design.

The quality of the development suitability information could be improved by acquiring more RADARSAT-2 images over priority communities during the summer season. Longer-term comparisons (e.g., 2 – 3 years or more) could provide a better appreciation for the dynamics expected in permafrostlandscape that is expected for all communities.

The image acquisitions only began in mid-September with snow cover in all imagery for some communities, significantly limiting the ability to determine permafrost indicators using these techniques. Snow cover restricted the ability to determine:

- land cover classifications;
- water/land boundaries;
- drainage / presence of soil moisture;
- displacement measurements.

Ground motionin permafrost terrain is either associated with freeze-thaw cycles in Spring and Fall, thaw consolidation settlements and frost heave during Summer and Winter, or creep displacement associated with ice-rich conditions on slopes, respectively. Hence, they are often seasonal and not continuous. These deformations can further be very slow and may therefore not be captured if RADARSAT-2 images are only compared over a short time span. By extending the observation period and adding more images to the series, it should be possible to obtain a much better appreciation of the landscape’s secular dynamics.

The quality of development suitability at communities where mainlysnow coveredimagery was acquired (Chesterfield Inlet, Kimmirut) was not as strong.

Measuring displacement from RADARSAT-2 SARdata is only possible when surfaceconditionsremain reasonably stable between acquisitions (‘coherence’),and vegetation coveris sparse and low enough to preserve the signal. In many of the communities (Cambridge Bay, Cape Dorset, Sanikiluaq), the data quality was goodenough to identify areas of displacement and RADARSAT-2 was shown to be an effective tool (figure 3). Moreover, continued image acquisitions over a community incrementally improve the quality and accuracy of the displacement information.Secular, long term trendscan also be studied once a multi-year dataset has been collected.

Conclusion

While this project showed that deriving suitability maps from RADARSAT-2 data could be effective, there were important considerations for exploitingthe derived information. During this pilot project, the most valuable information was generated from data acquired during periods with less snow cover. Someimages were lessusefulfor determining ground classificationand the quality of displacement data was also limited. Whilst SAR data can sometimes penetrate snow and ice, this breaks down if moisture is present also.

The suitability for development will oftendepend on the ground conditions for the foundationsand in particular, the ground ice content. The techniques used in this studycanonly provide information on the surface conditions as well as surface deformations, but not directly on the ground ice content. The latter is usually interpreted based on empirical field measurements. Current SAR processing techniques are therefore valuable for general development planning, but should not be used for foundation design, where site specific investigations must be undertaken. It is therefore recommended that local geotechnical site investigations be carried out before any development commences. The development suitability layers supplied provide general guidance, and serve as screening tools prior to targeted geotechnical assessment of the foundation conditions.

Acknowledgement

3vGeomatics Inc. and BGC Engineering Inc. thank the Government of Nunavut, in particular Robert Chapple, for the support during this project and providing all the logistics during the site visits.

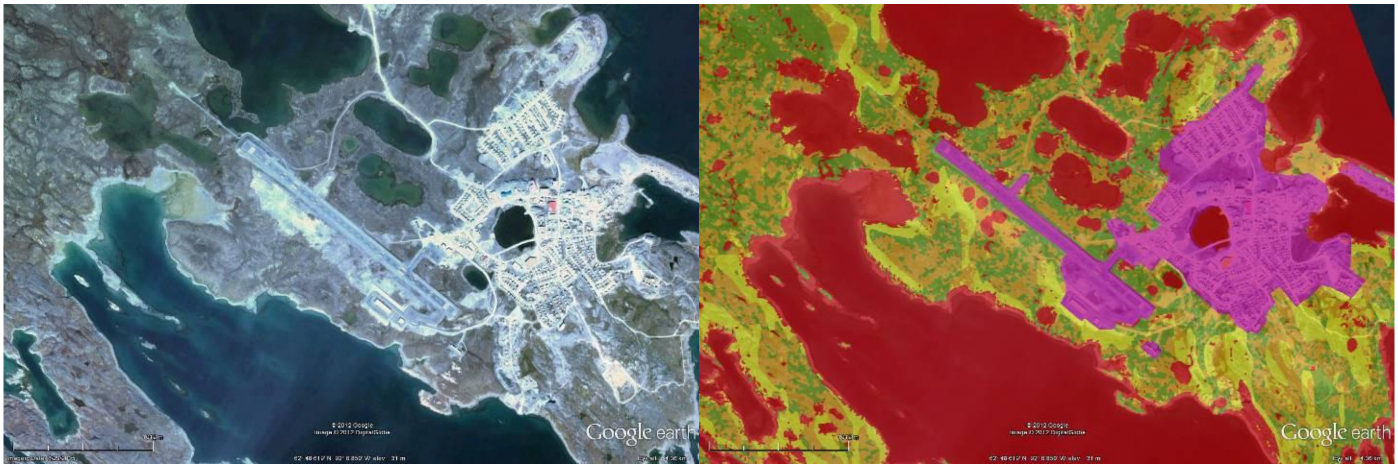

Figure 2. Suitability map for Rankin Inlet (left satellite image for reference). See text for color coding.

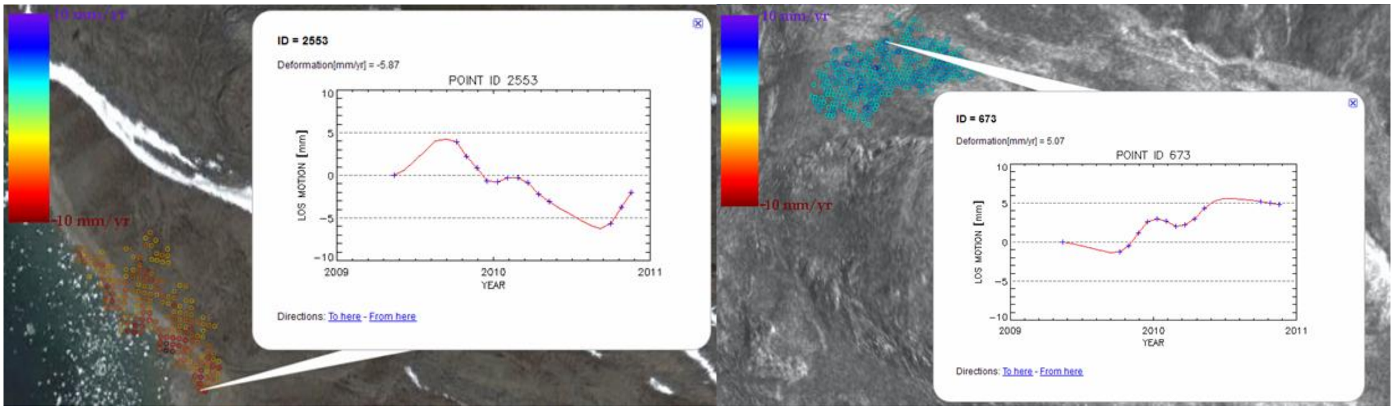

Figure 3. Displacement history for selected points in the uplift and subsidence zones. It is likely that the subsidence sites are associated with thermokarst / permafrost degradation (situated close to water bodies), whereas the uplift may be segregation, i.e. formation of massive ice in the ground.

Field Studies of Cryogenic Processes in Norilsk Region

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Introduction

During an expedition to the Enisey River's lower reaches, the authors studied the basic cryogenic processes that determine the dynamics of natural systems of this region and impact geotechnical stability.

Cryogenic processes are widely distributed in the Igarka and Norilsk areas. These are primarily thermokarst and heave processes that have maximal impact on the stability of buildings, structures and infrastructural objects.

Methods

Investigations conducted during the field trips included: description of cryogenic processes; performance of linear measurements of the corresponding relief forms; assessment of the impact on geotechnical and cryological environment; measurement of the seasonal thawing layer in the zone covered by relevant processes using a permafrost probe; profiling of these zones; thermometric works with thermometers and loggers.

Results and Discussion

Generally, cryogenic processes in the developed areas manifest themselves in the form of the buildings' subsidence as well as the heaving of piles and posts. Height of the pile shown in Figure 1 at the moment of its drilling-in [*1989*] was just about 2.5 m. This is a good illustration of the velocity of this process. Another hazardous cryogenic process, that is thermokarst, is widely distributed in the Norilsk suburbs, at the place of former forced-labour camps' vegetable gardens. Cultivation of the top soil layers disturbs their heat exchange with the atmosphere, strengthening moisture and heat inflow into the seasonally thawing layer. It caused the growth of thermokarst lakes, which led to abandonment of many vegetable gardens. Thermokarst development was facilitated by high natural ice content of the soils characteristic of the central part of the Norilskaya River valley. Also, thermokarst is observed in the roadside areas. Due to incorrect drainage (or its total absence), atmospheric and melt water stagnated close to the motor- and railroad embankments, facilitating permafrost thawing under its level. It should be noted that construction of the road beds practically was not taking into consideration the groundwater seepage channels within the seasonal meltwater layer.

Thermokarst and heaving are the processes that are frequently met in the natural environment, so, they do not indicate any disturbances of natural territorial complexes [*General Geocryology 1978*]. In Norilsk Region, thermokarst is represented by small, often drawn-down lakes and saucer-shaped alases. Heaving is represented mostly by frost heaves up to 2-3 m high and patterned heaving peatlands.

Thermoerosion is an important cryogenic process observed on the territory of Middle Siberia. Typically, it can be observed on icy banks of rivers and water bodies. This process is very important in terms of construction of the shore facilities, since their existence depend on the presence and activity of thermoerosion [*General Geocryology 1978*].

The formation of medallion spots caused by frost differentiation of ground fractions is one more cryogenic process in the tundra area.

Figure 1. Pile heave caused by frost heaving in the active layer without stress. Oganer (Norilsk suburbs), July 2010.

Medallion spots were described on site CALM No. 32 near Talnakh. It should be noted that, in addition to new, incipient spots, the old ones grown with vegetation have been observed. This is an indicator of a substantial time period of their existence on this territory [*Zepalov et al. 2008*]. Also, the formation of such polygons on tundra sites should be noted. This process is caused by the fact that the top soil layer becomes a solid frozen body when the season of freezing begins, and it cracks in the conditions of the existing thermal gradient. Fissures are growing over time, forming patterned wedge ice relief [*Mudrov 2007*].

In terms of engineering geocryology, one of the most hazardous processes is cryogenic weathering of solid bodies (e.g., stone, reinforced concrete of piles, asphalt concrete road surfaces). This process consists in the alternation of freezing and melting of water in micro-fissures of materials, which is accompanied by the increase or reduction of water volume. As a result, fissures' number and size grow, leading to the deterioration of strength properties of material. Thorough examination of on-surface parts of about 200 piles with operational life from 25 to 30 years in the cellars of three nine-store residential buildings in the northwestern Norilsk outskirts revealed that practically 100% of them were touched by the so-called frost destruction (cryogenic weathering). The found damages include fissures and micro-fissures in the protective concrete layer, numerous caverns, destruction of the protective concrete layer through to reinforcement rods and its corrosion.

Conclusions

Cryogenic processes in the Norilsk Region are numerous, active and relief-forming. They also impact the biota, soil generation, accumulation or denudation of depositions, and the stability of engineering structures.

Acknowledgments

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On the Need to Develop Criteria for Consideration of the Intensity of Grounds Weathering in Time During the Construction of Linear Structures (the Case of the Amur-Yakutsk Mainline)

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Abstract

The study reflects the problem of destruction of grounds composing the railway embankment under the influence of cryogenic weathering, based on the case of the Amur-Yakutsk Mainline. The study also reflects the necessity to change the regulatory base in the field of construction of linear facilities under complex natural and climate conditions.

Keywords: cryogenic weathering; railway transport; regulations; reliability; zoning.

Today, the problem of ensuring the strength and the stability of the railway subgrade in Yakutia is especially important. Specifically, construction completion and commissioning of the Berkatit-Yakutsk Mainline (Fig. 1) will make it possible to accelerate the implementation of programs of assimilation and development of Eastern Russia, to accelerate field development

and funding of the budgets of different levels resulting from the realization of the end product of these projects. But the most important issue is that it will provide for an increase in the life quality of the population.

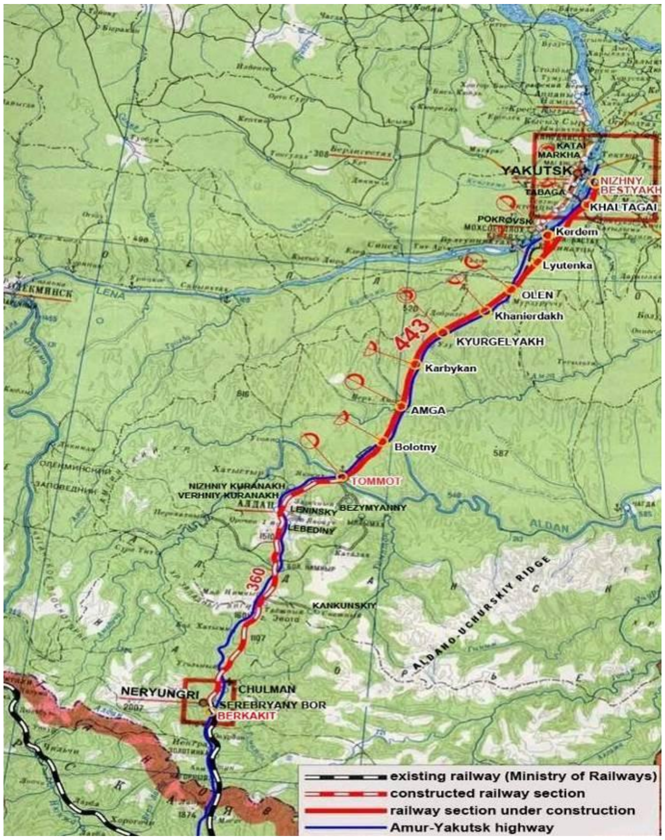

Figure 1. The map of the Berkatit-Tommot-Kerdem Railway.

However, the construction of the mainline to Yakutsk and its further extension to Magadan as well as the construction of northern railways, road corridors and transport accessways to the large fields of natural resources in Siberia are implemented under the extreme climate conditions [*Belozerov 1998, Kondratev et al. 1997*].

The most effective method of research and assessment of the natural-geographical and natural-climate conditions for the road construction that provides for an increase in reliability of design, construction and operation of roads is the road zoning. But at the same time, Russian road zoning scheme stipulated by the specific regulations does not take into account regional particularities of some Russian territories, and in particular, of the Sakha (Yakutia) Republic. The practice and the experience in operation of the roads constructed testify to the fact that the areas unified within the existing zones are heterogeneous, and the projecting regulations generally recommended for the zone do not always provide for the reliability in operation of road constructions and transport facilities.

For example, the processes of cryogenic weathering play an considerable role in destruction of rocks used as a construction material both in Yakutia and in all the regions with the harsh climate [*Vyrkin 1983, Zabelin & Pavlov 2000*]. Nevertheless, norms and regulations for the construction of linear facilities still do not reflect the quantitative criteria for the consideration of the intensity of rocks weathering in time. This leads to the contradiction between the requirements for the grounds used in landfilling of railway subgrade and the methods for determining their physical and mechanical properties as well as operation terms of extensive facilities.

Thus, a high level of territorial generalization within the distinguished road-climate zones determines the need for a new approach in elaboration of the existing scheme of road-climate zoning.

New principles of processing of the existing regulatory base and formation of a new one may become an optimal option for ensuring an effective work of the railway transport as well as for ensuring a reduction in the cost of repair and maintenance of the existing railway network, especially under the complex natural and climate conditions of Yakutia.

Proceeding from the aforementioned, according to the reconnaissance investigations as well as to the engineering and geological investigations conducted by the authors at the strip of construction of the Amur-Yakutsk Mainline at the section of the Tommot-Kerdem Railway in 2010-2012, a number of particularities characterizing the reliability of railway stability are observed:

1. Construction of such a large-scale unit as the Amur-Yakutsk Mainline requires a substantial funding (it is worth noting that during all the construction time an underfunding caused a suspension of the active works 20 times), this is why one of the dominant factors in selection of the grounds for subgrade landfilling is the distance of transportation of construction material (normally it does not exceed 15 km). Thus, virtually regardless of all the geocryological conditions of construction of one or another section of the mainline, a narrow range of natural rocks is used as construction material for subgrade landfilling: it is local grounds. The reasonability of their use is questioned at some sections of the Tommot-Kredem Railway due to their weak resistance to the processes of cryogenic weathering [*Tectonics… 2001, Geology… 1981*].

2. The degree of destruction of the same type of a rock used as construction material significantly varied already after the first tens of kilometers. Most consequences of the negative weathering impact on the railway embankment stability were mainly associated with the mainline sections passing within river and stream valleys and their "frequency" increased as the mainline advanced to the North.

3. The technical solutions used at the examined mainline section are unproductive due to the lack of attention to the processes of cryogenic weathering of the embankment grounds.

Thus, the problem of ground destruction due to weathering under the harsh climate conditions of Yakutia is being resolved by the authors in the following directions:

a) Development of Methods for laboratory tests of rock specimens for determining their physical and mechanical properties with regard to their resistance to cryogenic weathering, depending on engineering-geological, geocryological and other conditions of the construction area.

It implies the following new approaches:

- conclusion on the suitability of rocks for the use as construction material must take into account the mechanisms of aerial ground destruction (grounds in natural conditions without a water underrun), aquatic ground destruction (grounds in a water-saturated state) and nival ground destruction (the intermediate state between aquatic and aerial types specific for conditions of snow patches and icings in the spring and summer period). These particularities are important due to the fact that a significant part of the Amur-Yakutsk Mainline lies within river and stream valleys.

- well-grounded alteration of freezing-thawing cycles for increasing the frost resistance of grounds. For example, the recommendations of the State Standard on determining frost resistance after 25 freezing-thawing cycles do not comply with the requirements for the grounds used in the railway construction under the conditions of the sharply continental climate, as the surface of the railway embankment in Yakutia may undergo more than 75 freezing-thawing cycles per year.

Then, a strict limit on the use of rocks as a construction material is introduced, which allows to increase the reliability of an engineering and technical facility during its operation.

b) Composing of a zoning scheme of the Amur-Yakutsk Mainline according to the degree of resistance to the processes of cryogenic weathering.

Route zoning will allow to predict the hazard of emergencies caused by interaction between a technical system and the cryolithozone.

c) Composing of a detailed scheme of the road and climate zoning of the Sakha (Yakutia) Republic with regard to the weathering impact on the stability of linear constructions, which will make it possible to plan and develop the processes of construction and maintenance of a railway system more rationally.

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Provision of the Reliability of Bases and Foundations under Gas Production and Gas Transport Facilities in the North of Western Siberia in the Conditions of Climate Warming and Permafrost Degradation

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Climatologists' and geocryologists' investigations testify to the presence of the long-term trend to the increase in annual mean air and permafrost temperature within the major part of the Russian Federation. The increase in the annual mean air temperature between 1976 and 2010 made up 0.52 °C/10 years on average for the territory of Russia. The warming during the recent 30-35 years is estimated by the value 0.42 °C/10 years for Western Siberia, according to the data of the Rosgidromet (the Federal Service for Hydrometeorology and Environmental Monitoring).

The data of regime monitoring of few geocryological stations operating in Western Siberia confirm the presence of the annual mean permafrost temperature increase by 0.03 °C/year on average.

In 2003-2010 a large volume of geotechnical research was conducted on the Bovanenkovo, the Kharasavey and the Medvezhe fields in connection with designing of arrangement of new fields at the Yamal Peninsula and the upgrade of the facilities of the Nadym-Purovskoe interfluve fields. It allowed the researchers to evaluate the modern background of permafrost temperatures and to carry out the comparative analysis with the data on the permafrost thermal state in the region on the basis of 1970-1980 research results.

The analysis results received with the use of the temperature measurement data of more than 1000 wells testify to the fact that the thermal regime of permafrost changed significantly in the North of Western Siberia during the recent 35-40 years under the impact of climate warming. The background values of annual mean permafrost temperature increased by 1.0-2.5 °C and at some sites by 4.0 °C. Taking into account the observed trend of the annual mean air temperature increase, this is rather logical and corresponds to the earlier forecasts. The most significant increase in annual mean permafrost temperature was registered within the Yamal Peninsula. The permafrost temperature increase is not so obvious in the Nadym-Purovskoe interfluve.

The available data on the change in the permafrost thermal regime within the 10-15 m surface layer of the geotechnical section are confirmed by the temperature measurement results of more than 70 wells with the depth of 50-450 m that were drilled within the Bovanenkovo and the Kharasavey fields. Either the absence of the ground temperature gradient or the negative temperature gradient is generally noted within the 40-60 m interval from the surface (Fig. 1).

With regard to the results of research on the change in permafrost thermal regime in the region and with regard to the climate warming forecasts and the local technogenic impacts, the reliability backup of bases and foundations is provided in the process of the arrangement design of the Bovanenkovo gas condensate field that is the largest field on the Yamal Peninsula. The backup ensuring the bearing capacity in case of an increase in the annual mean air temperature by 2.0 °C in the region is assumed in design solutions connected with bases and foundations for the period of the existence of the facilities. The backup is mainly achieved by means of forced permafrost cooling with the use of vapour-liquid heat stabilization systems. Technical solutions connected with heat stabilization are developed with the use of prognostic thermotechnical calculations.

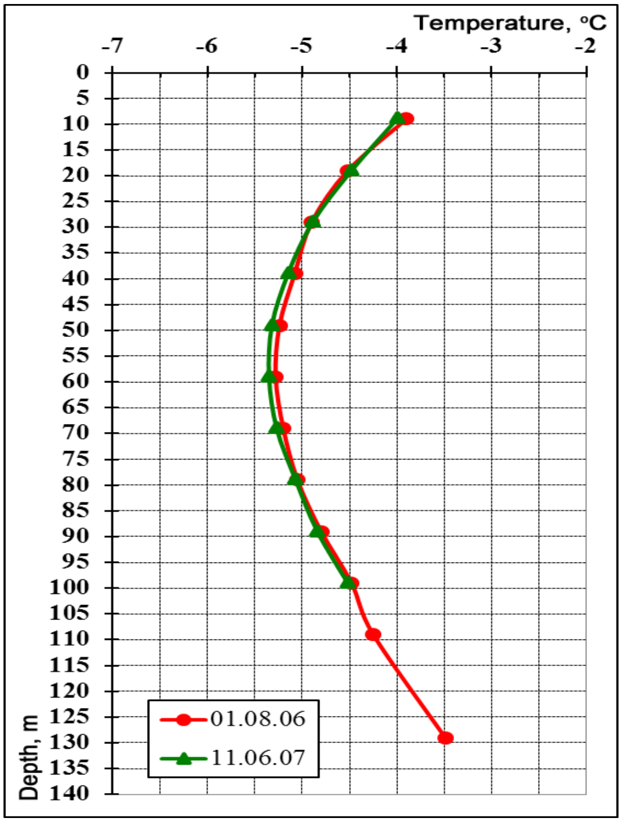

Figure 1. The Bovanenkovo field. Results of temperature logging of parametric permafrost well 29-P-1 (on the basis of the materials of NTF KRIOS LLC).

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Svalbard Active Layer Freeze Thaw Dynamics 2007-2010

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Introduction

Background

During the IPY 2007-2009, under the TSP NORWAY project, 12 new permafrost boreholes were installed in different periglacial landforms in Svalbard in both central and maritime Nordenskioldland, bringing the total up to 15.Temperature data from these boreholes, in combination with local meteorological data and landform characteristics, allow us to study what controls the active layer freeze thaw cycle, the numerous local variables and/or the meteorology. Thus the objective is to study the links between annual active layer dynamics such as freeze-thaw timing, maximum depth, refreeze direction and thaw rate. As well as to which degree these conditions are controlled by the local micro-climate of the different periglacial landforms and/or the overall meteorology.

We present active layer dynamics from 15 different sites in the periglacial landscapefora four year period from summer2007 to summer 2010. Data are collected in the Nordenskioldland Permafrost Observatory, and are available through the Norwegian Permafrost Database NORPERM (http://www.ngu.no/kart/permafrost_svalbard) [*Juliussen et al. 2010*].

Site Characteristics

The Svalbard permafrost boreholes were installed with the goal to cover the dominant types of Svalbard periglacial landforms, permafrost conditions and climate. The climates range from more continental in central Svalbard (i.e. Adventdalen) to the most maritime on the west coast (i.e. Kapp Linné). The lowest borehole is located in Adventdalen at 9 m a.s.l., while the highest is at 900 m a.s.l. further south at Lunckefjellet. The boreholes are installed in a pingo, ice-wedge polygon, strandflat, rock glacier, blockfield, solifluction slope, peat bog, loess terrace, fluvial plain, annual snowpatch, blockfield and an ice cored moraine.These landforms are in different substrates ranging from bedrock to marine clays [*Christiansen et al. 2010*]. Ground temperatures are recorded down to depths of 3.5 – 87 m, with a higher number of sensors located within the first 1-2 m allowing for high vertical resolution of the active layer thermal regime.This allows us to study the differences in active layer processes between the periglacial landforms.

Methods

Data

Data (2007 to 2010) have been analyzed in their respective hydrologicalyears (i.e. 1 Sept 2007 to 31 Aug 2008). They are used in combination with local meteorological data, gathered at nearby automatic weather stations, provided by the Norwegian Meteorological Institute (Met.no) and the University Centre in Svalbard (UNIS). This allows for quantification of the links between local meteorology and active layer freeze-thaw dynamics.

The meteorological station data have been used to calculate the local freezing and thawing degree days (FDD & TDD respectively). FDD are calculated for the entire hydrological year. TDD are calculated for full thawing periods from when the ground surface temperature rises above 0°C and until the ground begins to freeze. These periods can be seen in Table 1 below.

Borehole Instrumentation

All boreholes, except those denotedin Figure 1 with a “*” were drilled by hammer drilling. Samples of dust were analyzed to obtainsome data on the underlying substrate as drilling was being done. A PVC casing was used and either a 10 sensor Geoprecision thermistor chain or, in the deeper boreholes, a 25 sensor Campbell Scientific thermistor chain were installed in the boreholes [*Christiansen et al. 2010*].

Active Layer Thickness

The active layer thicknesses (ALT) were obtained by linear interpolation between thermistors. ALT was taken as when the 0°C isotherm reached its deepest point during the hydrological year. Data missing through time have not been corrected or filled in. During the 2007 hydrological year all sites are missing the first half of the year at least. However the ALT measurements are made using the measurements from the second half of the year (i.e. June-Sept). For subsequent hydrological years the missing data occur during the coldest periods or only for a few days during the thaw period, not affecting out interpolation of the ALT.

Annual Freeze-Thaw Period

Manual inspection has extracted the dates of annual thaw and freeze changes. Table 1 below gives these dates for each site organized by elevation.

Based on interpolation of the ground thermal regime it has also been possible to determine the direction of freezing of the active layer as well as the rate of freezing and thawing, two controlling factors for the generation of segregated ice bodies and subsequent ground heave and settlement.Following Harris et al. [*2011*] zero curtain (ZC) periods have been extracted by plotting the annual 0°C and -0.2°C isotherms and determining the time needed for the active layer to reach -0.2°C after freezing (Table 1). The zero curtain signifies a period of time when the ground temperature is at roughly 0°C and remains due to the release of latent heat from the phase change of water to ice [*Barry & Gan 2011*].

As can be seen in Figure 1, eight of the sites show an overall increase in ALT over the 4 years, with just 5 sites showing an increase for each year. 6 sites show a decrease over the entire period. The bedrock site shows a much larger ALT compared to the strandflat sediment over bedrock site and even more so compared to thepeat bog strandflat sediment site.

Table 1:Active layer characteristics for the 2007-2010 period.

	Thaw Date / Freeze Date			
Site	**2007**	**2008**	**2009**	**2010**
Ice Wedge	29-Sep	17-May / 1-Oct	4-May / 12-Oct	22-May
Fluvial Plain†	29-Sep	13-May / 1-Oct (46)	4-May / 14-Oct (29)	13-May
Snowpatch †		19-Jun / (161)	14-Jun / 19-Oct (123)	21-Jun
Bedrock outcrop	25-May / 10-Oct (31)	3-May / 4-Oct (37)	15-May / 24-Oct (27)	24-May
Strandflat†	17-May / 9-Oct (28)	18-May / 29-Sep (36)	20-May / 21-Oct (22)	27-May
Peat bog†	29-Sep	13-May / 14-Oct (61)	29-Apr / 12-Oct (36)	22-May
Moraine†	30-Sep (26)	12-May / 27-Sep (30)		
Beach Ridge†	2-Oct (91)	13-Jun / 4-Oct (25)	18-May / 16-Oct (11)	
Solifluction slope†	10-Jun*/ 27-Sep (41)	9-Jun / 30-Sep (72)	23-May / 16-Oct (68)	2-Jun
Fluvial Plain†	3-May / 10-Oct (16)	9-May /		
Pingo	2-May / 30-Sep	4-May / 18-Sep	4-May / 15-Oct	
Block Field	27-Jun-06 / 22-Sep	21-Jun / 14-Sep	26-Jun /	
Weathered Slope		16-Jul / 14-Sep	23-Jul /	

(x) The number in parentheses is zero curtain length in days
*denotes data point from (Harris et al. 2011)
† denotes sites with visible zero curtain

Results

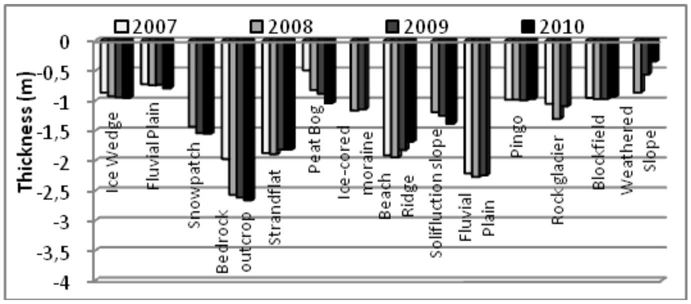

Figure 6: Active layer thickness for the 2007-2010period in the 15 sites in order of elevation from low (left) to high (right). The landform of each site is included.

The ALT of the central snowpatch is ~0.7m thicker than the upper snowpatch site. Though these sites are separated by only a few meters, the upper snowpatch is located in the flat, exposed valley of Adventdalen, where it only accumulates a few cm of snow annually, whereas the central snowpatch is located in the center of a natural snowdrift site, accumulating annually a drift of snow up to ~3m.The presence of a thick snow drift is shown to have an insulating effect on the ground during both the cold winter months (i.e. 14°C warmer minimum surface temperature) and during the summer months by reducing the length of the thaw period.

The climatic differences between central and maritime Svalbard are seen both in the differences in ALT of the Kapp Linné sites (bedrock outcrop, strandflat and peat bog) and the Ny Ålesund site (beach ridge) vs. the other more centrally located sites. However a careful look at the annual FDD and TDD shows a large difference between the number of FDD (~15-20% more) at the western sitesvs. the central sites, while only a minor difference in TDD.

Most of the sites appear to exhibit rapid one-sided freezing or possibly double sided freezing in the fall, some being equally frozen from both sides and others freezing faster from the surface than the bottom.

Discussion & Conclusion

Initial results and analysis show a close link between ALT of the different periglacial landforms with the physical and environmental factors. In the cases of bedrock vs. sediment differences may arise out of differing thermal properties (i.e. diffusivity), for sediment only sites the local and to some degree the regional location will affect the amount of precipitation and/or wind and thus water/ice content (e.g. snowpatch). Landforms displaying a clear ZC are displayed in Table 1. The presence of the zero curtains signifies a period of potential ground ice formation and thusground heave. For this to happen enough water has to be present to delay complete freezing. The remaining sites freeze quickly, as thus without any significant ice formation due to dry site locations.

Several of the landforms experience a melting lag in spring. This step like progressing could be explained by the presence of ice bodies that need to first be brought up to 0°C, before finally melting. Both snowpatch sites in Adventdalen and the NyÅlesundsite show distinct signs of this, most likely due to significant refreezing of meltwater in the snow pack.

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Geophysical Characterization of Unstable Permafrost in the Turtmann Valley, Switzerland

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Introduction

Permafrost in high alpine regions is highly susceptible to changes of the air temperature. Rising mean annual temperatures due to global warming in combination with increased rainfall can lead to permafrost degradation and may act as trigger for rock falls, landslides and other ground instabilities, which threaten infrastructure and human life [*e.g. Crosta et al. 2004*]. To assess the associated dangers and to understand the underlying thermo-hydro-mechanical (THM) processes a detailed geophysical, geotechnical and hydrological characterization of a permafrost soil is needed. Based on this characterization, THM models can be developed to predict general permafrost behavior under changing environmental conditions. An interdisciplinary project has been set up to tackle these problems. Here, we present preliminary findings.

Study Site

A rock glacier in the Turtmann valley, Canton Valais, Switzerland, has been selected as study site. It lies on the western flank of a mountain between 2750 and 2900 m altitude. Increased moving speeds observed from remote sensing [*Roer et. al, 2005*] and signs of thermokarst such as opening lateral crevasses at the surface make this rock glacier to an ideal site for studying the complex processes of permafrost degradation.

Field Investigations

To get a consistent and comprehensive model of the subsurface, extensive geophysical and geotechnical measuring and monitoring campaigns have been carried out over the last two years to delineate (i) the volume of the rock glacier, (ii) the occurrence of ice and (iii) the distribution of internal shear horizons. Seven boreholes, each approximately 25m deep, were drilled to obtain geological information. The boreholes were equipped with thermistor chains and inclinometers to measure temperature and deformation over time. To monitor metrological parameters such as long and short wavelength radiation, precipitation, wind speed and direction and air temperature, a meteo station was set up near the boreholes, as well as surface temperature sensors.

Seismic Refraction tomography (SRT)

Four seismic profiles were measured, one in longitudinal and three in transversal direction of the rock glacier. We choose 2m geophone spacing and an explosive source was fired every 4m. The measuring campaign took place in spring, when the rock glacier was still snow covered. This provided both good coupling conditions for the geophones the source, which was put under the 1-2m thick snow cover. The data were analyzed using refraction tomography [*Lanz et al., 1998*] and the resulting tomograms allowed the gross internal structure to be identified.

Electrical Resistivity Tomoraphy (ERT)

Two 200m long geoelectric lines parallel to the longitudinal and to the central transversal seismic line and one 60mx40m 3D patch in the central part of the rock glacier were measured using a Syscal Pro system with 96 channels and 2m electrode spacing. To reduce the contact resistance we used sponges soaked in salt water to fix the electrodes to the ground. We measured standard Wenner and dipole-dipole configurations, as well as gradient configurations in the 3D survey. For the tomographic inversion of the data a finite element code, described in Günther et al., 2006 was employed.

Ground-Penetrating Radar (GPR)

Several intersecting profiles were acquired across the rock glacier using a 50MHz PulseEkko ground-penetrating radar system mounted on a wooden sledge. The position of each trace was measured using a GPS system installed on the sledge. A standard processing scheme including a mute of the direct wave, a multiplication with a gain function and a bandpass frequency filter was applied to the data. To reduce the influence of coherent noise in the data, we employed a moving window single-value-decomposition filter. This improved significantly the subsurface images. After processing, the data were converted to depth with a constant speed of 0.12m/ns and an altitude correction was applied. Then reflectors were picked on each profile and correlated at the crossing points between profiles. This allowed identifying several internal horizons to a depth of about 70m. Most of the reflectors could be tracked over several profiles.

Results and Interpretation

The low seismic velocities between 500 and 1500 m/s near the surface, shown in the tomogram in Figure 1a, suggest the presence of an active layer. This is supported by temperature measurements in the boreholes, which indicate an active layer thickness of about 3 to 4 m. The slight overestimation of the active layer thickness in the seismic tomogram can be explained with smearing of the low velocity snow layer by the smoothing constraints in the inversion process [*Lanz et al., 1998*]. Below the active layer, there is a lateral very heterogeneous zone characterized by intermediate velocities of 3000m/s-4000m/s, which is indicative for permafrost. In the same depth range we also observe velocities >4500m/s, that are typical for bedrock and/or large boulders.. Over large parts of the profiles there is no clear bedrock interface visible, therefore it is expected to be at least 50-60m deep, which is below the resolution depth of our geometrical source-receiver setup (the deepest rays reach a depth of ca 30m). Only on the lowermost transversal profile a bedrock barrier is found, which subdivides the flow in two parts (not shown). This agrees well with visual observations at the surface.

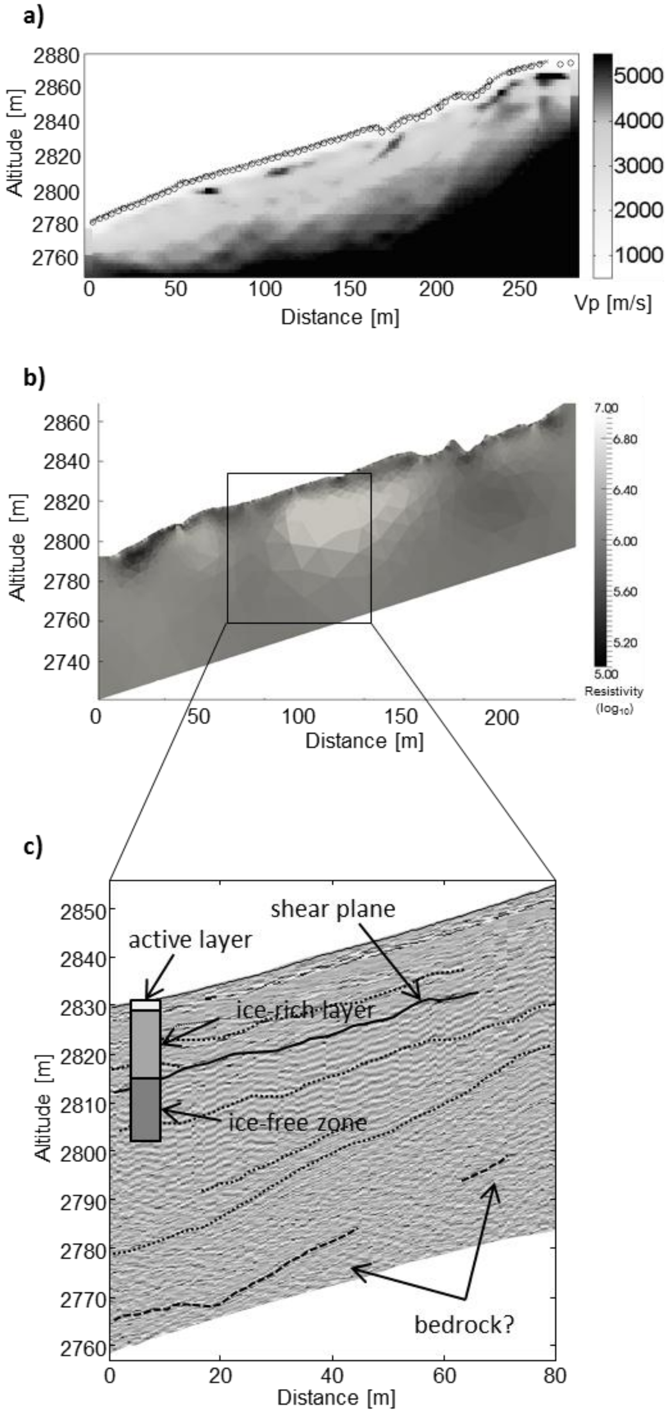

Figure 7 (a) SRT profile along the longitudinal axis of the Furggwanghorn rock glacier. (b) Resistivity tomogram parallel to the seismic line. (c) GPR profile through the central part of the rock glacier. Also shown is a generalized stratigraphy from a borehole 5m away from the profile. Several internal shear horizons are visible, one of them is the active shear horizon (solid line). The lowermost reflector indicates bedrock depths of up to 65m (dashed line).

The high resistivities found in the geoelectrical tomogram below the central part of the rock glacier (Figure 1c) are likely to be ice rich zones. This is consistent with the interpretation of the seismic tomogram in Figure 1a. Furthermore, the observation of ice in nearby boreholes at the corresponding depths supports this interpretation. Lower resistivities near the surface depressions at 160-180 m are indications for permafrost degradation and give hints on a possible mechanism why in this area the movement opens cracks whereas in zones with an ice-rich layer the top layer moves as a rigid block.

The GPR section in Figure 1c shows several prominent reflectors. One of them occurs at a depth of about 15 m. Deformation measurements in the boreholes show that most of the displacement is focused in a ca. 0.5m thick shear zone between 14 and 17m depth. Therefore, this reflector is thought to be caused by the currently active shear horizon. A second reflector below the active shear horizon at about 25 m depth may represent an older, non-active shear plane. The deepest reflectors in Figure 1c lie between 55 and 65 m depth. They are interpreted as the bedrock interface, which is consistent with the minimum depth estimates from the seismic tomography.

By combining all the geotechnical, geophysical and surface measurements, we are currently establishing a comprehensive subsurface model, which will form the basis for subsequent numerical THM modeling.

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Thermal erosion problem solution while developing Yamal gas-condensate deposits

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Abstract

Technology of steadily sod grass cover formation without applying top-soil layer in accordance with a concept of original soil-formation has been developed. Rapid formation of biogenous humus-accumulative layer is provided by a high productivity of phytocenosis as a result of polymer cover formation after grass sowing. Formation of sod grass cover is the most ecologically appropriate solution to stop wind, water and thermal erosion.

Keywords: gas-condensate field, development, cryogenic processes, thermal erosion, damaged lands, sod grass cover formation.

The West-Siberian oil-and-gas bearing province is a major basis for hydrocarbon raw material production in our country. The territory under consideration (region of the Urengoi, Bovanenkovskoe, Kharasaveiskoe and Tambey fields) lies in the northern part of the West-Siberian plain, from the Kara Sea coasts to 66 parallel of north latitude. Development of large-scale gas-condensate, gas and oil-condensate fields in the northern regions of West Siberia began in the middle of 1970s and is still proceeding at an ever increasing pace. This results in destruction of tundra cover and natural permafrost conditions. Destruction scale directly depends on a technogenic influence degree and landscape environment (Fig. 1).

Figure 1 – General view of territory with an exploratory well completion

Territory of the Yamal gas-condensate fields' development having perennially frozen soils on its largest part is characterized by severe climatic conditions with restricted radiation resources, low negative temperatures, excess humidity and strong wind activity. Reasons for increased vulnerability of tundra ecosystems are complicated permafrost conditions, thermodynamic instability of perennially frozen rocks, relief roughness, biocenose development under extreme conditions with reductive structure creation. Small thickness of the soil cover depleted with fertilizer elements and underlying perennially frozen soils affect the soils resistance to technogenic loadings and determine a low potential of soil-vegetable cover self-regeneration. During oil and gas exploration, production, collection and transportation the soil is used for numerous oil-field facilities, such as wells, technological reservoirs, transmission facilities, pipelines, oil-gathering points, facilities for oil and gas treating, group pumping stations, compressors, oil processing stations, transportation services and others. Development of oil and gas fields in the zone of perennially frozen soils propagation leads to destruction of the soil cover, which acts as heat insulator. In its turn this results in an intensive thermal erosion development.

In case of partial or total destruction of soil-vegetable cover a depth of a seasonal-thawed layer increases; cryogenic processes develop, such as thermokarst, solifluction, heaving, frost-shattering fracturing with larger intensity than under in-situ conditions of natural complexes. If under in-situ conditions velocity of solifluctional soils flow is about some centimeters per year, under the technogenic damage velocity reaches to 5-7 m per day, especially on the highly damped slopes. Under the solifluction action within 24 hours from thousands m^2 area a surface soil layer can be removed to the slope foot at a depth of 1 m [*Research… 1987*]. Thermokarst leads to formation of subsidence relief types as a result of surface subsidence occurring during local thawing of perennially frozen soils. «Technogenic» thermokarst is appeared in formation of micro-catholes with water and running soil and developed at the flat and low parts with damaged soil-vegetable cover. Process of soil heaving caused by frost penetration and embedded water volume increase when transferring into ice state results in day surface elevation and can deform facilities constructed at this zone. The most vulnerable territories are lowlands and flat parts consisting of sandy-loam and silt soils. Frost-shattering fracturing leads to day surface deformation as a result of cracks occurrence due to wide temperature fluctuations in winter when snow accumulation regime changing and as a consequence of this temperature soils regime changing.

Industrial sites, drill and production wells and areas along pipelines are characterized by the highest degree of cryogenic processes activation. It stimulates numerous damage of oil-field facilities (deformation, soil sink and subsidence in exploratory wells mouths, foundation piles upfreezing and etc.), and impacts facilities reliability and their operating conditions. In this respect remediation of Yamal damaged lands is important not only for ecological problems solving and grazing lands remediation, but also for solving a problem of operating facilities stability in the permafrost area. World experience proves the best way to cease erosion processes is a grass sod cover creation. A traditional scheme of biological reclamation supposes to apply a top soil layer (earthing) and grass sowing. But recovery of a top soil layer from other territories automatically makes those damaged. Peat recovery from tundra zone inevitably results in intensification of thermal erosion processes. Besides, expenses on reclamation in mining industry are 4.5% of world mineral marketing or 14.1 % in initial investment [*Counting… 1994*]. So, development of effective methods to create a sod cover on the mineral substratum with at lower cost is important.

Specialists of the Mining Institute of the Kola Science Center RAS have developed technology of damaged lands remediation by grass sod formation without applying a top soil layer in accordance with a concept of original soil-formation [*Mesyats 2004*]. Biological productivity of a sown phytocenosis is a determining factor at a grass sod creation.

Evolutionary fixed property of plants to adsorb selectively chemical elements in a certain quantity and capability of a mineral substratum with growing vegetation to keep them during plant fragments decay are initial and final points of biogenic accumulation. During biological organization of mineral substratum, biogenic accumulation leads to humus formation, which is a specific organic substance capable to deposit elements-biogenes as organo-mineral complexes.

According to modern concepts a «humus – vegetation» system is characterized by feedback determining natural systems capability for self-regulation. The system «humus – vegetation» is regulated by a positive feedback, i.e. every partner stimulates development of another one and through this it does its own development (Fig.2).

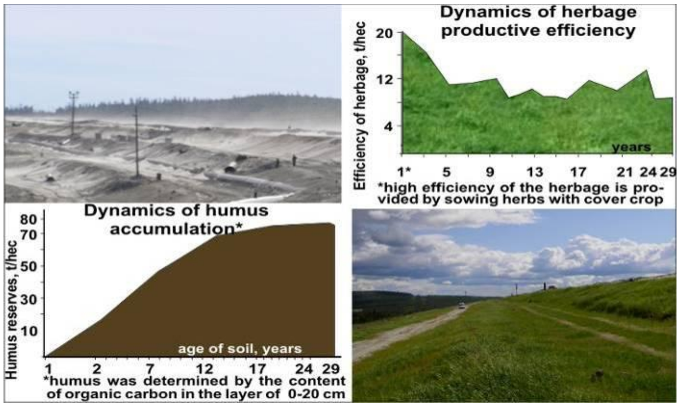
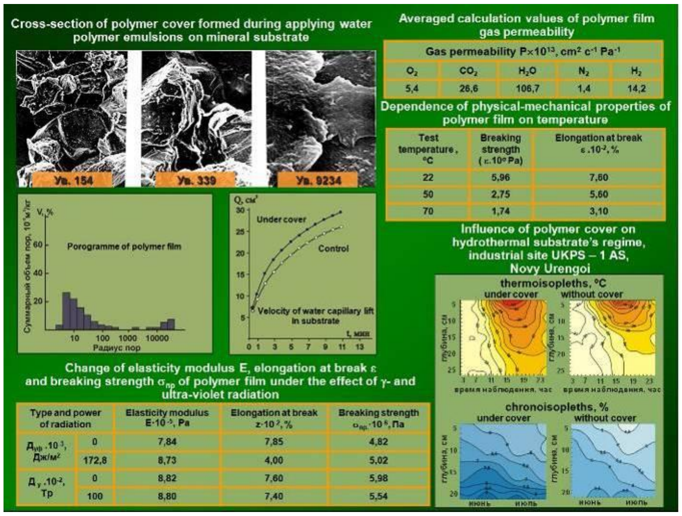


Figure 2 – Results of long-term monitoring for biological organization of mineral substratum during grass sod cover creation without applying top soil layer on the concentration tailings under Arctic Region conditions

Success of the technology implementation is provided by creation of a polymer cover after grass sowing on the basis of starting mineral fertilizers. The polymer cover solves a set of tasks on improvement of environmental setting of root zones and providing stable high herbage productivity. Under northern conditions it results in fast humus accumulation in a substratum, about 80 ton per hectare (Fig. 2).

Research of radiation, photochemical and temperature impacts on the polymer cover and study of diffusive, adsorptive and transport processes of mass transfer in the cover have shown that the polymer cover is characterized by high erosion resistance, good gas and water permeability, resistance to atmospheric precipitates impact, temperature fluctuations, radiation resistance, ecological purity, and over time is exposed to biodestruction (Fig. 3) [*Mesyats & Melnikov 2005*].



Averaged calculation values of polymer film gas permeability

Gas permeability $P \times 10^{13}$, $cm^2\ c^{-1}\ Pa^{-1}$				
O_2	CO_2	H_2O	N_2	H_2
5,4	26,6	106,7	1,4	14,2

Dependence of physical-mechanical properties of polymer film on temperature

Test temperature, °C	Breaking strength (ε.10⁶ Pa)	Elongation at break ε.10⁻², %
22	5,96	7,60
50	2,75	5,60
70	1,74	3,10

Change of elasticity modulus E, elongation at break ε and breaking strength $\sigma_{пр}$ of polymer film under the effect of γ- and ultra-violet radiation

Type and power of radiation		Elasticity modulus $E \cdot 10^{-5}$, Pa	Elongation at break $\varepsilon \cdot 10^{-2}$, %	Breaking strength $\sigma_{пр} \cdot 10^{6}$, Па
$Д_{уф} \cdot 10^{-3}$, Дж/м²	0	7,84	7,85	4,82
	172,8	8,73	4,00	5,02
$Д_{\gamma} \cdot 10^{-2}$, Тр	0	8,82	7,60	5,98
	100	8,80	7,40	5,54

Figure 3 – Physical-chemical and operating properties of polymer cover

Creation of the polymer cover provides for diminution of wind and water erosion, optimization of hydrothermal regime, increase of biochemical root zone activity, localization of technogenic pollution preventing its propagation into adjacent environments and by trophic chains. The technology has 30-years experience of implementation on diverse objects under different climatic zones, including Arctic region.

The technology formed the basis of the complex program of dust control in order to decrease radioactive dust transfer during accident consequences management in Chernobyl EPP. Based on this technology soil-vegetation cover has been formed on thousands of hectares of deactivated areas.

Developed technological solutions have been applied for many years in mining enterprises of the Kola mining and industrial complex. Biogeobarrier created in the ore concentration tailings that occupy thousands of hectares, stops wind and water erosion, provides conservation of technogenic mineral raw materials and provides for environment improvement [*Innovative… 2010*].

Monitoring of the grass sod cover confirms similarity of its formation main trends on the different objects, despite difference of climatic conditions, mineralogical and chemical composition of technogenic raw material:

- the polymer cover forms grass stand which is characterized by fast growth and steadily high productivity, timely passing of every phenological stage of plants growth and development, including reproductive one, and by annual self-regeneration without care;

- for the first three years a biogenous - accumulative layer is formed; quantitatively it is yet expressed insignificantly;

- main features of biogenous humus-accumulative layer are formed to the end of the first decade; under second decade diagnostic traits get qualitative and quantitative characteristics;

- steadily high bioproductivity of sown phytocoenosis provides for rapid pace of humus accumulation and the reserves formation (Fig 2).

Formation of biotop soil layer on a stage of sown phytocenosis provides for more rapid transfer during succession to phytocenosis with a structure of surrounding landscape. Appearance of layered structure and extension of biodiversity increases compensatory resources and support resistance of sod grass cover for a long period of time [*Research… 1991*].

The Yamal testing areas had been founded at a stage of geological prospecting operations completion on the Bovanenkovskoe field (open-pit № 4), the Khrasaveiskoe field (an old open-pit), the Tambey oil-bearing province (drilling site № 30 TEGRB), an industrial site UKPG – 1AS (New Urengoi) (Fig. 4). Observations were carried out systematically in the period of 1987 - 1991.

In process of investigations carried out there has been realized a selection of grass mixtures, determined separate grass species composing this grass mixture and agrotechnical conditions for the growing. Also there have been developed technological regimes for the polymer cover formation. There have were researched phenological stages of growth and development of sown phytocenosis, thickness of grass sod cover and winter resistance of separate species.

Determining grass mixtures composition besides analysis of agro-climatic characteristics and particularities of tundra soils and biological particularities of each species it was taken into consideration that a natural vegetation cover of Yamal is presented with such local Gramineae as Festuca pratensis and Festuca ovina, Poa pratensis, ecological types of Festuca rubra and Calamagrostis. Local different permanent grasses among first plants populate damaged lands during the self-rehabilitation. It is reasonable to take into consideration such feature as complementarity which is appeared through a structural organization of species diversity that provides for resistance of a vegetation cover in time.

Selection of species of different ecology and ontogenesis duration provides for more equal arrival of phytomass into substratum in time based on complete use of environmental conditions. Therefore, grass mixtures should be preferably composed from species which are different by their requirements to existing environmental conditions.

So, aggregate features of recommended Gramineae are rapid growth, high bioproductivity, and ability to last into grass stand for a long time and add each other with aim of more complete use of natural resources. According to estimation of sown phytocenosis during some vegetation periods the conclusion has been made about necessity to add into grass mixture low grazing enduring grass species permitting to form grass sod cover resistant to deer grazing.

Under short vegetation period conditions, terms of sowing are of importance. According to monitoring results during sowing in the second decade of June permanent grass goes to winter with maximum quantity of shorten (wintering) spears and sufficient reserve of fertilizer elements in a tillering zone.

Development of agrotechnical methods, including determination of grass mixtures composition was realized under methodical maintenance of the Polar experimental plant-growing station of the Russian Academy of Agricultural Sciences.

During monitoring of sown phytocenosis there was recorded quite fast accumulation of fertility elements. After three years there was observed the element exceeding almost by all agrochemical factors compared to virgin soils. Polymer cover creates the optimum conditions for soil microflora and improving the plant root nutrition, provides for plant biomass growth, organic matter accumulation and fast formation of biogenous- humus accumulative layer [*Research… 1990*].

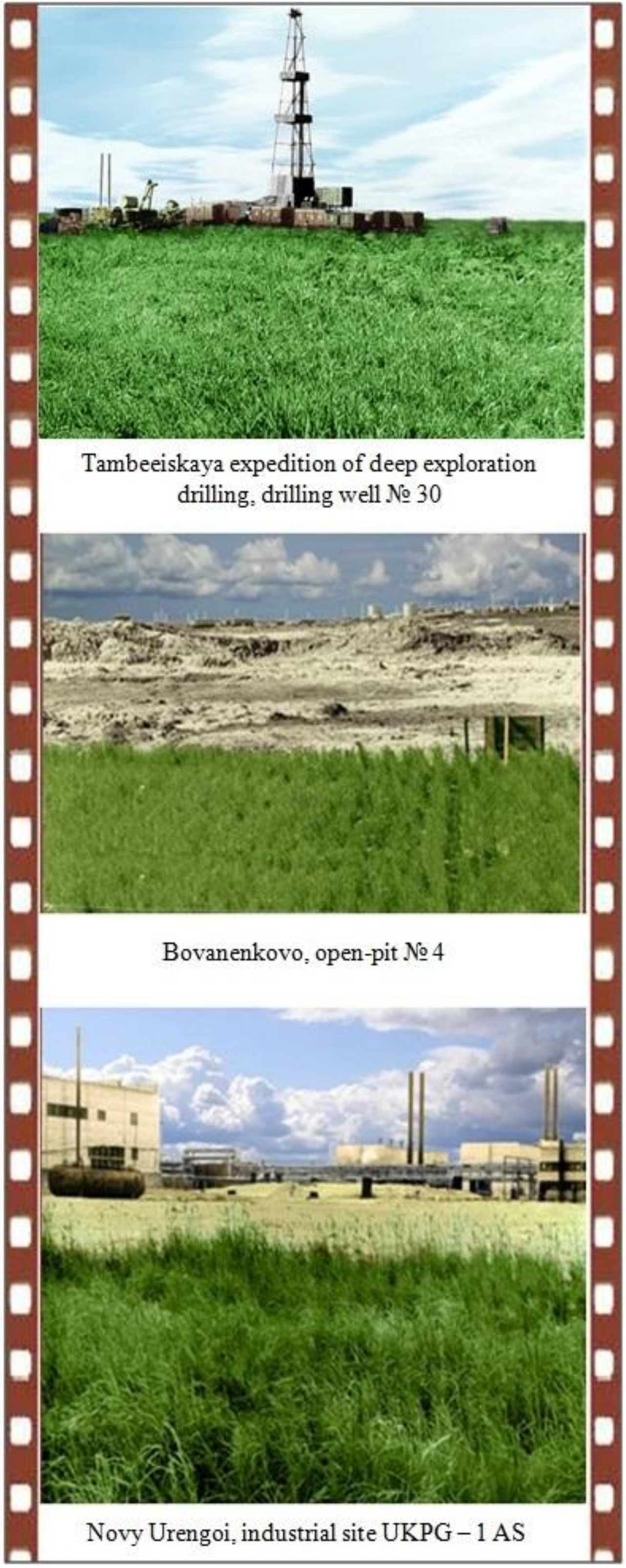


Figure 4 – Creation of vegetation cover in Yamal testing areas without applying a topsoil layer, 3rd year after sowing

Based on results of pilot testing carried out in Bovanenkovskoye deposit (open-pit mine № 4) and drilling site of Tambey oil and gas province, the justification of technical solutions was performed concerning water polymer emulsion application in order to create polymer cover after grass sowing (Fig.5).

Figure 5 – Pilot testing works in Bovanenkovskoye deposit (open-pit mine № 4)

On the basis of carried out investigations and pilot testing the process procedures have been developed on remediation (creation) of soil-vegetative cover for damaged lands of Yamal.

In 1991 an international conference “Environmental measures during oil and gas fields’ development in the Arctic regions” was held by «Gazprom» state gas concern jointly with «Amoco» company, USA. According to the conference decision the technology was declared as the most economically, technologically and ecologically effective and it was recommended in a feasibility study for project on the Yamal gas-condensate fields’ infrastructure development.

The technology proposed is:

- a universal (it is effective in different substratum types, in different climatic zones and applicable on any relief);
- a technological (use of series-produced multipurpose technique provides for fast technological realization on various – scaled objects);
- a highly productive (it provides for remediation of large areas in a short time);
- an environmentally friendly and cost effective (materials used are cheap enough, nontoxic and exposed to bio-destruction in time).

Formation of resistant sod grass cover during remediation of damaged lands under permafrost conditions, in addition to environmental problems solving provides for resistance of operational facilities due to thermal erosion diminution. Expenses are of one-time as regenerated lands don't need re-treatment.

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Assessing (paleo)climatic information from ground ice – A detailed stable isotope study of recent precipitation and ice wedges in North Siberia

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Introduction

Since the 1990s numerous multi-disciplinary investigations have been carried out in the Siberian Arctic during Russian-German cooperative scientific projects such as “System Laptev Sea” in order to improve the knowledge of the Arctic climate and environmental system. The Laptev Sea Region is a key region for understanding the development and the dynamics of ice-rich permafrost and its responses to past, recent and possible future climate change. However, paleoclimate reconstructions in remote permafrost areas are sparse and generally spatially restricted and, in many cases, based upon paleoecological, thus, summer indicators such as pollen. In the past couple of years, ice wedges have been successfully used for paleoclimate research as winter temperature tracers on different (glacial-interglacial to millennial) timescales [*Vaikmäe 1991*]. The isotope information from ice wedges has been combined with Radiocarbon-dated organic matter enclosed in ice wedges and presented as new mid-resolution centennial-scale climate records [*Meyer et al., 2010; Opel et al., 2011*].

However, climate interpretation of the stable-isotope information from ice wedges is based upon several assumptions, which need to be tested. These are related to: (1) the seasonality of precipitation; (2) the origin and pathways of atmospheric moisture; (3) the direct dependency of ice-wedge isotope composition from atmospheric moisture; (4) no significant isotope changes during snow melt and after ice-wedge formation.

Background and methods

Ice wedges are the most abundant type of ground ice in Arctic permafrost deposits. Stable water isotopes in ice wedges are considered to be suitable winter temperature tracers because they are believed to be directly linked to atmospheric precipitation and the filling of frost cracks with snow (or snowmelt) occurring in winter/spring. The isotopic composition ($\delta^{18}O$, δD) of precipitation (rain, snow) strongly depends upon the condensation temperature out of an air mass at a specific locality. Furthermore, the d excess as a second-order parameter (*d excess* = δD-8* $\delta^{18}O$), reflects evaporation conditions (mean relative humidity, (sea) surface temperature, wind speed) above moisture sources (oceans) and therefore can be used for reconstructing the origin and transport of moisture to a specific study site [*Merlivat & Jouzel 1979*]. To assess the stable isotope and climate background for the interpretation of ground ice in the Laptev Sea region, an event-based precipitation sampling has been established at the meteorological station in Tiksi since 2003.

This was combined with meteorological data of the NOAA (National Oceanic and Atmospheric Administration) database available at http://www.ncdc.noaa.gov/oa/mpp/freedata.htm.

Since snow-melt water, which enters a frost crack, refreezes rapidly enough to prevent isotopic fractionation [*Michel 1982*], the stable water isotope composition of ice wedges should correspond to that of the initial snow. If this is the case, ice wedges can serve as a proxy for mean winter temperatures at the time of their formation and potentially a reconstruction moisture source is possible. Stable water isotopes were measured in the stable isotope lab of the Alfred Wegener Institute in Potsdam, Germany.

The organic matter included in ice wedges can be dated by AMS Radiocarbon methods back to about 50 kyr BP, hence allow age control of discrete parts of an ice wedge. However, for a successful application of the ^{14}C dating technique to ice wedges a careful selection of the samples to be dated is a prerequisite. Organic matter enclosed in ice wedges was dated by AMS technique at the Radiocarbon laboratories in Kiel and Cologne, Germany.

Results

In the frame of fieldwork in Siberia ice wedges and enclosing sediments were studied and sampled in detail. Here, we present the stable water isotope composition ($\delta^{18}O$, δD, d excess) of recently-formed ice wedges in comparison to that of recent precipitation at Tiksi since 2003.

The stable isotope composition displays low values for Tiksi precipitation (mean annual $\delta^{18}O$: -24.4 ‰, δD: -192 ‰; N=614) and represents the cold and arid continental climate conditions of Siberia. Atmospheric moisture reaches the region with the westerlies and mainly originates from the North Atlantic. This is especially true for the winter season (mean snow in Tiksi; $\delta^{18}O$: -28.7‰, δD: -225‰; N=398) when open water areas are mainly frozen and no - so called - secondary moisture has been added to the precipitation.

The precipitation isotopic background is compared to recent ice wedges of the region, especially to ice wedges in the Lena Delta. Recent ice wedges show lower $\delta^{18}O$ and δD values (mean $\delta^{18}O$ = -22.4‰; mean δD = -168‰). However, the linear correlation for recent Lena Delta ice wedges: $\delta D = 7.84\ \delta^{18}O + 7.2$) is close to the Global Meteoric Water Line and to the $LMWL_{snow}$ for Tiksi ($\delta D = 7.87\ \delta^{18}O + 4.8$) which points to no significant secondary isotopic fractionation during recent ice-wedge formation. Hence, ice wedges of the central Lena Delta can be considered as directly linked to atmospheric moisture and as suitable proxies for the winter temperatures.

The heavier isotopic composition of recent ice wedges compared to snow is likely due to the seasonality of precipitation, which may enter an open frost crack. A comparison between recent ice wedges and remnants of snow patches at a given site i.e. in the Lena Delta revealed a high similarity between their isotope signatures. Therefore, further studies on isotope fractionation during snow melt are needed to explain the isotopic differences between freshly fallen snow and snow patches.

An isotopic exchange after ice-wedge formation could be detected only close to the contacts of the ice wedge to the surrounding sediment. These samples have to be discarded for paleoclimate interpretation.

In order to link the isotope composition of older ice wedges (and by that the winter temperature) to the time of their formation, we used AMS-dating of organic matter enclosed in ice wedges. We were able to establish a Holocene winter isotope thermometer for the Lena Delta based on more than 30 dated ice-wedge samples with sufficient suitable datable organic matter.

Ground ice of the first terrace of the Lena Delta was mainly formed in the second half of the Holocene between about 7 kyrs cal BP and today, and, thus mostly contemporaneously to sediment accumulation. In general, ice wedge-growth was particularly active in the past 2 kyrs. The ice wedges display a marked variability in their isotopic composition reflecting changing Late Holocene winter conditions. According to our reconstruction, warmest winter conditions were observed in the most recent centuries, whereas around 5-6 kyrs cal BP winter climate was significantly colder. The winter warming trend between Mid Holocene and present is gradual and in line with the winter insolation curve and also detected in ice wedges at the Oyagos Yar study site, Dmitrii Laptev Strait, NE Siberia [*Opel et al., 2011*]. However, our data contrasts with other Arctic climate records showing a Late Holocene cooling trend. The application of stable isotope methods to Holocene ground ice for paleoclimate records in North Siberia is the topic of a paper by Opel and co-authors.

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Dynamics of Coastal Permafrost

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Abstract

Investigation into coastal dynamics of the Russian Arctic is an important theoretical and practical issue. The Arctic coast is a highly changeable natural system that evolves in the conditions of permafrost being controlled by interaction between the sea and the land. By the time being, the origin and evolution of continental permafrost, as well as processes on the Arctic shelf, have been quite well explored. However, the coastal areas remain poorly studied, both in terms of sea-land interaction and environmental geology. The evolution of the Arctic coast, as a complex system, is driven by climate, fluid-dynamic, and permafrost factors. The main agents are temperature, air circulation, wave energy, sealevel change, land geology and geomorphology, ice content, and lithology of sediments that host ground ice.

Keywords: coastal geomorphology; permafrost; shoreline.

Studies of coastal dynamics: State of the art

The Arctic coast and ice have always attracted the attention of travelers and explorers. The earliest evidence of the coastline, frozen ground, ice, and environment of Northern Siberia dates back to the 1730s when Dmitry and Khariton Laptevs led the Great Northern Expedition. The Russian Arctic explorers of the 19th century were Matvei Gedenschtrom, Pyotr Anjou, Adolf Nordenskiöld, etc. Later, there came Eduard von Toll, Alexander Kolchak, and many others who contributed a lot to the knowledge of the Arctic.

The studies of the Arctic coastal dynamics have a long history. Its first stage spanned the time from the 1820s to the 1930s. Pyotr Anjou was apparently the first who measured coastal erosion in 1823 in Vasilievsky and Semenovsky islands [*Solomatin et al. 1998*], which was the onset of data accumulation on the coastal dynamics, permafrost, and water-borne and bottom ice. Although being not systematic for the lack of instrumental support, and sometimes based merely on historic accounts, the early evidence had an important implication of instability and rapid erosion of the Arctic coast.

The next stage lasted from 1930 to the late 1990s. That was the beginning of instrumental observations of the Artic coastal dynamics, mainly with descriptive approaches to geographical and geological studies. It was during the second stage that permafrost first became a subject of a separate science which developed its methodology, theory, and approaches. That background has defined the main course of further research in coastal dynamics, permafrost, and oceanic cryology.

Permafrost-geological conditions

The structure of the Artcic coast has been produced by joint action of natural events, namely: the opening of the Arctic ocean, global-scale change of the high-latitude climate, and a eustatic sealevel rise in the Holocene. The Arctic ocean is a young geological structure evolving upon continental and transitional crust of the northern periphery of three continents. The ocean opening began with subsidence at the Early-Late Cretaceous boundary, and dispersal of continental blocks occurred in the Paleogene. The subsidence rates were nonuniform: slower in Late Paleozoic and Mesozoic orogens between plates of different ages but faster in plates and basins corresponding to later fold zones with thin continental crust. Thus there formed a broad shelf of continental crust around the young and relatively narrow basin of the Arctic ocean, which morphotectonic rises divided into several seas.

The permafrost-geological and lithological frameworks of the Arctic coast differ strongly in mountainous and lowland areas. The former are mainly plateaus and mountain slopes with the respective stratigraphic sequences.

Changes in permafrost conditions

The rates of coastal erosion depend on several factors: thermal resources of the thaw season; air circulation; position of close floating (drift) ice; sea depth at the fetch line; permafrost conditions. The major control is from drift ice and frequency of heavy storms, which make up jointly about 70 % of the total effect of all main agents involved. On the other hand, one has to bear in mind that the drift ice boundary, the erosion activity of waves, the duration of the ice-free season, as well as the stability of ice-rich coast, depend, in turn, on summer air temperatures in the Arctic.

Results and conclusion

An improved model has been developed, which provides quantitative estimates of the effect the storm frequency variations associated with variations in mean summer air temperature cause on the dynamics of ice-rich coast in the changing climate conditions. The model can be used for predicting the rates of erosion in the Eastern Russian Arctic caused by the presumed global change in the 21st century. Furthermore, the new model ensures 23 % better reliability of estimates for the rates of coast-forming processes within relatively short time spans. The obtained value is close to the measured contribution to these processes from the storm frequency.

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Hydrometeorological Conditions during the Periods of Mass Mudslide Formation on Sakhalin Island

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Introduction

Impact of the maximum fallen liquid precipitation values on the process of formation of periods of mass mudslide formation on Sakhalin Island is taken up.

Treating the problem

Atmospheric precipitation which falls on the island is a result of an intense cyclonic activity. Annual precipitation sums in the valley bottoms and on the sea coast of the southern areas are confined within the interval 800 mm - 1100 mm (in the mountains, mean values of the sums of precipitation fallen depend on a specific altitudinal zone and are as large as 1500 mm - 2000 mm; these sums can exceed 3000 mm in certain years). This is distinctly indicated by the comparison diagram which delivers the long-term precipitation trend presented in Figure 1.

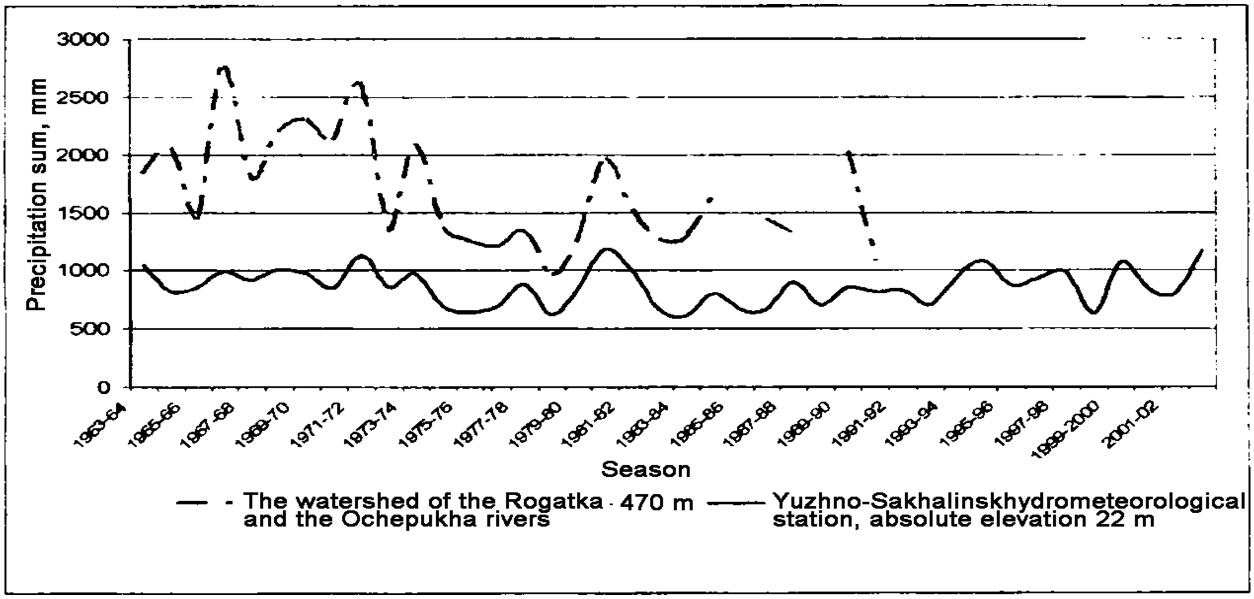

Figure 1. Comparison diagram of the precipitation trend according to Yuzhno-Sakhalinsk hydrometeorological station and the accumulative precipitation gauge which was located in the watershed of Rogatka and Ochepukha rivers near the city of Yuzhno-Sakhalinsk.

65% - 80% of the annual precipitation norm fall during the warm season. According to the data of the hydrometeorological stations, the precipitation sums are 300 mm - 600 mm on average and reach the maximum value of 1100 mm during the mudslide risk period (June - October). This should be noted that the largest part of the observation network of the Hydrometeorological Center of Russia is located along the coasts or in the bottoms of the river valleys of the island. Considering the fact that 3/4 of the territory is occupied by mountains with absolute elevations of 350 m - 1600 m, use of the precipitation data accumulated by the hydrometeorological stations alone causes an underestimate of parameters of hydrometeorological phenomena. Data on their observations cannot be used for mudslide forecasting.

The cyclone which passed over Sakhalin Oblast on September 18-19,1970 covered a large area of the island. The maximum 24-hour precipitation reached the following values in the following sites of mudslide formation: 80 mm at the Makarov hydrometeorological station, 80 mm at the Nevelsk hydrometeorological station. The precipitation level in the southern mountains (the Pereval avalanche station the absolute elevation of which is 300 m) was as large as 121 mm during 12 hours. Such a large precipitation amount caused mass mudslide formation in Nevelsk, Kholmsk and Makarov districts of Sakhalin Oblast.

The next period considered is September and October 1972 when the passage of a few cyclones led to intensive precipitation, moistening of the area and mass mudslides in the abovementioned areas. The maximum 24-hour precipitation levels reached the following values: 148 mm at the Makarov hydrometeorological station, 91 mm at the Nevelsk hydrometeorological station, 68 mm at the Yuzhno-Sakhalinsk hydrometeorological station (during 9 hours). The precipitation level in the southern mountains (the Pereval avalanche station) was as large as 121 mm during 12 hours.

Another period of mass mudslide formation which covered a large part of the island was August 1978. The maximum 24-hour precipitation levels were confined in the interval from

76 mm (the Kholmsk hydrometeorological bureau) to 116 mm (the Poronaysk hydrometeorological observatory). In the island's mountains, precipitation was even more intensive: 40 mm per 3 hours (the Pereval avalanche station). During the passage of typhoons Phyllis and Eugene on August 2-7, 1981, the precipitation sum at the Yuzhno-Sakhalinsk hydrometeorological station (the absolute elevation is 22 m) was 220 mm. According to the data delivered by accumulative precipitation gauges with absolute elevations from 400 m to 600 m, precipitation sums in the Susunayskiy mountain ridge exceeded 1200 mm during the same period.

The precipitation fallen caused an intense mudflow formation during all these mudflow formation periods.

However, a large amount of precipitation fallen does not necessarily cause massive mudslides. For example, during passage of a cyclone in September 1982, the 24-hour precipitation level was 124 mm according to the Makarov hydrometeorological station. Water discharge of the Makarova River was 850 m^3/s. This value is the second largest registered during the whole monitoring period. It is second only to the disastrous water discharge rate of 1722 m^3/s in August 1981. Despite this, there was no mass mudslide formation observed in the region. This is explained by the fact that the mudflows completely cleared mudslide triggering zones from potential mudslide accumulation mass a year earlier, after typhoon Phyllis had passed. This means that the critical mud volume in landslide triggering zones, which is the necessary condition of descent of mudflows in the low-hill areas of the Sakhalin Island, was absent.

Conclusions

During the mudflow risk period (June - October), precipitation sums in the central and southern regions of Sakhalin (in the valleys and at the sea costs) are 300 mm - 600 mm on overage reaching the maximum value of 1100 mm. In the highland areas of the island, there can precipitate more than 1200 mm per one event depending on elevation of an area.

In the mountains of the island, precipitation intensity may exceed 40 mm/h. During passages of typhoons, the difference between precipitation levels registered in the valleys and the highland areas of the island may reach 1000 mm per one event.

Mudflow formation precipitation sum on Sakhalin Island exceeds 50 mm provided precipitation intensity is (20 - 50) mm/24 hours.

Mass mudslide formation needs accumulation of the critical amount of potential landslide mass with a thickness of 0.5 m - 1 m in mudslide triggering zones.

Prediction of Changes in Geocryological Conditions at the Area of the Designed Dam (Western Yamal)

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Introduction

The site of the designed water storage dam is located on the territory of the Kharasavey gas-condensate field, seven kilometers from the Kharasavey field camp on the western coast of the Yamal Peninsula. The water storage basin is designed to provide water supply to the Bovanenkovo and Kharasavey gas-condensate fields.

Natural environment

Climate

The studied region is characterized by rather severe climatic conditions and extremely complicated geocryological conditions. The analysis of meteorological data revealed that the long-time average temperature of air in this region is 9.5ºC. The minimum average monthly temperature of air is observed in January-February and is equal to -23 ÷ -24ºC, while the maximum temperature typical of July-August is +6 ÷ +7ºC.

Geological structure

The geological structure of the survey area within the studied depth of 15 m includes:

- the Holocene deposits of alluvial genesis (a IV) represented by silty sands, sandy silts, clayey silts, clays and ice grounds;
- upper Pleistocene-Holocene marine and lagoon-marine deposits (m, lm III-IV) represented by fine sands, silty sands, sandy silts, clayey silts, clays and ice grounds.

Geocryological conditions

In all geomorphological elements of the Kharasavey field permafrost grounds are characterized by continuous distribution from the surface.

The average annual temperature of the grounds at the depth of zero annual amplitude varies from -1.1 to -7.1°C depending on the landscape conditions.

The permafrost thickness in the studied area is 200 m and together with the underlying cooled grounds the permafrost thickness in this area reaches 370 m.

The sides of the valley of the Khardeyakha River are composed of icy and very ice-rich grounds containing deposits of ice grounds (with the thickness of 0.3-4.4 m) and massive ice. The grounds have different salt content through the section. The area is also characterized by the presence of cryopegs [*Report… 2006*]. Any disturbances of surface conditions (the heating impact of the water storage basin, thermal abrasion of coastal line from the upstream side, disturbance of the soil cover by construction machinery, etc.) can cause intense thermodenudational destruction of the massif of ice-rich grounds at the foundation of the dam and at the adjoining areas, and this intensity can have catastrophic character. In such circumstances it is impossible to suggest sound design solutions for trouble-free operation of facilities without a scientifically based geocryological forecast.

Mathematical modeling of geocryological conditions in the dam body and foundation grounds

Mathematical modeling of thermal interaction of the designed water storage basin with permafrost grounds was carried out in the Teplo software [*Emelyanov et al. 1994*] developed to solve non-steady non-linear tasks of thermal conductivity with distributed thermal sources and movable phase boundaries in one or two dimensional areas by finite-difference method with setting initial and boundary conditions. Initial conditions describe a temperature field at a certain moment of time that is taken as a starting point. Boundary conditions describe heat exchange of the investigated system with the ambient environment.

Dam parameters

The studied territory is designed for an earth dam that will be made from the local sandy ground with a diaphragm wall from steel sheet piles. The normal water level (NWL) is 7.00 m, the crest level is 9.50 m. The dam height is 9.0 m, the crest width is 10 m and the crest length is 402.0 m. Seasonal cooling units are planned to be installed along the dam crest at the interval of 2 m to insure ground strength characteristics of the dam during the summer period.

Identification of ground boundary conditions, composition and thermophysical properties

When performing mathematical modeling, the geological section was taken based on engineering-geological sections of the site and publications data [*Baulin et al. 2003*].

Long-time average monthly temperatures of air and thermal resistance of snow cover required for calculation were derived from publications data and calibration estimates.

In order to exclude the impact of lateral and bottom boundaries of the area on heat exchange process in the studied zone, the design area was assumed to extend for 170 m horizontally and 100 m vertically, which significantly exceeds the dam's dimensions.

The design area was divided into blocks in accordance with the real geometry and geological structure of the facility.

8 areas with different boundary conditions were singled out on the surface of grounds. These are: a section of the road bed on the dam's surface with extremely disturbed snow cover (area 1); subaerial zones of the dam and ground surfaces at the downstream side with normal snow accumulation (area 2); a zone of the freezing of ice with the dam's upstream slope (areas 3, 4, 5, 6) is divided into 4 groups of boundary conditions depending on the ice thickness increment; water reservoir

bottom with continuous water intrusion at the depths from 2 to 6 m (area 7) and from 6 to 8 m (area 8).

A time-constant heat flow was set at the lower and lateral boundaries of the design area: 0.02 W/m^2 at the lower boundary and 0 W/m^2 at the lateral boundaries.

The grounds' thermophysical properties required for calculation were assigned based on regulatory documents. [*Shur 1988*].

Analysis of obtained results

The analysis of the results of the modeling for 50 years ahead from the construction of the water storage basin shows that even without any measures for engineering protection the dam body freezes through rather quickly. It is extremely important that the expected talik boundary does not run beyond the water edge towards the dam body. Thus, long-term thawing will not affect the basic part of the engineering structure. While a talik develops, the ground under the axial part of the earthwork features only a slight temperature growth but the temperature never rises above -2 C, which guarantees a solidly frozen state of sandy grounds. But it should be noted that, during the first years of the structure operation, the dam body contains a core that has a temperature close to zero and does not completely freeze through, that is why, in order to increase the durability of the structure and prevent filtration during the initial years of operation, seasonal cooling units can be installed on the dam's crest, as it was proposed in one of the draft projects. It can be also recommended to fill the water storage basin with water after a year so that the dam body would freeze quicker experiencing more severe conditions.

The performed mathematical modeling of geocryological conditions of the water storage bed showed that during the water storage operation permafrost grounds under its bottom will be thawing over years with the formation of a talik. The modeling also showed that the grounds' temperature will undergo slight average increase compared to the natural grounds on the territory adjoining the water storage basin because of the lateral heat flow from the water storage bottom. The thawing halo depth by the ultimate estimated moment of time (after 50 years of operation) will be 13.6 m (Fig. 1).

Since the grounds have various salt content through the section and, accordingly, different freezing onset temperatures, the zero isotherm does not coincide with the border of permafrost and thawed/cooled grounds. At the initial moment of time the zero isotherm under the water storage basin center was located at the depth of 0.5 m, and by the final design time it lowered to the depth of 8 m (Fig. 1). For the same reason, according to the modeling data, a permafrost interlayer will be forming during the operation period and it will thaw up completely in 50 years.

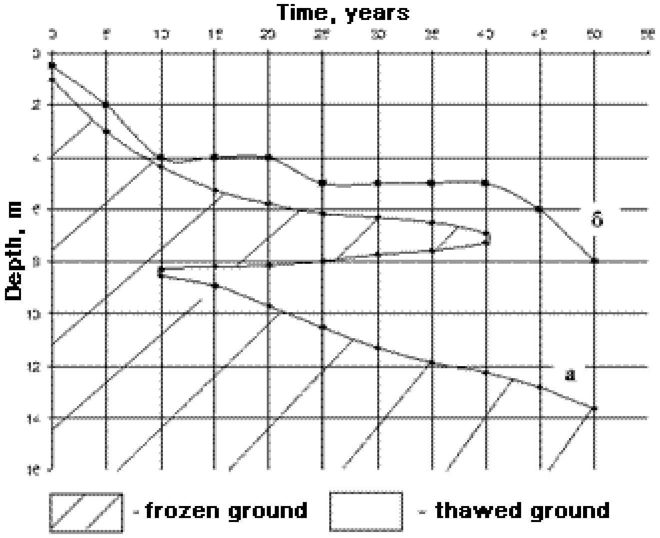

Fig. 1. The dynamics of the formation of the grounds thawing halo under the center of the designed water storage basin (a) and the temperature of grounds (b).

Based on the modeling results, the settlement of the bottom's grounds can reach 2.5 m (method [*SNiP 1990*]) by the end of the design period (in 50 years) because of the presence of ice grounds and deposits with increased ice content.

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Geocryological Conditions of the North-Eastern Part of the West Siberian Plate

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Deep freezing of the Earth's crust occurs not only in space but also in time. Frozen rocks emerged at a certain stage of the Earth's development not simultaneously in different areas. After formation permafrost was in the process of constant alteration of surface and thickness. Along with the alteration of surface conditions , frost and thaw processes occur in the subsoil, which affects morphology and thickness of permafrost. This regime of frozen rocks is known as unsteady. Unsteady permafrost is widely developed in the West Siberian Lowland as well as in some parts of Eastern Siberia. The study of the permafrost, its thermal regime and thickness is one of the objectives of geocryology and has tremendous value for paleoreconstruction of a regional natural environment.

In 2007-2010, the authors performed cryogenic geothermal research in the north-eastern part of the West Siberian Lowland, in the middle course of the Bolshaya Kheta River – the left tributary of the Yenisey River (Fig. 1) The range of tasks included evaluation of the depth of seasonal thawing, the characteristics of exogenous processes and assessment of the temperature regime of rocks. Geothermal studies were performed in 20 geotechnical wells (down to 15 m deep) and in 8 deep (down to 1300 m) wells.

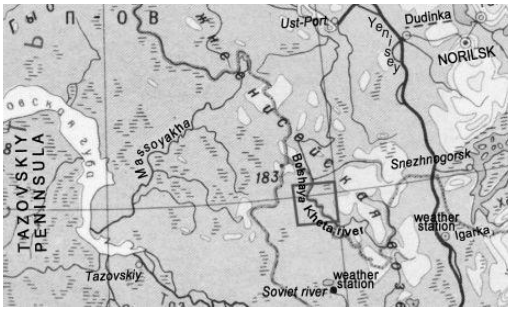

Figure 1 The overview map of the research area

Environmental conditions

According to the indications of weather stations Igarka and the Soviet River (Fig. 1), the climate of the region is extremely continental, with large-amplitude temperature variations during warm and cold seasons, and average annual temperature of -8-9 °C. The average annual precipitation rate is 480-540 mm, 260 - 330 mm falls in the cold season and 200 – 260 mm falls in the warm season. Maximum snow depth is fairly stable from year to year and exceeds more than 0.8 m in March and April. Its thickness in gullies, hollows and flows amounts to 1.5 m or more [*Climate of Russia 2001*].

Geocryological conditions

In geocryological aspect, the West Siberian Plate is characterized with unsteady permafrost and relict permafrost [*Baulin 1971; Balobaev 1971*]. High-latitude position of the territory, its development history and regional factors determined the conditions of formation of practically continuous permafrost. Open taliks developed here only under large lakes with a radius of not less than 1000 m.

The depth of seasonal thawing here ranges from a few tens of centimeters to 1.5 m. Minimum depths of seasonal thawing (10 – 20 cm) are typical of peat and clayey silt grounds of scarcely drained flat, kame-and-kettle terrain of the first fluvial terrace above flood-plain of rivers and lakes, with low shrubs, grass and mosses. The maximum depths of seasonal thawing (up to 1.5 m) occur on relatively dry sand grounds and sandy silt grounds that can be low-hillocky, flat and kame-and-kettle, drained and sometimes with birch-larch, or low shrub-lichen hessians. Some data on the maximum depth of seasonal thawing of grounds of different composition in 2007-2009 are shown in Table 1.

Table 1 The typical depths of seasonal thawing of grounds

Geomorphology	Composition of the grounds	Soil vegetation cover	Depth, m
Valleys	Clay silts dusty	Low shrub and lichen	0.9
Slopes, watersheds	Clay silts in spot-medallions	missing	1.5
Slopes, valleys	Sandy silts dusty	Moss-grass-lichen	1.2
Watersheds	Sands shallow	Low shrub and lichen	1.5
Valleys	Peat	Moss-lichen with low shrubs	0.4

Exogenous (prevailingly cryogenic and aeolian) processes and phenomena are widely developed within the targeted area. Among cryogenic processes the following ones are developed here: thermokarst, water-logging, solifluction, cryogenic cracking and cryogenic heaving. Deflation widely and intensively develops in watersheds.

The temperature of grounds at the depth of the annual heatturn changes in the range from -0,25 °C in valleys and foothills of the slopes to -1,9 °C in watersheds. According to the geothermal measurements in deep wells, permafrost thickness in most cases varies from 465 to 490 m and only in one well it was registered at the depth of 630 m (Fig. 2).

The temperature of grounds at the depth of 500 m varies from -0.2 to +1.4 °C and at the depth of 1,000 m it varies from +8.9 to +13.5 °C. For the greatest depth value - 1,500 m, the temperature varies from +23 °C to +26 °C. However, despite the considerable thickness of permafrost in the middle course of the Kheta River, insular and discontinuous development of permafrost with thickness of 20-50 m is recorded already at 140 km to the southeast of the river course in the vicinity of Igarka. The temperature field of rocks and the thickness of permafrost depend largely on the composition and thermal conductivity of rocks. Determination of thermophysical properties of rocks was performed in cores in laboratory conditions with use of calculation methods. Laboratory measurements were taken by means of heat comparator instrument UIT-1. Measurements aimed at evaluation of thermal conductivity coefficient of moisture-rich types of rocks in the frozen and the thawed state; volumetric heat capacity of the samples was calculated. According to the obtained research data, the thermal conductivity of sandstones, depending on the composition of the cement material, varies from 1.93 to 2.74 W/(m·K) in the thawed state and from 2.21 to 2.82 W/(m·K) in the frozen state. Lower values λ are caused by the predominance of chlorite composition in the cement. Using these data and the information of the reference book [*Gavrilev 1998, 2004*], R.I. Gavrilev calculated the effective thermal properties and the physical parameters of the basic suites of the section. Based on the results of geothermal measurements in deep wells and on evaluation of effective thermal conductivity of rock horizons in wells, we calculated the value of the Earth's internal heat flow. This value varies in permafrost from 0 to 15 mW/m^2, while in subpermafrost horizon it varies from 46 to 62 mW/ m^2. The outstanding difference between the obtained values of the heat flow confirms the unsteadiness of the thermal field in permafrost and the ongoing degradation of the permafrost. The value of the identified heat flow found at depths greater than 850 m fluctuates from 54 to 57 mW/m^2. Permafrost within the targeted area is characterized by distinctly unsteady thermal regime resulting from its degradation. The current low limit of permafrost is determined by climatic conditions of the previous cold Sartan period as well as by the internal heat flow. According to the research data, the geothermal gradient in permafrost varies from 0.0 to 0.5 °C, changing its sign to negative in some cases. At all the geothermal curves (well Bh-4 drilled more than 20 years ago), the temperature gradient abruptly changes after passing through the phase boundary and its value in the thawed zone reaches 3 °C/100 m (Fig. 2). This indicates that the entire heat flow directed from the Earth's subsoil to permafrost base is spent for "ice-water"phase transitions and for reduction of permafrost thickness.

In subpermafrost there are several horizons with different values of geothermal gradient, which is due to differences in lithological composition of grounds. Within the Yakovlev and the Dolgan suites the thermal conductivity (λ ef) is equal to 2.27 W/(m*K), and the geothermal gradient (g) varies in the range of 2,45-2,55 °C/100 m. The values for the Nasonov and the Dorozhkov suites are: λ ef = 2.0 - 2.15 W/(m*K) and g = 2,23 -2.50 °C/100 m; for the Malokhet and the Sukhodudin suites the values are: λ ef = 2.23 - 2.42 W/(m*K) and g = 2,35 -2.50 °C/100 m.

Permafrost geothermal section encompassing the depth down to 1600 m was produced according to geothermal research data and thermal calculations (Fig. 3).

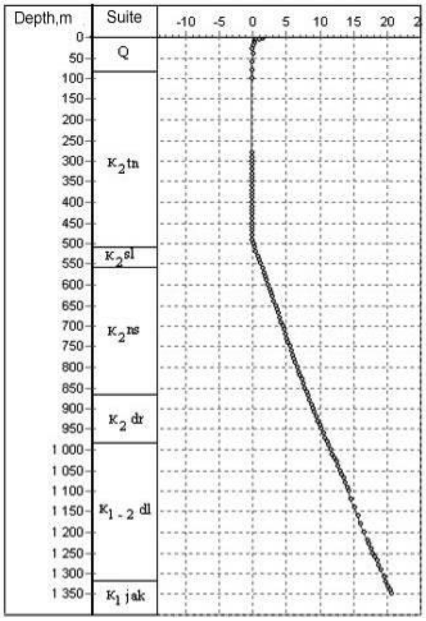

Figure 2 The temperature curve of well Vn-4

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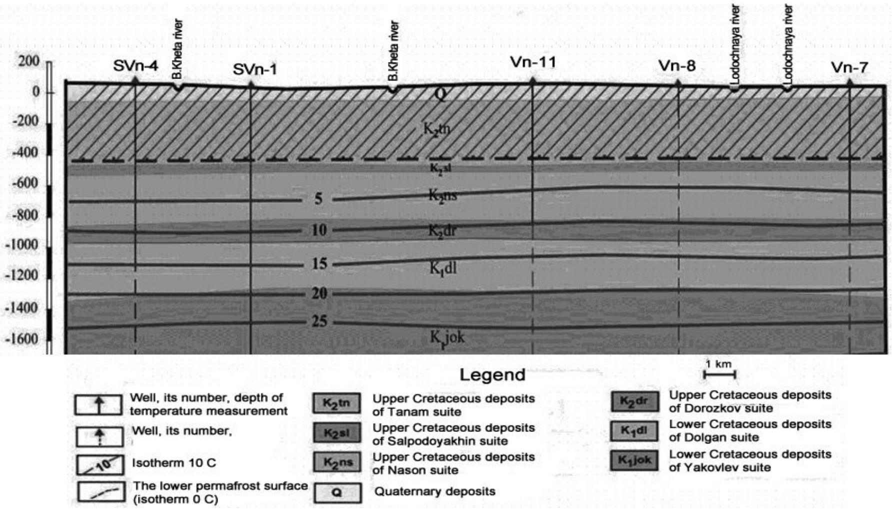

Figure 3 Geological and geothermal section in the middle course of the B. Kheta River.

Characteristics of Active-Layer Temperature Profiles Related to Arctic Transportation Management on the North Slope, Alaska

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Introduction

Arctic transportation networks are extensively used by the oil and gas industry for supporting drilling and maintenance activities. These seasonal networks include snow and ice roads, runways, working pads, ice bridges across streams, rivers and lakes. Their use prevents or minimizes adverse impacts to the tundra. The Alaska Department of Natural Resources (ADNR) is the agency currently responsible for authorizing winter tundra travel on Alaska state lands. This includes activities for ice-road construction. The criteria are a soil temperature colder than -5°C at the 30-cm depth and, in the coastal plain region, a snow depth greater than 15 cm, and in the foothills region a snow depth greater than 23 cm [*Bader 2005a, Bader 2005b*].

The number of days available for tundra travel, and thus the winter-work season, has been steadily decreasing. In the 1970/1971 season, 219 days were available. When compared to the 137 days available in the 2010/2011 season there is a decrease of 37.4%. The year-to-year variation appears to be increasing at the same time.

Water frozen in soil adds strength by decreasing slippage between particles as well as cementing particles together. Soil water influences the rate that soil freezes and thus the time for the soil temperature at 30 cm to reach -5°C [*Romanovsky & Osterkamp 2000; Lilly et al., 2008*]. The thermal conductivity of water is much higher than that of air; however, water requires more thermal energy to change temperature than air, as a result of its higher heat capacity. Ice has a much higher thermal conductivity than water. As water freezes, it releases thermal energy, thus holding the temperature at around 0°C until the water is frozen. This phenomenon manifests itself in the "zero curtain" effect exhibited by soils undergoing freezing. Dry soils generally freeze quicker than wet soils. However, soil strength as a function of water content is not completely understood.

This study examines the thermal state of the active layer, with a focus on the soil temperature characteristics at the 30 cm tundra travel management depth. Soil properties and soil water content are two of the variables examined as they affect the freezing process and resulting soil strength. Multi-year data from a network of stations in northern Alaska are used to examine the freezing process of soils in natural settings and better understand the timing of various potential measurement standards.

Methods

Several different networks of weather and permafrost stations have been in place on the coastal plain and northern foothills of the Brooks Range in northern Alaska. Some of the stations are still operational, some have been discontinued. The operation of most of the stations is funded by short-term research projects. There are some long-term stations in the UAF Permafrost Observation Network, but there is a limited set of stations with long-term records of temperature.

Soil temperature in the active layer is measured at a variety of depths, which vary between data networks. Measurements of soil temperature are usually taken at hourly intervals. Many of the stations had no sensor at the regulated 30-cm depth, so data were interpolated by averaging values for the 20- and 40-cm measurement depths or the next two closest measuring points.

Soil-water content is monitored at some stations using CSI616 Time Domain Reflectometry (TDR) soil moisture sensors. Where present, these sensors usually are located at soil depths of 10, 20, and 40 cm, respectively. In addition to the soil variables, many stations monitor atmospheric variables including air temperature, relative humidity, wind speed and direction, snow depth, net radiation, and rainfall.

Dataloggers are used to measure and store the measurements. Some networks have data collected hourly using line-of-sight radios which transmit data to a base station. This allows for near real-time data reporting.

The relationship between frozen soil temperatures and soil strength is important for understanding the various bearing loads and trafficability of soils of different types and at different soil moisture and temperature conditions. Bray, 2010, reports testing for soils typical of some found at stations on the North Slope. Soil samples were tested, at temperatures between 0°C and -5°C, using unconfined compression tests for soil strength. The strain rate was 1-percent/min.

Results and Discussion

The freezing of tundra soils is a slow process. Figure 1 shows an example temperature record for a site in the upper foothills of the North Slope, where the timing between different temperature thresholds is indicated for a 20-cm depth. As soil water freezes it changes phase from liquid to solid, releasing energy that must be dissipated for the freezing process to proceed. During the thawing process, energy is required for the soil water to thaw and is often supplied by percolating snow-melt water to the ground surface. Whereas active-layer soils freeze from both the top down and the bottom up, they thaw from the top down only.

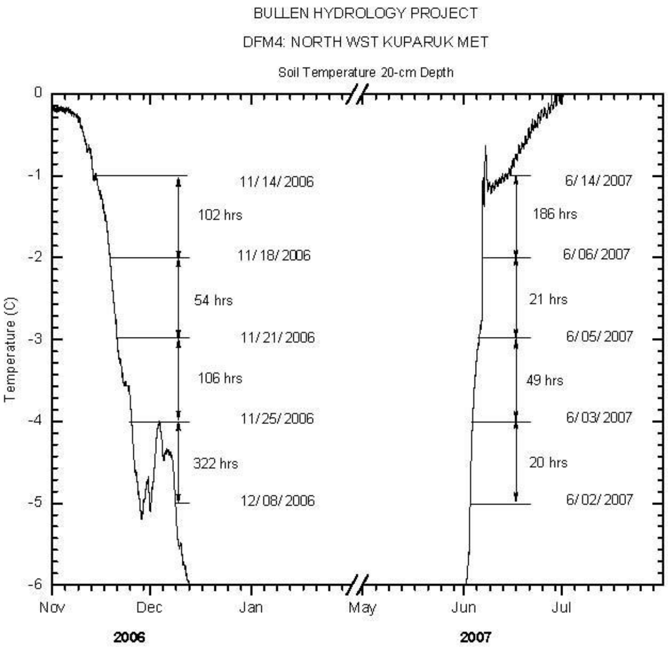

Figure 1. Soil temperature for the 20-cm depth at the Northwest Kuparuk Met (DFM4) site.

Snow insulates the soil, slowing down the freezing process. This insulating effect can create a delay in soil temperatures at the 30-cm management depth reaching the -5°C guideline. Some companies pre-pack snow to lower the thermal insulation properties and to reduce the delays in reaching the required soil temperatures. Soil strength increases as the temperature goes from -1°C to -5°C [*Bray 2010*]. The active layer is completely frozen when the soil temperature at 30 cm is -5°C (Fig. 1). As the soil freezes and the temperature at 30 cm reaches -5°C, the soil above 30 cm is colder. During the summer thaw, the soil temperature profile is much steeper, because by the end of snowmelt period solar insulation and the air temperatures are already high. Under these conditions, the ground surface temperature increases quickly and the soil above 30 cm thaws relatively fast.

A variety of stations monitored over different time intervals helps provide an understanding of the variation in timing of freeze-up to meet the early winter soil freezing criteria and the relationship to the complete freezing of the active layer. Perhaps a shallower depth or higher temperature threshold could be used for the fall freezing criteria for tundra travel without risking environmental damage.

Summary

The freezing process of soils under natural settings was examined using multi-year *in situ* measured soil temperature and soil moisture data. Soil strength information was used to supplement the results in order to better understand soil characteristics relating to winter tundra travel. Soils freeze slow in the fall due to the latent energy release of ice formation. It is important to understand the soil-strength requirements for transportation in choosing temperature management levels. Slight changes in temperature management levels could help lengthen tundra travel seasons, but need to be carefully evaluated.

Acknowledgements

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Water quality and key anthropogenically-induced processes in lakes of Russian Arctic

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Abstracts

The article represents current trends of water quality changes in the lake systems of Russian Arctic regions on the example of Kola and Western Siberian North. It was revealed that the arctic water vulnerability is related to anthropogenically-induced water eutrofication, toxification and acidification processes.

Keywords: Arctic lakes, water eutrofication, water toxification, water acidification.

Introduction

The Arctic region is a part of the Planet where the territory is covered by a very great number of lakes. The high provision of the Arctic regions with water till recently has not caused a trouble about the state of the latter. At the same time, intensive development of the rich deposits of mineral recourses, including gaze – oil production and trans-boundary transmissions of pollutants lead to a rapid disturbance in the fragile aquatic environmental equilibrium already in many urbanized and industrial Arctic regions, which leads to qualitative depletion of the water resources.

The Russian Arctic region - Kola North and Western Siberia are the most densely populated and industrially developed. The spectrum of anthropogenic impacts on the lakes is wide: mining, metallurgy, oil-gaze production, chemical industries, nuclear power plants, etc. Large water systems serve as reservoirs and utilizers of wastewater facilities, remote from industrial centers small lakes are impacted with airborne flow of pollutants. To understand the current trends of water quality changes in the conditions of regional and global anthropogenic impacts in the Russian Arctic (Murmansk area and in the north of Tyumen area) was conducted large-scale research of lake systems. For the research used modern analytical equipment with international requirements for chemical analysis of natural low-mineralized water.

Reference condition and vulnerability of arctic water

Climatic conditions in the Arctic region determine a number of specific features of the water chemical composition formation there, making the waters vulnerable to anthropogenic impacts [*Moiseenko 2008*].

Recharge of lakes and rivers is greatly determined by precipitation - to 75-90% of the annual runoff are provided by spring flood and summer-autumn rainfalls. Accumulation of precipitation in the snow cover takes place during a long winter (6-8 months), rapidly penetrating during a short period of spring flood into drainage basins.

During snow melting the topsoil remains in the frozen state, so its upper layer is actually impermeable during the entire snow melting period. The weak development of vegetation and thin soil cover provide a high drainage of falling precipitation in summer. Predominance of precipitation amount over evaporation and slow mineralization of organic matter results in availability of a large number of surface small-sized logged lakes with a high content of humus and natural acid waters or so-called “Wetland ponds”.

Formation of the surface runoff in the conditions of excess wetting causes a low water mineralization and oligotrophic character of the lakes due to that the bedrocks are leached lowly. Quaternary rocks are intensively washed out, and the topsoil cover is thin. Low average annual air temperatures weaken the processes of water erosion, resulting, thus, in low water mineralization. Lack of development of the topsoil cover makes the geochemical composition of the underlying rocks determinant in formation of salt composition.

In conditions of low mineralization the migrating ability of pollutants is high, their cycling in water bodies is longer, ionic equilibrium is unstable, and toxic effects on aquatic inhabitants in lowly-mineralized waters are much higher.

Thus, in the Arctic predominantly oligitrophic, fresh and ultra-fresh waters are being formed. For large lakes (with an area of over 100 km^2) the reference conditions of water chemistry parameters are very similar. These lakes are typically ultra-fresh and oligotrophic with low concentrations of suspended material (0.7 – 1.0 mg/l), microelements (<1 µg/l), and nutrients. The concentration of total phosphorus is less than 2 µg/l; phosphates during the vegetation period are practically completely utilized in the production processes. Water transparency is about 8 m.

For small lakes (with an area of 0.4 to 10 km^2) the water chemical composition has a high variability. In mountainous areas the lakes are characterized by low contents of organic carbon, salts and nutrients. However, the water in many lakes has a high colour degree and high contents of dissolved organic carbon (DOC). In swamped areas the high saturation of water with humic acids indicates to lake dystrophy. Judging from the above-mentioned data, it can be concluded that naturally the major part of lakes are characterized as oligotrophic and dystrophic.

Anthropogenic impacts

The largest influence on the state of lakes in the Russian part of the Arctic region is exerted from mining and metallurgical enterprises, oil and gas extracting companies, heat-power electrostation, as well as from the (concentrated in this region) objects of nuclear power station, objects of tourism, etc. Waste waters of metallurgic and mining and processing manufactures containing heavy metals, oil products, phenols, fluorine, fine-disperse suspensions, products of ore flotation, etc. [*Moiseenko 2008; Soromotin 2011*]

- pollution of atmospheric air (oxides of sulphur and nitrogen, benz(a)pyrene, nickel, mercury, carbon fluoride, aluminium, strontium, radionuclides, dust, oil products and others);
- tail depositories, dumps of stripped rocks, sludges, discharge of untreated waste waters;
- pollution of surface waters (organic matter, oil products, heavy metals, flotation reagents, suspended substances, sulphates, chlorides);
- pollution of lands (abandon machinery, unsanctioned landfills), possibly – radioactive.

Key anthropogenically-induced processes in lakes

The technologies used at the acting mining, smelting, chemical enterprises and oil-gas industry in Russian Arctic result in pollution of lakes by waste waters, as well as airborne contaminants. As a result of direct sewage dumping into the lakes and airborne pollution of their water catchments, there are appeared some negative processes in water chemistry in the Russian Arctic:

Water toxification

Water toxification by heavy metals (Ni > 20 μg/l ,Cu > 10 μg/l, Cd> 1 μg/l) is characteristic of the large lakes, such as Imandra, Pyasino, Kuetsjarvi, where the sewage waters from smelters input and it is similar for the small lakes within the radius of 30 km around the smelter complexes. In the Kola region at a radius up to 30 km the impact zones of pollution have appeared where the concentrations of these elements are equal to toxic levels. Lakes surrounded by Khibiny and Lovozero Mountains are characterized by the high content of Sr. Here large apatite-nepheline mining has resulted in an increase of Sr, Al and other elements. In Siberian Arctic the most part of lakes have the low metals and oil concentration (except Norilsk areas).

Monitoring of surface water quality within the sub-Arctic gas fields did not reveal any hydrocarbon contamination (TPH analysis), values of concentrations (from <0.02 – 0.30 mg/l, 35 objects) are within background values (from <0.02 – 0.24 mg/l, 55 objects). Increased concentrations of heavy metals are also not revealed. In some lakes revealed excess of water quality standard (MPC) for manganese.

Water acidification

Water acidification occurs beyond the limits of dust emission effect - at a distance of more than 30 -100 km from the smelters where sulfur load is more than 1gS/m3yr and the area vulnerability is high. In the north of Western Siberia revealed acidified lakes in which nitrates dominate in the ionic composition. Domination of nitrates is obviously connected with a long period of accompanying gas popping and pollution of the atmospheric precipitation with nitrogen oxides. Water acidification results in higher mobility of many trace elements, primary of which is Al. The high level of Al concentration is characteristic of acidified lakes (mainly in the eastern parts of the Kola Peninsula).

Water eutrofication

Water eutrofication in the subarctic regions has a local character in the lakes, where the municipal sewage or heated waters from the Nuclear Power Station come. Accumulation of nutrients (P>20 μg/l, N > 200 μg/l) in the arctic lakes does not lead to alga development relevant for these concentrations because of low water temperatures and intensive water exchange. Only in some shallow well-heated lakes or inlets the phytoplankton development may run into the level of meso- or eutrophic lake.

Integrated pollution

The negative factors may simultaneously develop in all the industrially-developed areas (impacts zones) of Russian Arctic (Norilsk and Kola mining-metallurgical complexes, Severodvinsk production), i.e. toxification, a change in salt content and eutrophication.. During the flood period in Arctic region the pulse of metals in combination with low pH values can have a dominant negative effect on the fauna after the long Polar night. The danger is also in rapidly washing out of heavy metals from catchments and release of their ionic forms by acid snow-melt water. During the ice period of the long Arctic winter for eutrophic lakes or lakes rich by humic matter there is the dramatic situation associated with anoxic condition near the bottom layer and recycle of metals at the redox boundary. The eutrophication aggravates the unfavorable effect of toxic metals.

Thus, in cold regions the pollutants have much more expressed negative effects. At the same time, lakes here get a special value due to high-quality water resources and good fish production. The basic principle of Arctic lake preservation should be given up as follows: priority of the clean water and fish production; refusal from non-limited Arctic water resources due to their high vulnerability to anthropogenic loadings; differential approaches to protection of lakes depending on natural conditions and on lake purpose; preventive maintenance of pollution sources instead of struggle with consequences: withdrawal of toxic substances from industrial discharges; prevention of emergencies connected with burial places of industrial and radioactive wastes, transport of petroleum, localization of non-point contaminated flows from mining activity.

Acknowledgements

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The Study of Strength Properties of Thawing Grounds

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Keywords: ball die device; concentration of pore solution; equivalent adhesion; strength properties

(Saline) permafrost areas seriously impede development of the natural resources of the Russian European North. The use of frozen grounds as foundation grounds needs evaluation of bearing capacity of foundation grounds and forecasting this capacity considering all the natural and man-caused factors. Reliability of such forecasting depends on accuracy of identification of strength characteristics of frozen grounds and temporal regularities of their development. According to State Standard 12248-96, tests of saline grounds are prohibited due to the fact that they are plastic frozen grounds and do not reach the state of relative stabilization. The coefficient value of 0.8 that reduces Ceq obtained during 8 hours to the extremely long value (Ceqx = kCeq) is recommended for hard frozen grounds and is valid in case of hard frozen grounds with massive cryogenic structure whereas this value is overestimated in case of the mentioned plastic frozen ground types. According to the results of numerous investigations of, for example, saline grounds, the k coefficient may decrease to a value of 0.4 - 0.6.

The study was based on an approach that included the following procedures. Ceq of each sample is measured five times during 8 hours. The sixth measurement is carried out until relative stabilization of the ball immersion depth is reached. This is equal to 0.01 mm per 12 hours and is used for calculation of Ceq∞. All the data accumulated during the eight-hour period is subject to statistical treatment. The mean value $\overline{Ceq8}$ is calculated. The k coefficient is calculated as Ceq∞ divided by Ceq8 taking into account the results of the test that is carried out until the relative stabilization of the ball immersion depth is reached (Ceq∞ is determined based on the value of the relatively stable ball immersion depth).

The mean value for a sample tested $\overline{Ceq\infty}$ is calculated then:

$$\overline{Ceq\infty} = C_{eq8}*k \qquad (1)$$

It should be noted that the relative stabilization state may be reached in a rather long test time, namely, 1.5 - 2 weeks.

Equivalent adhesion Ceq takes into account impact of both adhesion and friction on strength. This was calculated in the following way:

$$Ceq = \frac{0{,}18P}{\pi dSt}, \qquad (2)$$

where P is constant load on the die; d is the die's diameter; St is the die's immersion depth during a time interval t.

The diagram of the measuring setup is shown in Figure 1.

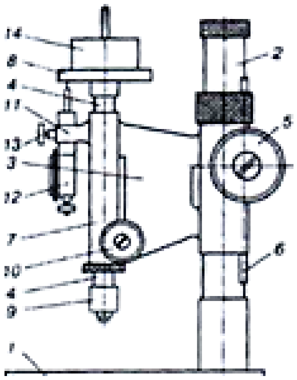

Figure 1. Single-rod spherical die designed by NIS Hydroproject: 1 - bearing plate; 2 - guide post; 3 - arm; 4 - rod's upper end; 5 - leveling screw; 6 — rack bar; 7 - guide sleeve; 8 — platform for weight; 9 - ball die; 10 - lock screw; 11 - indicator holder; 12 - indicator for measurement of deformations; 13- securing screw; 14 — weight.

We have carried out a few tests for sand and clayey silt samples from the Lek-Kharyaginskoe oil field reaching the relative stabilization of the die's immersion depth. In order to detect impact of physical properties, salinity and temperature, artificially prepared samples with disturbed structure were studied.

Statistical treatment of the experimental data was performed in compliance with State Standard 20522-96.

The results of the study indicate that the dominant parameter determining the strength of frozen ground is concentration of pore solution that to a great extent determines initial freezing temperature of grounds. Figure 2 presents freezing temperature T_{bf} as a function of concentration of saline pore solution taking into account moisture content in ground.

NaCl has high solubility and low eutectic temperature, which significantly increases the range of active phase transitions into the interval of negative temperatures. For example, water content in saline clayey silts where concentration of NaCl varies from 0.5% to 1.5% changes from 4.5% to 12.0%.

Achievement of a maximally long equivalent adhesion is the result of the experiments performed. The tests were carried out at temperatures of -1 °C, -4 °C and -10 °C.

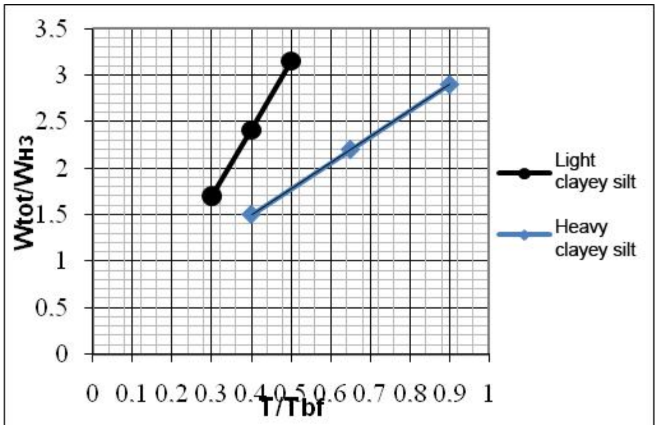

Figure 2. Freezing temperature Tbf as a function of concentration of saline pore solution taking into account moisture content in ground.

Analysis of the results indicates that the general dependence of decrease of equivalent adhesion due to increase of salinity and moisture content in the frozen grounds that we have studied is similar to that one which has place in case of the ground investigated.

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Development of 3D Permafrost Models Based on the Complex of Seismic and Well Data with the Purpose of Forecasting Geocryological Hazards during Development of the Deposits of the Yamal Peninsula

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Problems of geological and geophysical study and development of the Yamal Peninsula are to a great extent caused by the complicated near-surface geotechnical conditions present here, in particular the extensive development of permafrost. These conditions determine peculiarities of methodology and methods of engineering, geological and geophysical investigations, ways of rational location, erection and operation of engineering structures.

In order to solve the problems of development of the Yamal Peninsula caused by the geocryological situation in the region and forecast reactions of the geological environment to anthropogenic impact, one has to have knowledge about major regularities of structure and distribution of the frozen grounds. To this end, we perform activities with the purpose of developing complex models of the structure of the upper part of a section including permafrost which are based on seismic and well data. The results of both the previous geocryological investigations of general nature and interpretation of geophysical methods, in particular the three-dimensional seismology and geophysical investigations of wells which enable more detailed development, are the basis of the models.

Interpretation of the field and geophysical data on wells is carried out for the depth interval that includes the permafrost layer. The complex of the geophysical investigations of wells (in the permafrost area) used for the analysis includes standard well logging operations (3 probes, SP), caliper measurements (caliper logging), radioactive well logging (gamma-ray logging, neutron logging) and thermometry.

The model of the upper part of a section is an integral part of the velocity-depth model typical for the northern part of West Siberia. In this context, the work carried out by us in order to develop permafrost models is a part of the activities aimed at interpreting seismic data.

Experimental seismic investigations of terrigenous rocks indicate that the typical velocity range of P-waves at a depth of up to 500 m is 1700 m/s – 1800 m/s if permafrost is absent. Propagation velocity of elastic waves in frozen layers of sedimentary rocks may be as high as 3500 m/s - 4000 m/s which is 1.5-2 times more if compared to thawed rocks. This is a cause of significant anomalies of traveltime parameters of reflected waves when the permafrost thickness changes from 0 m to 500 m - 600 m. It should be noted that only a part of these anomalies is excluded from the To times during input of static corrections. The residual components of the anomalies are preserved in the time field and can be used for interpretation of the data of the common depth point seismic reflection method.

This creates real preconditions for extraction of information on velocity inhomogeneities from seismic traveltime parameters (To, V, H) and development of a model of the upper part of a section including the permafrost layer which is based on this information.

Analytic transformations alone cannot constitute enough basis to solve this problem. Therefore, the approach is underlain by a principle of subsequent sophistication of the model. As regards the initial approximation, it is obtained by means of computations applying available a priori data on the structure of the model of the upper part of a section. Optimization of the development results is performed taking into account additional model factors (e.g. topography, groundwater level) and results of well measurements. All the calculations are performed for areas, i.e. at the level of numerical surfaces of the parameters.

The development results are numerical complex 3D multilayered models of structure of permafrost thicknesses consistent with 1D (well) models in well drilling sites. These models present alternation of ice-rich, icy and ice-poor rocks in a section as it is shown in Figure 1.

The carried out developments of 3D models of permafrost formed the basis for geocryological zoning of the Kruzenshtern, Severo-Tambey, Zapadno-Tambey, Tasiy and Malygin fields, development of recommendations concerning location of areal and linear sites in this areas and gas hazard forecast for the cryolithozone within the boundaries of the Bovanenkovo gas condensate field.

Detailed geoecological mapping using multisource remote sensing imagery (Adventdalen, Svalbard)

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Introduction

In the vicinity of Longyearbyen, Adventdalen shows a flat floor with a braided river system bordered by gently sloping terraces showing complex patterns of tundra polygons (The study site is located at 78º10'42.8''N, 16º16'24.9''E). These are mostly low-centered and can show orthogonal, as well as polygonal patterns generally with 5 to 6 neighbours.

In the framework of the project ANAPOLIS - Analysis of polygonal terrains on Earth as Mars analogues we aim at characterizing and classifying the spatial patterns of the tundra polygons in Adventdalen and at understanding the environmental causes for the different patterns. Our approach includes using high resolution aerial imagery, as well as a detailed ground truthing surveys. One approach that we are using in order to characterize the tundra polygons and to better understand the environmental factors constraining them, is to study the spatial patterns of vegetation formations. Vegetation is highly sensitive to changes in hydrology, snow, dryness and salt in the ground. Therefore spatial patterns of different types of vegetation can be used for defining an ecological zonation in the terraces where tundra polygons occur. The terraces show a quite homogeneous topography which is hard to characterize without an expensive survey using LIDAR, ground based geodetical techniques, or photogrametricak techniques. Since the above mentioned ecological factors are highly sensitive to minor topographical changes (such as from the border to the center of a polygon) and since plants react quite well to these changes, by mapping the vegetation one should be able to determine the spatial distribution of the limiting ecological factors. This is the main objective of our approach of geoecological mapping. The survey was based on the automatic classification of aerial imagery supported by pre and post-classification ground truthing.

Methods

Our main test site for the mapping was the UNIS tundra polygon monitoring site in Adventdalen, where we were also able to collect a significant amount of information on geomorphology allowing us to better analyse the vegetation patterns. A first visit to the test site took place in June-July 2010 aiming at identifying the main vegetation types, focusing in the polygon surfaces. We targeted at identifying the main species and/or formations through a visual inspection of their spatial coverage. As expected, significant differences were easily identifable from polygon centers to borders, reflecting topography and hydrology, but also exposure to wind.

In the field campaign of 2010, we manually mapped vegetation types in order to create sample sets for supervised classification tests to be conducted in the GIS lab. These were performed using high resolution aerial photos from a Norwegian Polar Institute flight of 2009, with a ground resolution of about 20cm. The scenes have 4 bands, visible (RGB) and near infra-red. The orthorectification was performed using selected ground control points inside the study area, with the coordinates obtained using a DGPS.

In the 2nd field campaign in August-September 2011 we found some changes in the vegetation from previous years, mainly since this was later in the summer and several species were already drying. However, the units classified in 2010 were still clearly visible and allowed for a field validation of the maps obtained by supervised classification. These provided, extremely good results. In that same campaign, we used the DGPS to resurvey vegetation with higher accuracy and to be able to quantitatively validate the accuracy of the classification.

Results and discussion

The main vegetation types in the Adventalen terraces were classified within the following formations:

- Graminea grassland;
- Salix sp. formation;
- Moss formation;
- Bare ground with salt extrusions
- Alluvium.

Geoecological mapping from the vegetation units obtained by means of supervised classification of high resolution aerial photos (vis and NIR) shows very good results and is very promising for the detailed analysis of large areas.

A very clear spatial pattern reflecting the ecological zonation in the polygon areas has been found, with a ring pattern developing especially in the wetest polygons showing higher borders, more exposed to wind and to salt segregation. These differences allow to classify the polygons according to vegetation types and therefore to ecological factors that reflect environmental characteristics.

The first results of the mapping are presented, but we expect that in the near future we will extend this approach to the whole alluvial plain of Adventdalen downstream of Janssonhaugen. This approach should allow for the better understanding of the genesis of the different types of polygons.

Acknowledgements

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Overcooling and Ice Mass Changes in Ventilated Terrains: Comparison Between a Dynamic Ice Cave and a Low Elevation Talus Slope

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Background and objectives

In the Swiss Alps, mountain permafrost – subsurface materials remaining at negative ground temperatures throughout the year – is encountered discontinuously above about 2300 m.a.s.l. Nevertheless, abnormally cold ground conditions indicating possible occurrence of isolated permafrost patches have been reported in many locations at much lower elevation where the external mean annual air temperature (MAAT) is definitely positive. These particular overcooled conditions are created by a process of reversible internal air circulation (the chimney effect or wind tube). All these cold environments are inside caves [*Luetscher et al. 2008, Morard et al. 2010a*] or are located in the lower parts of debris accumulations, mostly talus slopes and relict rock glaciers [*Delaloye et al. 2003, Zacharda et al. 2007, Morard et al. 2010b*].

Overcooled low elevation talus slopes

Since 1997, thermal monitoring is conducted at the ground surface in the Creux-du-Van talus slope (Jura mountains, Switzerland1, 1'190 m. a.s.l., MAAT +5.5°C). These measurements show a strong negative thermal anomaly in the lower part of the slope (tab. 1) with occurrence of cold wind blowing out of the blocks and ground ice during summertime [*Delaloye et al. 2003*].

Tens of others similar porous debris accumulation of different elevation, orientation and geology were also instrumented. The analysis have showed that the thermal regime is similar between all these different investigated sites [*Morard et al. 2010b*]. In November 2004, two boreholes were drilled at Dreveneuse d'en Bas confirming the existence of sporadic permafrost inside and below this porous debris accumulation [*Morard et al. 2010b*].

Ice caves at mid-latitude

Both (ice) cave and talus slopes are open medium, inside which air can flow. Nevertheless contrary to talus slope, direct measurements inside cave system are possible to study more precisely the heat exchange, the ice mass and underground climate evolution [*Luetscher et al. 2008*]. Cave and ice cave studies are also carried out from longer time

The sense and goal of this extended abstract is to compare the thermal regime of these two kind of ventilated mediums, in order to know if the understanding of various processes which can be directly measured inside cave system could be extrapolated to porous debris accumulation like talus slope. Ground air temperatures measured about 1m inside a windhole in the lower part of Creux-du-Van talus slope are compared with the cave air temperature of the lower entrance of the small dynamic Diablotins ice cave (2'000 m. a.s.l., MAAT +2.2°C) [*Morard et al. 2010a*] which could be seen as a simple talus slope with one wind channel and two entrances located at different elevation.

Table 1. Elevation and mean annual, winter and summer temperatures at the Creux-du-Van talus slope and the Diablotins ice cave (between November 2009 and October 2010).

	Creux-du-Van		Diablotins	
	Outside	Windhole	Outside	Cave
Elevation (m.a.s.l.)	1'192	1'190	2'010	2'000
MAAT (°C)	+5.4	-0.8	+2.2	-1.6
Winter* (°C)	-1.1	-2.8	-3.7	-2.5
Summer** (°C)	+11.5	+1.4	+7.7	+0.2

* Mean November to March ** Mean May to September.

A similar annual thermal regime

Wintertime

The outside, windhole and cave air temperatures between November 2009 and October 2010 are shown in figure 1A. During wintertime, cold outside air is aspirated inside the lower parts of the two ventilated systems and temperatures drop deeply and rapidly below 0°C. The thermal regime is quite similar and synchronous between the outside atmosphere, the windhole and the cave entrance. A short shift of relative minimal temperatures occurred since February in the talus slope due to the presence of a 1m thick snowcover above the windhole. Nevertheless, this snowpack does not stop the strong ground freezing.

Summertime

During summertime, the windhole air temperature is on average +1.41°C and the cave temperature +0.18°C, while mean outside air temperatures reach +11.5°C at the Creux-du-Van and +7.67 at the Diablotins (tab. 1). These negative thermal anomalies are caused by the outflow of cold air coming from the inside of the system. During this period, the short-term variations of temperatures (standardized values) are almost perfectly the same between the windhole and the cave entrance (fig. 1B), with r^2 Pearson coefficient of correlation from +0.735. Moreover a clear inverse relationship could be seen with the outside air temperature: more the atmospheric conditions are warm, more the windhole and cave air are cold due to accentuated ventilation [*Delaloye et al. 2003, Morard et al. 2010b*]. This thermal behavior is typical evidence of the occurrence for chimney effect ventilation.

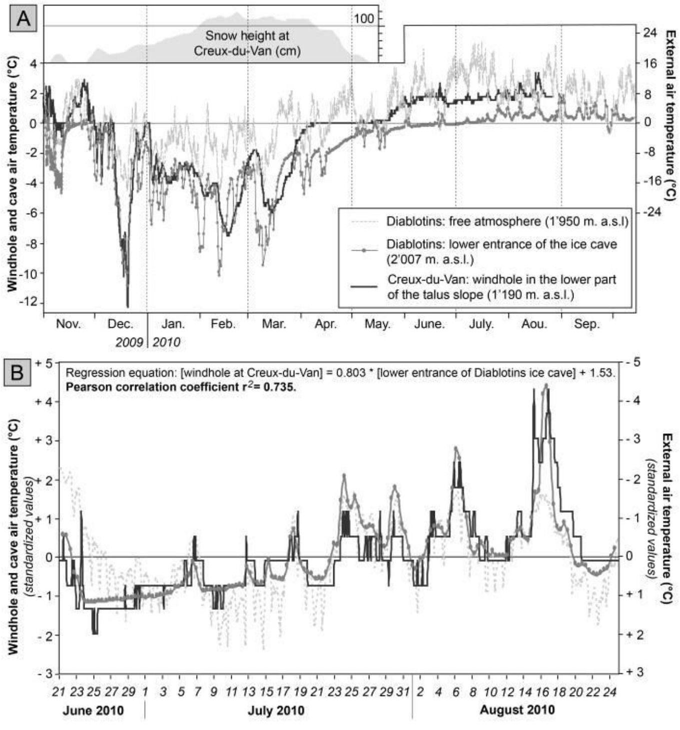

Figure 1. A. Evolution of air temperature in the Creux-du-Van windhole, in the lower entrance of Diablotins ice cave and outside the cave between November 2009 and October 2010. B. Standardized values of air temperatures for summer 2010 (note that the y-axis for outside air temperature is reversed).

The thermal measurements clearly show that the effects of air circulation are similar between the inside of the ice cave and the porous debris accumulations. Deep inside the Diablotins ice cave, the cave air and the rockwall are strongly cooled but also dried, and a significant decrease in the ice mass by sublimation is observed in winter [*Morard et al. 2010a*]. Based on our results, the same processes are probably also effective inside ventilated talus slope. Knowledge about heat exchange into cave system [*eg. Luetscher et al. 2008*] could also be extrapolated with high degree of confidence to ventilated talus slopes. Finally for both environments, the key-factor of evolution is the outside air temperature during wintertime [*Morard et al. 2010a, b*].

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Evolution of a Thermokarst Basin in Ice-Rich Permafrost, Siberian Lena Delta

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Introduction

Thermokarst lakes and basins are ubiquitous landforms in arctic lowlands. Current research has a particular focus on thermokarst processes in ice-rich permafrost deposits in Siberia and the North American Arctic, because these deposits are highly vulnerable to degradation under a warming climate. Their high content of excess ice accounts for their high thawing potential, and the large amount of carbon, which has been stored in these deposits for several thousand years, has a high potential for the release of green house gases. Thermokarst in Siberian ice-rich permafrost massively developed at the transition from Pleistocene to Holocene, but after the Boreal period (9-7.5 ka BP), the thermokarst landscapes appeared as today and have experienced only minor changes during the rest of the Holocene [*Kaplina 2009*]. This contradicts the perception of thermokarst as a highly dynamic process and the concept of a thaw lake cycle being repeated several times during the Holocene.

Our investigations aim at the detailed characterization of the temporal and spatial dynamics of thermokarst in Yedoma landscapes of the Siberian Lena River Delta. Field investigations of a partly drained thermokarst basin (alas) in Ice Complex deposits of Kurungnakh Island with three large lakes (72°19’N; 126°12’E) (Fig. 1) will be combined with remote sensing, Geographic Information System (GIS), and sediment analyses to distinguish different stages of thermokarst dynamics.

Methods

We used ALOS PRISM satellite data with a geometric resolution of 2.5 m and a DEM derived from all according stereo pairs [*Günther 2010*] for general analyses of the Kurungnakh Island setting and relief. For high resolution spatial analyses of the 7.5 km² large alas, an Alas DEM with 3 m pixel size was produced from detailed tacheometric field measurements [*Ulrich et al., 2010*]. Spatial data processing and analyses were performed using the GIS software package ArcGIS^{TM} 10.0.

Field work in 2008 included detailed surface characterization of the whole study area, bathymetric measurements of the three large alas lakes as well as sampling of short lake cores and of two outcrops at alas margins for stratigraphical reconstructions [*Morgenstern et al., 2008*]. In 2009, a 4 m deep permafrost core was drilled at the alas floor (Fig. 1). Sediment samples were analyzed for grain size and organic matter characteristics (AWI Potsdam) and AMS ^{14}C dating (Poznan Radiocarbon Laboratory); samples of the permafrost core were additionally analyzed for pollen (CCG Novosibirsk).

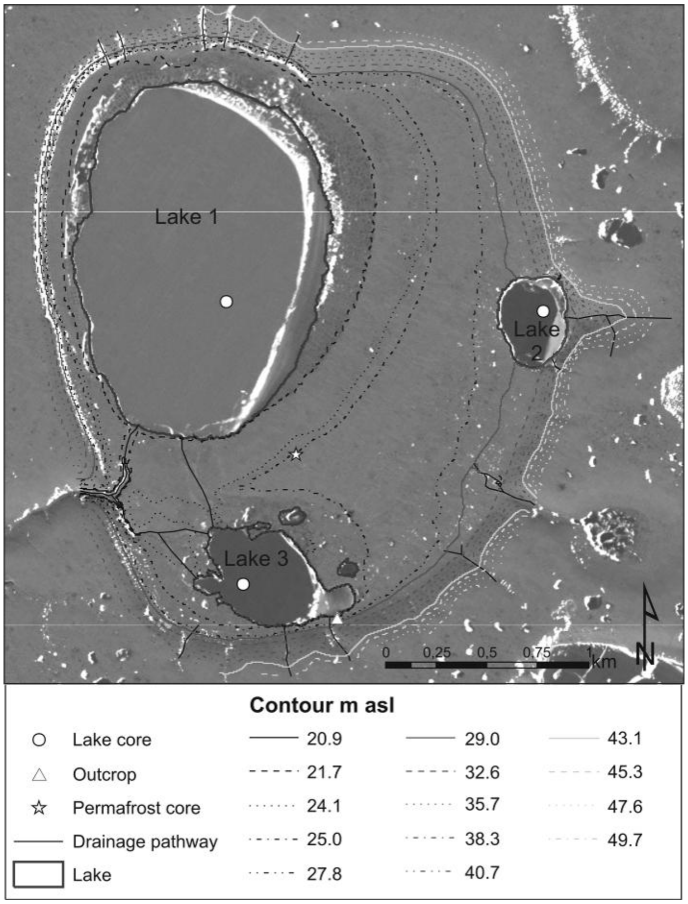

Figure 1. ALOS PRISM satellite image of the investigated alas with field sampling sites and contours (in part tracing lake terrace levels) derived from the Alas DEM. Acquisition date: 21 September 2006; white patches are snow that persisted on lake and pond ice and at protected slopes.

Results

Alas morphometry

The investigated alas is about 3.3 km long (N-S) and 2.5 km wide (E-W). It is a single, closed basin of oval shape surrounded by Yedoma uplands. One drainage outlet in the southwest discharges the alas via a thermo-erosional valley into the Olenyokskaya Channel. Three large lakes are situated on the alas floor close to the alas margins in the northwest (Lake 1), east (Lake 2), and south (Lake 3) with areas of 1.7, 0.1, and 0.2 km², respectively. Their lake levels were measured in August 2008 at 21.0, 28.4, and 24.0 m asl, respectively; maximum depth of all lakes is about 4 m. Lakes 1 and 2 prograded into the adjacent alas slopes thereby interrupting the initial oval alas outline.

The relief height range of the alas as derived from the Alas DEM is from 19.3 m asl at the drainage valley in the southwest to about 50 m asl at the upper alas slope in the east. Elevations of the alas floor, slopes, and surrounding Yedoma uplands are generally lower in the west than in the east (Fig. 1). Mean alas depth is 20-25 m. Around Lake 1, two lake terraces are evident with their upper borders at 21.7 and 24.1 m asl. Lake 3 has one lake terrace with its upper border at 25.0 m asl. Direct hydrological connections via distinct beaded streams exist between Lakes 1 and 3 and between each of these lakes and the discharging drainage valley. Outflow from Lake 2 into Lake 1 occurs diffusively over the alas floor through widened polygonal troughs. The surrounding Yedoma uplands drain into the alas via several small thermo-erosional gullies.

Stratigraphy

The permafrost core contains two stratigraphical main units as inferred from the results of grain size, organic matter, and pollen analyses. The lower unit (400 to155 cm depth) is interpreted as thermokarst lake deposits, the organic-rich upper unit (155 to 0 cm depth) as subaerial boggy deposits. The radiocarbon age of 5660 ± 50 years BP in 154 cm depth suggests that the change from lacustrine to terrestrial depositional conditions occurred about 6 ka BP.

The sediment characteristics of the outcrop at the southeastern shore of Lake 3 reflect a terrestrial depositional environment. Three radiocarbon dates were retrieved from this outcrop, the oldest from the lowermost sample being 5440 ± 50 years BP.

The short lake cores of Lakes 1 to 3 with a maximum depth of 31 cm do not reach the base of the lake deposits. The three cores have different sediment characteristics, but reveal similar radiocarbon ages for the lowest core sections of about 1.5 ka BP. This proves the continuous existence of these lakes during this time period.

Discussion

From the spatial and stratigraphical analyses, several stages of thermokarst development have been distinguished:

1. Formation of a primary thermokarst lake on Yedoma uplands with complete thawing of ice-rich deposits, lake sedimentation, and lateral expansion to its present N-S extent. Slightly oriented in NNE-SSW direction.
2. Drainage of primary lake at about 6 ka BP through a large thermo-erosional valley at the SW that discharges into the Olenyokskaya Channel.
3. Permafrost aggradation with accumulation of ground ice in taberites (thawed and refrozen deposits) and lake sediments and aggradation of ice-rich boggy deposits with ice wedge growth on the exposed alas floor. Terrestrial deposition and ice accumulation led to the elevation of the alas floor.
4. Development of secondary thermokarst lakes in the ice-rich alas deposits at the alas margins and modification of the residual lake (now Lake 1) that possibly remained at the northwestern alas margin if drainage was not complete. Lakes 1 and 2 grow into the initial alas slopes thereby eroding them and modifying the initial alas outline.
5. Stepwise drainage of Lakes 1 and 3, possibly due to a lowering of the base of erosion in the system thermo-erosional valley – Olenyokskaya Channel, and formation of lake terraces.

Conclusion

The evolution of the investigated alas proceeded in two phases. The first phase was the continuous development of the primary thermokarst lake. It was initiated on Yedoma uplands probably at the transition between Pleistocene and Holocene and continued until the drainage of the lake about 6 ka BP, which was triggered by the breaching of the formerly closed basin contour by a large thermo-erosional valley. The second phase comprised different processes such as permafrost aggradation on the exposed alas floor, development of secondary thermokarst lakes in the alas and their stepwise drainage, and the modification of the initial alas contour by these lakes. The second phase can therefore be considered more dynamic.

The combination of high-resolution remote sensing and GIS data, that provide detailed spatial information, with classical sedimentological data derived from cores and outcrops, proved a highly successful method to reconstruct the evolution of thermokarst landforms.

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Ensuring the Stability of Bases as a Condition for Sustainable Development of the Urban Environment in Permafrost of the North-East of Russia

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Introduction

Yakutsk is a unique city built on permafrost, the capital of the largest federal subject of the Russian Federation and the largest administrative unit in the world. The permafrost area occupies 60% of the territory of the Russian Federation. The city is located in the area of continuous permafrost that constitutes the basis for the whole urban infrastructure.

The climate on the entire territory of Yakutsk is formed by insufficient humidity values, moderately warm summers and severe cold winters with low amount of snow.The air temperatures above 0º C are observed here for five months a year. The temperature values cross the 0º Cmark twice a year - in spring in early May, and in early October in fall. The amplitude of annual variations in air temperature reaches almost 100º C, ranging from -55º C to +35º C. The average annual air temperature for the period of continuous weather observations (1883-2010) ranges from -7.2 to -12.1º C.

Technogenic impact on ecosystems leads to very serious consequences, includingdisturbance of natural equilibria and complications in running economic activities. Unfortunately, the available experience in development of the urban environment in the north-east of Russia reveals that the human factor has a great negative impact on the nature in general, and especially on permafrost environment. Since the beginning of the multi-storey construction in Yakutsk in the 50s of the twentieth century up to the present, the ground temperature at a depth of 10 meters rises significantly as well as the depth of seasonal thawing. The increase in the average annual temperature of permafrost combined with the increase in the moisture content and the salinity content in the grounds of the seasonally thawed layer leads to destabilization of foundation grounds in Yakutsk. Analysis of the irrigation map of urban territories that is based on the evaluation of the satellite images of recent years indicates the further and rather active deterioration of the situation. Previously recorded isolated irrigation centers bordered by strips of excessively moist grounds have turned into vast stagnant water reservoirs located at different hypsometric levels. Uneven placement of man-made ground during planning of the area for construction has led to the redistribution of surface and ground water and to formation of new vast areas of technogenic irrigation that slowly transitioned to the stage of intensive overmoisturing of grounds with gradual water-logging.

Subsidence of buildings observed since the 70s of the past century sometimes leads to their partial destruction. The observations show that among the factors causing irregular subsidences are out-of-date technologies of foundation construction (the formation of a thaw cup under such buildingsis up to 10 meters wide), improper operation of utility facilities (leakage and, consequently, increased ground salinity) and roads (disturbance of the natural drainage of surface water and ground water that leads to the local water-logging of the territory).

Solution to the problem

Considerable progress was made in dealing with the first factor. Building on piles in permafrost, in our opinion, excludes any direct negative impact of buildings on the structure of foundations. Where the construction was carried out without violating technological provisions and horizontal marks, the temperature goes down and the foundation stabilizes.

Piling is used for over 50 years and there is not a single building constructed on piles that was destructed.Today, we may note a positive experience in application of piles of different types.

In this regard, it is advisable, in our opinion, to apply piling to the construction of group of buildings, neighborhoods and entire urban areas (industrial, residential, entertainment etc.), placing them together on integrated platforms connected with roads on the supports at different levels. All life support systems (electricity and heat generating stations, water supply facilities, sewerage, parking lots and garages) can be located on the first (technical) floor of such platform. Residential, administrative, industrial and other buildings are located on the surface of the platform. Thus, we eliminate many factors of technogenic impact on the frozen grounds of foundations.

The "Olonkho land" project is a high-tech complex – cluster: territorial entity on the territory ofYakutsk that is a relatively autonomous unit providing a complete set of urban functions (residential, administrative, business, trade, entertainment and leisure). The southern part of the cluster houses a group of buildings – innovative housing areas covered by domes and interconnected by roofed pedestrian crossings and passages for urban transport. The territory of the cluster is surrounded by major overpass with buttresses and adjacent secondary roads and cross overs to the earth's surface. Each building is independent like a small quarter. The first technical floor is designed for operational services (boiler, engineering, sewage etc.). Besides, power generating stations can be placed for emergency electricity supply for houses, garages and parking lots. In this regard, we have to gain experience in how to operate such clusters and autonomous systems, how to improve and upgrade them, if necessary. In the future, if we have positive results, we will be able to build larger platforms, similar in dimensions to several urban quarters.

The next step should imply covering of such platforms with a dome. Moreover, the idea of a city under the dome was already announced as early as in 1970. The German company Hoechst designed "The city in the Arctic" covered with an inflatable hemispheric coating with the diameter of two kilometers and the height of 240 meters. At that time, it seemed a risky endeavor, but today the idea is technically realistic.

In 2006, Alexander Bolonkin, a space scientist, and Richard Cathcart, a geographer, suggested construction offrameless "Evergreen Polar Zone Domes" (EPZD)the form of which are kept in a straightened state by a slight excessive pressure within the settlement (and not within the double walls, which is often used to supportinflatable architectural structures). The area covered by the dome may be large enough to house a city similar to Houston in the U.S.A. The domes can be of various shapes and designs. We think that they should have removable or sliding sections for ventilation, or just for the opening of some sections of the cluster to stay connected with the outside world. Perhaps, they can be used to install solar panels, rain harvesting systems, sunlight filters and other functions of which we are not aware now but which may be important for the operation of such structures. In order to find this out, we suggest implementing the "Olonkho land" project.

Conclusions

Thus, we approach creation of urban clusters with a given microclimate. Establishing water purification, sewage and air conditioning systems in such structures, we turn them into the urban systems of the closed type.We can completely eliminate the negative impact of the human factor on the environment and the negative impact of the aggressive environment on a human. This may result in the construction of the zones suitable for work and residencein any extreme conditions existing on our planet. In the future, such experience will certainly be useful in solving problems related to establishment of human communities on the Moon and on other planets.

Gas Hydrates in Permafrost

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Introduction

Uncommon sources of natural gas have aroused much interest lately, for several reasons. First, the producing gas fields in areas of large consumers are about depletion while the uncommon sources are predicted to be abundant and exceptionally rich. Second, production at most of giant gas deposits in northern West Siberia is declining but their storage, processing, and transportation infrastructure may work for a long time on if gas production resumes from newly available sources. Third, the presence of gas hydrates implies intense gas flow from deeply buried oil and gas fields. Finally, knowledge of gas hydrates stored in sediments is important to mitigate the hazard posed by their possible decomposition.

Thus, the gas hydrate potential of northern West Siberia is worth special studies.

Objectives of the study

In spite of numerous explicit and implicit signatures of permafrost-borne gas, drilling in high-latitude oil and gas fields has provided very little evidence of the origin, location, occurrence forms, and amount of natural gas within the permafrost depth interval.

Another problem associated with gas in permafrost is its sudden seeps or even blowout while drilling or quarrying. Note that gas shows of different intensities may occur both inside and outside oil and gas fields.

There is one more, environmental, problem: neither the size and extent of gas and gas hydrate accumulations in permafrost nor their sensitivity to the current climate change are known enough. Meanwhile, this is a natural storage of greenhouse gases lying very closely to the ground surface. The question arises how this gas may behave in the conditions of global warming and thawing of permafrost.

The present study focuses on the patterns of formation, spread, and evolution of gas and gas hydrates in permafrost. The relevant objectives are:

- Systematizing the available data on gas seeps from permafrost and creating a theoretical background for the conditions and forms of gas occurrence;
- Developing experimental modeling methods for gas hydrate-bearing frozen ground;
- Developing sampling methods for gas and gas hydrates from natural frozen drill cores;
- Explaining the origin and forms of natural gas in permafrost;
- Explaining the formation and distribution mechanisms, the ways of evolution, and sizes of gas and gas hydrate accumulations in permafrost.

Results and conclusions

A new integrated method has been developed to model the processes of formation and flow of gas in permafrost that stores gas and gas hydrates. The method has been applied to predicting possible contents of gas hydrates in cores retrieved from potentially hydrate-bearing sediments, both on the land and in the sea. As a result, various parameters can be estimated which characterize the formation and occurrence of gas hydrates in genetically and compositionally different rocks.

Another new method allows detecting the presence of gas hydrates in the field and in laboratory, in frozen cores, and is suitable for prospecting uses.

The obtained geological models of gas and gas hydrate formation in permafrost furnish new evidence on the Neogene-Quaternary geological history of permafrost regions and thus provide more exact paleo-reconstructions.

Methodological recommendations have been suggested for exploration of permafrost-borne gas and gas hydrates and assessment of the related gas potential, including commercial-scale gas occurrences.

Other methodological recommendations elaborated in the course of the study concern drilling in gas-bearing permafrost and allow predicting the depth intervals prone to gas blow hazard.

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Modeling of the Permafrost State in Contrasting Climatic Conditions

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The main purpose of this work is modeling of the permafrost state for contrasting climatic conditions. Contrasting climatic conditions are typical paleo time slices which are studied within the framework of the international Paleoclimate Modeling Intercomparison Project (PMPI) [http://pmip.lsce.ipsl.fr]. The first typical time slice is the era of the Late Pleistocene cryochron (21,000 calendar years Before Present, hereafter referred to as yr BP), i.e. the last glacial maximum. The second slice is the era of the Holocene optimum (6,000 yr BP), which represents warm climate. The third so-called "basic" slice is the modern climate. The main objective of the PMIP project is to compare the results of the leading climate models that simulate the climates of the aforementioned periods, and also compare them with the "standard". For the modern climatic conditions the "standard" is represented by the observational data, and for the paleoclimate time slices – by paleoreconstructions. Comparison of the modeling results with the actual data (observations and reconstructions) will make it possible to assess the simulation quality of both modern climatic conditions and contrasting climatic conditions (Late Pleistocene cryochron and Holocene optimum).

To solve the problem of numerical modeling of permafrost, the SPONSOR land surface heat and water exchange model is used. The model was developed in the Laboratory of Climatology of IG RAS and participated in all the international model inter-comparison experiments [*Slater et al. 2001; Etchevers et al. 2004; and others*]. The SPONSOR model calculates all the components of the heat and water balance on land, as well as variable conditions (effective temperature of the landscape surface, soil temperature, its moisture content, the amount of frozen water in soil, albedo etc.) All the parameters mentioned are calculated at each time step (for the stable operation of the model the step should not exceed 6 hours). During the operation of the model the values of several meteorological variables should be set at each step. The variables include air temperature and humidity, wind speed, precipitation, radiation flows etc. The values of a series of landscape parameters are required for the scheme operation. Some of the parameters may have seasonal variations. These parameters are tightly related to the type of vegetation or soil type in each cell of the land. The values of deep ground temperature, as well as groundwater depth values are also set (as lower boundary conditions of heat and moisture). The number and thickness of the calculated levels in the soil may vary. The detailed description of the SPONSOR model is given in the works of [*Shmakin 1998; Shmakin & Rubinshtein 2006*].

The boundary conditions for the SPONSOR model in this case are the output data of the climate models participating in the PMIP project. Thus, it is possible to carry out various numerical experiments simulating permafrost conditions of the Late Pleistocene cryochron, the Holocene optimum and the modern climate. On the one hand, this approach makes it possible to observe the dynamics of cryolithozone in Northern Eurasia in more detail, to assess the sensitivity of permafrost to changed climatic conditions, and on the other hand, to assess the quality of the model operation by comparing the obtained results with the paleoreconstructions data.

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Geotechnical Problems of the Buried Oil Pipeline Operation in the Cryolithozone of the North of Western Siberia

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Abstract

The types of areas that are different in section, characteristics and properties of the active layer grounds and of permafrost were identified on the subsurface part of the Vankor oil pipeline operation of which triggered adverse engineering and geological processes. Heating effects of the natural-technical system "pipeline-thermal stabilization means" on host grounds were shown and evaluated for each type of the areas, based on the forecast calculations.

Keywords: geotechnical processes; permafrost; permafrost zone; temperature field.

Introduction

The operational problem of the oil pipeline in icy permafrost areas is associated with the fact that with the subsurface pipe laying and with temperature of the pumped product equaling 70 °C, the pipeline has a warming impact on host grounds. The process results in activation of thermokarst, loss of bearing capacity of foundation ground and uneven vertical movement of the pipe with the hazard of a rupture.

Seasonal cooling systems (heat stabilizers) with the distance of 2500 mm from each other were designed and put into operation in areas of permafrost development within the Sedelnikovo-Purpe section of the Vankor pipeline route, in order to resolve this problem. Their effectiveness for some areas was confirmed. This applies mainly to the areas of relief depressions where flat-topped polygonal peatlands and peat bogs underlain by ice-rich clayey silts are developed. The major part of the pipeline is built on such areas. Forecast calculations were made to assess the thermal impact of heat-insulated pipeline on permafrost with regard to the operation of heat stabilizers.

Within the first years after the oil pipeline started functioning, the adverse geotechnical processes were activated in its area: subsidence and water-logging of the surface. Examination of the linear part at the end of the warm season of 2010 showed that the accumulation of groundwater in the trench led to the formation of linearly-stretched technogenic water bodies.

The objects and methods of study

Types of ground heat exchange conditions were outlined along the axis of the examined section of the Vankor-Purpe oil pipeline located between the Taz River and the town of Tarko-Sale. The length of the subsurface part of the pipeline located in the zone of discontinuous permafrost is about 325 km. Areas similar in geological structure and permafrost development were identified. Three types of the area prevail each of which is characterized by a certain type of section.

The first type of the section is characterized by the presence of a peat layer with the thickness of 0.5 m and a layer of frozen clayey silt. The peat is highly and medium decomposed with a normal ash content and less often with a high-ash content. It is plastic frozen, ice-rich with porphyric, reticulate, layered and ataxitic cryogenic structures. The clayey silt is light, dusty, icy, subject to subsidence, with a layered cryogenic structure and fluid in the thawed state. The second type of the section is represented only by clayey silt without peat. According to its characteristics, this clayey silt is similar to the one of the first type of the section. The third type of section is represented by sand covered with peat having the average thickness of 0.5 m and the characteristics similar to the peat of the first section type. The sand is fine and silty, solid frozen, not subject to subsidence and with a massive cryostructure. The inclusion of pebbles and gravel varies from 5 to 10%. The number of permafrost development areas according to the section types makes up: Type 1 - 63 (total length - 28.5 km), Type 2 - 10 (3 km), and Type 3 - 19 (13.5 km), the total length of 45 km. The calculation of the heating effect of the oil pipeline on the host rocks was carried out for the 1st and 2nd types of sections in the «WARM» software environment developed at the Department of Geocryology in Moscow State University.

The estimated area of the mathematical two-dimensional model is a vertical half-plane perpendicular to the axis of the pipe and limited by the Earth's surface from above. Due to the symmetry of the thermal problem relative to the vertical plane of symmetry passing through the axial line of the pipe, the estimated area constitutes a half of the half-ground mass.

The dimensions of the estimated area represent a model of the ground mass that is 25 m wide and 50 m deep. The depth between the heat-insulated pipe and the upper generating line makes up 1.5 m. The pipe diameter is 820 mm. Accordingly, the lower generating line of the pipe is at the level of 2.32 m. The heat insulation of the 200 mm thick pipe is made of penoplex.

The upper mark of the estimated area was defined by such conditions as "Snow". At the side surfaces, the conditions of the second type with the zero heat flow were set. At the lower boundary of the area, the conditions of the first type with the constant ground temperature were set. The model of the pipeline was set up in squares with the dimensions of 0.1 x

0.1 m in the form describing a semicircle with the heat exchange conditions of the third type.

The temperature of the fluid is 70 °C. The heat exchange coefficient for the "Penoplex" heat insulation with the thickness σ = 200 mm was calculated according to Formula 1

$$\alpha = \frac{\lambda}{\sigma}, \qquad (1)$$

where λ - the thermal conductivity coefficient of "Penoplex" equaling 0.03 W/(m · °C). Thus, we obtain the following:

$$\alpha = \frac{0{,}03}{0{,}20} = 0{,}15 \ \mathrm{W/(m^2 \cdot °C)}$$

The heat exchange coefficient of the pipeline with regard to the insulation is 0.15 W/(m^2 · °C). The spatial model of the heat stabilizer was set in the form of squares with the dimensions of 0.2 x0.2 m from the laying depth of the pipeline. Some distance between the squares was compulsory, because the estimated area should not be fully covered due to the fact that the heat stabilizer does not serve as the boundary of the estimated area. The squares are set according to the conditions of the third type. In forecast calculations, the data on the temperature of the ground at different depths that were obtained during the first year of operation in the course of the measurements in the thermometric wells of the geotechnical monitoring network were used as the characteristics of the initial heat field. These wells were located at 1500 mm from the axis of the pipeline and at a distance of 500 mm from the heat stabilizer that is installed at 1500 mm from the axis of the pipeline (Fig. 1). Air temperature values were set according to the data from the Tarko-Sale weather station. The influence of technogenic water bodies was not taken into account.

Discussion of results

Forecast calculations for all section types proved that after 30 years of operation of the oil pipeline the ground foundation will remain in the frozen state, including the areas with the clayey silt section type without peat (Fig. 2).

A thawed zone with the thickness of 0.2-0.3 m will form only directly below the pipe. Thus, the heat stabilizers ensure the stability of the frozen state of the oil pipeline foundation grounds. Adverse geotechnical processes (subsidence of the ground, irrigation of the trench etc.) resulted from non-application of technical solutions that involve heat shields, i.e. the consideration of the influence of seasonal heatturns and of the hydrogenic processes' dynamics on the stability of the structure in the course of designing of the examined pipeline.

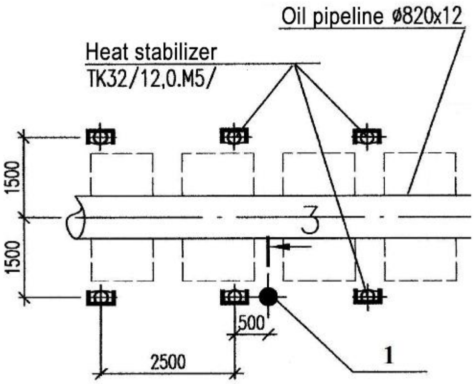
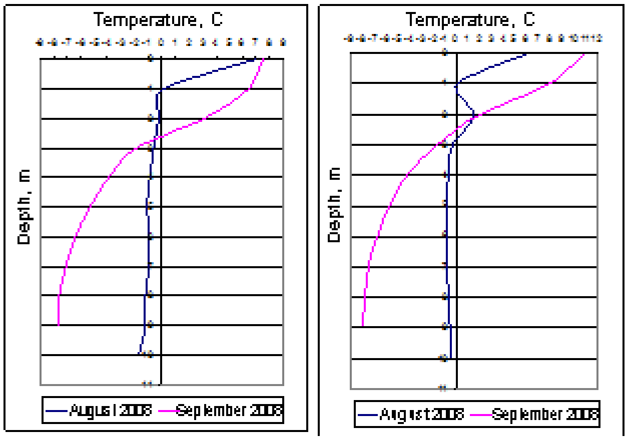


Figure 1. The layout of thermometric well (1) relative to the oil pipeline and the heat stabilizer.



a) b)

Figure 2. The temperature of host grounds of the pipeline base at the location point of the observation geothermal well in the first year - the factual data, and the 30th year of operation of the pipeline - the results of forecasting calculations (a, b respectively for the 1st and 2nd type of the sections).

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Psychobiological Description of Life Quality Among the Inhabitants of Northern Cities

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The results of the study along with the analysis of data included in the SF-36 questionnaire showed that the quality of life among healthy people and patients with bronchopulmonary and cardiovascular malfunctions living in the North is remarkably substandard, while the occurrence of stress-induces conditions and border psychic disorders among the subjectively healthy Tyumen inhabitants with high level of self-actualization was 127.6%.

Key Words: cardiovascular malfunctions, quality of life, stress-induced conditions.

The term “quality of life” as a social indicator and a significant characteristic of life support emerged in the 1960’s in the USA. According to the WHO team of experts [*1999*], “the quality of life is an individual relation between the objectives, plans and opportunities of a human society member and the status of a person in the social life in the context of the system of culture and values in a given society”. Another WHO team of experts offers a little bit different definition: “quality of life is a level of perception by individual persons and groups of the fact that their needs are satisfied and the opportunities required to achieve well-being and self-fulfillment are provided”. According to this definition, the essence of life quality has mostly social and psychological nature. According to Yu.V. Krupnov [*2005*], life quality characterizes and describes *objective subjectivity* and is determined by reflexive practices and knowledge, i.e. those practices and knowledge that are built by a subject based on his or her analysis of the means of organization of his or her thinking and activity. The biomedical studies define Life Quality (LQ) as an integral characteristic of physical, psychological, emotional and social functioning of a diseased person that is based on his or her subjective perception.

The key objective of this study is a comparative assessment of the data on the LQ subjective perception obtained based on the SF-36 questionnaires and the methods of L. Reader and A. Jones as well as on the clinic-anamnestic method of examination of subjectively healthy persons and patients with cardiovascular malfunctions and chronic obstructive lung disease.

The quality of life among the residents of the North – cities of Khanty-Mansiysk and Surgut (total number of people examined – 1859) was assessed by means of the SF-36 questionnaire and by L. Reader’s express method. For Tyumen inhabitants (total number of people examined – 5274, including 1822 women, 3452 men; experimental group – 1345 people), the identified parameter was the level of personal self-actualization [*Jones 1986*]. All respondents passed the complex clinical laboratory examinations under the standard program (minimum clinical analysis, measurement of blood pressure, bodymass index (BMI) calculation, examination by a therapist). Echocardiographic examination was carried out on TOSHIBA devices. **Spirographic examination of the North inhabitants was carried out on the Spirosoft SP - 5000 “Fucuda Deushi” device.** The results of the examination were statistically interpreted, Student’s t-criterion was determined.

Results of the Study

Among the residents of northern cities aged 25-55, 128 men and 135 women had the 1st degree of arterial hypertension; 133 men and 150 women had respiratory malfunctions; 128 men and 141 women had the 1st degree of arterial hypertension together with chronic obstructive lung disease.

Many years of studies of compensatory and adaptive human reactions caused by long-time psychic and emotional tensions and chronic stresses in everyday life allowed to reveal a large group of subjectively healthy men and women aged 25-55 who live and work in Tyumen. Their thorough examination (24-hour blood pressure monitoring, Holter monitoring, echocardiogram, biochemical blood testing) helped to make a first-time diagnosis of the 1st and 2nd degree of arterial hypertension for 43 men and 199 women, depending on the level of arterial hypertension. 72 men and 309 women showed border psychic disorders (BPD) of neurotic, depressive and psychosomatic levels. Men with BPDs demonstrated the highest registered levels of total cholesterol (6.49±0.12 millimole/l). 48% of patients demonstrated high echogenicity of aorta. Erectile dysfunction was the leading clinical syndrome among 80% of the patients with BPD and the predominant stressor. Clinical laboratory examination of 153 men and 169 women did not reveal any functional or morphological dysfunctions; however, this group demonstrated carefully hidden psychic and emotional malfunctions corresponding to the picture of non-specific asthenia.

Comparative assessment of anthropometric data and cardio-hemodynamic parameters among practically healthy people aged 25-55 depending on gender, age and place of living demonstrated no reliable differences. Most biological parameters and calculated indices of respiratory and cardiovascular systems of healthy people living in the North corresponded with the age parameters and were close to upper or lower standard limits. People with chronic obstructive lung disease and respiratory malfunctions demonstrated satisfactory or deteriorated status of basic studied volumetric parameters, along with the deterioration of velocity parameters.

Depending on the place of living, women with the 1st degree of arterial hypertension demonstrated no reliable differences in terms of morphofunctional heart status. At the same time, male Tyumen inhabitants demonstrated reliably higher systolic pressure (from 146.0±1.13 mm Hg to 148.0±0.72 mm Hg) and diastolic pressure levels (from 90.74±1.46 mm Hg to 97.80±0.78 mm Hg), compared to the arterial pressure level of the North residents (systolic pressure – from 140.19±2.07 mm Hg to 141.3±1.18 mm Hg; diastolic pressure – 92.85±2.36 mm Hg). For all smoking men in Tyumen, regardless of the type of malfunction, and non-smoking men with arterial hypertension mortality risk connected with cardiovascular diseases, by SCORE assessment, is equal - 10 years. Combination of a high level of basal anxiety, erectile dysfunction and accentuation of hypochondriac type of neurotic personal features predetermined the basic pathogenetic mechanism of the development of border psychic disorders among men. During the initial examination, practically all Tyumen inhabitants produce complaints characteristic of non-specific asthenia, i.e. high level of tiredness, sleep disorders, high meteosensitivity, unpleasant feelings or pains of various localization, low or high arterial pressure, headache and vertigo.

Common pattern was represented by decreased (with age) LQ of the North residents. The highest scores were registered on “physical functions”, “social functions”, and “pain” scales. The Life Quality Law of Khanty-Mansi Autonomous District states that every individual should appreciate and protect benefits and opportunities ensured by the level of life in the oil-producing region. The high scale of self-assessment based on the importance for other fellow citizens evidences the same thing (social functions). Pain is the greatest biological protector, and the understanding of its role guarantees early detection and avoidance of danger. Real social self-assessment is rather high. Females find the “emotional” function more important than the “physical” one. Chronic obstructive lung disease and respiratory malfunctions determine significant decrease in values of most scales, though “physical functions”, “role functions”, “role emotional functions” still hold first positions.

The scores among the women of the North are notably lower. Generally, women demonstrated less eagerness when asked to fill out the questionnaires, were more sensitive to changing conditions, they are more meteosensitive and demonstrate too high self-assessment in their answers to direct polls. For the time being, the fact is that, in spite of relatively higher social and economical opportunities granted to women by the society compared to other regions, their abilities in terms of self-support are lower: they get lower salaries, they face more obstacles trying to get a job, especially in the pre-retirement age. Naturally, they have a more negative attitude towards the diseases. The effect of psychological protection should also be considered. The analysis of risk factors carried out following the collection of information during direct polls showed that the most probable of them include: gender, age, rapid changes of climatic parameters, meteosensitivity, sleep disorders or dissatisfaction, short breath, smoking, sedentary way of life, cold, internal stress, fatigability. The first three of them were observed with equal frequency in all groups, while such factor as short breath is reliably more frequent among the people with respiratory malfunctions and chronic obstructive lung disease.

All men and women living in Tyumen, regardless of the type of malfunction, showed the self-actualization level more than 45, thus testifying to high LQ of respondents. The clinical study and direct polls revealed the significant personality problems among all female Tyumen residents (intrapersonal conflict of a working woman). Healthy women with asthenia and female patients with arterial hypertension demonstrated predominant subjective symptoms of cardiovascular disorders in the form of marked pain syndrome, high meteosensitivity and various non-specific general brain symptoms at the background of low resistivity to physical stress. A particular feature of the health state assessment performed by male Tyumen residents was subjective feeling of fear to lose the dominant role in the society.

Conclusions

Results of the study, along with the analysis of the data included in the SF-36 questionnaire, showed that the quality of life among healthy people and patients with bronchopulmonary and cardiovascular malfunctions living in the North is remarkably substandard. However, the residents of the northern regions of Western Siberia have better social support, since in 2006 the government passed the Law on Quality of Life in Khanty-Mansi Autonomous District. On the contrary, the detailed clinico-anamnestical examinations revealed significant personality problems among the people with high level of self-actualization, and these problems evidence the worse state of socio-psychological adaptation of Tyumen residents.

One should not forget that the main method of the LQ assessment is based on the patient’s opinion, as life quality is an objective criterion of subjectivity. Subjective symptoms identified in the process of careful collection of medical history information have the same level of reliability as the results of clinical laboratory and instrumental methods of examination, as they are the patient’s feelings connected with the pathological process and have the special importance in terms of premorbid state diagnostics. According to the statement made by A.A. Ukhtomsky, “subjective indicators are objective for those who can understand and interpret them”.

Geology and Gas-Bearing of Upper Turonian Deposits in the North of the Western Siberia

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Gaz-Sale sequence consisting of siltstones and clayey sandstones is identified in the marginal part of Yamal peninsula, Gydansky Peninsula and eastward of latitudinal flow of Pur River in the middle part of Kuznetsov suite of Late Turonian age.

More completely rocks of Gaz-Sale sequence are described by core data in Kharampurskaya area. On the results of petrography and mineralogy studies clastic material consists 50-85% of reservoirs in Gaz-Sale sequence and represented by quarts (up to 58%), field spars (up to 33%) and fragments of rocks (up to 15%). Clastic matter is middle an low grade of sorting with domination of semi-rolled grains. Grain size predominantly varies from 0.01 to 0.1 mm.

Deposits were discovered in Gas-Sale sequences in 7 fields in YaNAO and 1 in KhMAO (Festivalnoe, Kharampurskoe, Terelskoe, Novo-Chaselskoe, Yuzhno-Russkoe, Zapolyarnoe, Yuzhno-Messoyakhskoe, Verkhnekolikeganskoe fields), non-commercial gas flows achieved in other targets (Russkaya, Zapadno- and Vostochno-Messoyakhskaya areas), gas showings were registered in some targets during rocks penetration within this age interval.

Accumulations of commercial reserves of gas hydrates below the bottom of permafrost zone are possible in north-eastern part of West-Siberian region (Gydan peninsula, Prieniseysky District, eastern part of Messoyakha trough and in the area of Bolshekhetskaya depression). In the areas of proven gas bearing (Zapadno- and Vostochno-Messoyakhskaya, Messoyakhskaya, Pelyatkinskaya, Utrennyaya, Gydanskaya, Tazovskaya, Russkaya) gas hydrates could form both in reservoirs of Gaz-Sale sequence and in Cenomanian sands.

Actuality of item of gas hydrates bearing capacity in the upper part of sedimentation mantle in the north of the Western Siberia concluded in three aspects:

- commercial assessment of hydrocarbon (gas hydrates) reserves ;
- environmental and climate change effect of gas hydrates accumulations;
- evaluation of emergency situation during drilling operations in hydrate bearing part of section and development of recommendation for hazard prevention.

Sedimentological characteristics of ice-wedge polygon terrain in Adventalen valley (Svalbard)

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Introduction

Climate regime and sedimentological characteristics of the terrain in permafrost environments are a crucial factor controlling the formation of ice-wedges. The role of temperature conditioning the process of cracking has been largely examined in the high latitudes of the Northern Hemisphere [*Mackay 2000; Christiansen, 2005*]. Other studies have been focused on unveiling the role of sediments and how the sedimentary record may reveal past environmental conditions in the area where terrestrial polygonal networks have developed [*Fortier & Allard 2004*]. In this paper we introduce preliminary data about the sedimentological features in two study sites in Adventalen valley, Svalbard.

Study area

Our study area is focused on the Lower Adventalen valley, a glacial valley located at 78ºN in the central part of Spitsbergen (Svalbard), close to Longyearbyen, the largest settlement of the archipelago. Within the ANAPOLIS project - that is focused on the comparison between polygonal networks in Svalbard with Mars analogues - we have studied in detail two study sites where ice-wedge polygons are widespread.

The mean annual air temperature between 1961 to 1990 in Longyearbyen was -6 °C, with a large interannual variability and an increasing warming trend recorded over the last decades [*Härtel, 2011*]. Svalbard has the warmest permafrost conditions in the High Arctic [*Christiansen et al., 2010*]. The thermal contraction cracking of the ground responsible for the formation of these polygonal networks occurs during cold spells in winter with air temperatures below -20°C and a drop of ground temperatures to below -15°C near the top of the permafrost above the ice-wedge [*Christiansen, 2005*].

Polygonal terrains are widespread on both margins of the glaciofluvial terraces of the Adventalen braided river. We have studied the sedimentological characteristics in two sites of the northern (ADD.4) and southern (ADV.20) banks of this river.

Materials and methods

Tens of pits were excavated for sedimentological purposes on the glaciofluvial terraces where polygonal networks are distributed. Moreover, fluvial erosion has exposed sections on the cliffs of the fluvial terraces where sediment exposures can be analyzed at high resolution. In this paper we will only discuss data on two of these sections.

Samples from the cliff sections were collected according to the different lithostratigraphic units observed in the field for standard analytical procedures. Organic matter was determined by Loss on Ignition (LOI) at 550ºC (3 hours). For grain size measurements, samples were first pre-treated with hydrogen peroxide (H_2O_2) to eliminate the organic fraction and subsequently quantified individually with a Malvern Mastersizer 2000 laser particle size analyzer. All the analyses were undertaken at the laboratory of the Department of Geology of the University of Lisbon. Up to 10 samples were sent to AMS dating at the Centro Nacional de Aceleradores of Sevilla (Spain) in order to establish the chronological framework of the environmental changes deduced from the sedimentological sequences. By the time of writing of this paper, results were not available yet.

Results

In the northern margin of the Adventalen valley, a section was excavated on the cliff reaching a sedimentary sequence of 1.3 m (ADD.4). Permafrost was found at 120 cm depth.

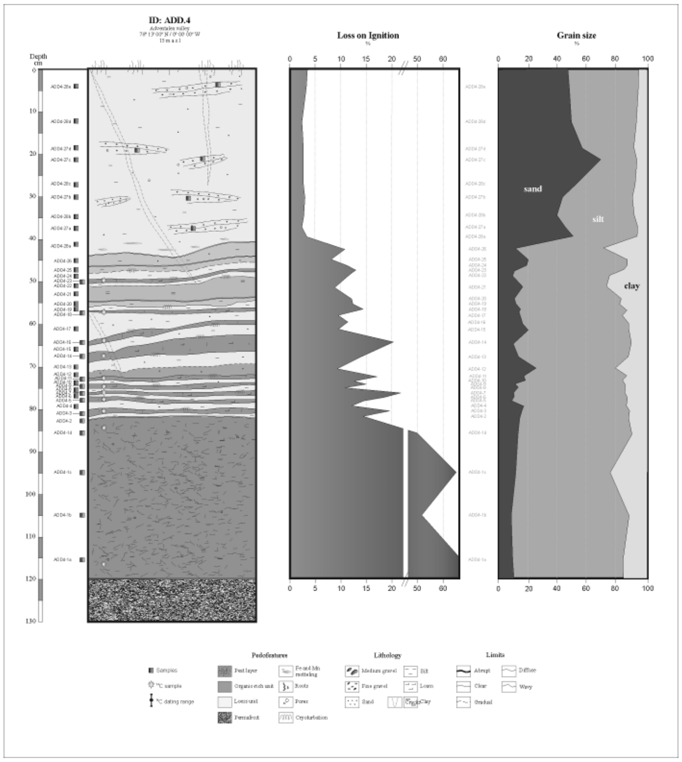

Figure 1. Sedimentological properties of the ADD.4 section.

Three very different lithostratigraphic units were observed (Figure 1):

- 0-41 cm: The upper part of the section is basically constituted by loess deposits, mainly silts with pockets of sands (up to >60% of the sediments.
- 41-82 cm: This unit shows an alternation of more organic units (15-20% LOI) and silty loess layers with lower content of organic matter (10-15 % LOI). A trend towards a lower proportion of organic matter in the sediments is detected within this unit.
- 82-120 cm: The basal unit corresponds to a peat layer with a large proportion of organic matter (LOI >50%) and little mineral content, mostly composed by silts.

In the southern section of Adventalen valley, the ADV.20 sequence is very similar to those sections studied by Härtel [*2011*]. In this case, no peat layer was observed in this site despite the fact that permafrost was found at 180 cm, much deeper than in ADD.4. The content of organic matter in this sequence is generally lower than in ADD.4. Two different lithostratigraphic units were observed:

- 0-95 cm: Thick loess cover.
- 95-190 cm: Alternation of organic bands and mineral silty sediments.

Interpretation and conclusions

Preliminary data of the two sections reveal significant changes in the pattern of sedimentation as well as remarkable environmental changes during the recent millennia in Adventalen valley. The results of the 10 datings - which are being now processed - will permit to infer the timing of the palaeocological changes suggested in the data presented in this paper.

According to the existing dates, the formation of the basal peat layer occurred between 2.8-3.4 ka BP [*see Härtel 2011*]. Therefore, environmental information for the Late Holocene may be inferred from these two sections. The period of widespread peat formation in Adventalen area must correspond to a phase with prevailing geomorphic stability with more favourable climate conditions for peat development, probably warmer than present-day. Sedimentary sequences show a period of alternating organic units and loess deposits, subsequently changing to a period of predominance of clearly aeolian deposition. Climate must have been decisive to imply these changes on the sedimentation processes prevailing in both sections, together with the geomorphological setting, which may explain the differences observed between them.

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Modeling Sub-Sea Permafrost in the East Siberian Arctic Shelf: The Laptev Sea Region

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Introduction

The Arctic region contains extensive amounts of carbon, accumulated over millennia in terrestrial and sub-sea permafrost, that can be re-introduced back into the present day atmosphere and biosphere biogeochemical cycle, and thus feedback processes affecting global climate dynamics may be accelerated. One of the feedback processes is related to destabilization of significant quantities of the gas hydrate deposits and to consequent production of methane that can seep to the water column through pathways in sub-sea permafrost.

The state of permafrost in Arctic is a potential key to understanding whether and how methane, preserved in seabed reservoirs, can escape to the atmosphere. Unlike the terrestrial permafrost in the Arctic which experienced a change in its thermal regime caused by the 6−7C mean annual air temperature increase since the last Glacial Maximum, sub-sea permafrost has been subjected to additional drastic transformations, e.g. inundation by the ocean, resulting in warming of the permafrost environment by as much as 17−20C.

As opposed to slow and gradual release of carbon from thawing terrestrial permafrost, Shakhova and Semiletov [*2009*] hypothesize that large quantities of carbon sequestered beneath and within the sub-sea permafrost can be released to the atmosphere rather quickly. Moreover, Shakhova et al. [*2010*] recently reported extensive methane venting at some locations on the East Siberian Arctic Shelf (ESAS), and Nicolsky and Shakhova [*2010*] demonstrated that open taliks can occur under the Dmitry Laptev strait region. These recent findings prompt us to re-examine current understanding of the thermal state and stability of submarine permafrost in the Laptev Sea area.

Since sparsely distributed measurements of the sub-sea permafrost temperature, salinity, and distribution, the present understanding of the current thermal state of sub-marine permafrost in the Laptev Sea shelf is primarily based on modeling results by Molochushkin, Gavrilyev, Danilov, Zhigarev, Soloviev, Fartyshev, Kim, Delisle, Romanovskii, Hubberten et al. Previously developed models significantly vary in the underlying assumptions, producing different results regarding the age, thickness and temperature of the sub-sea permafrost.

Two basic mechanisms of the sub-sea permafrost degradation are prelevant in models: the upward and downward. The former more prominently results from the geothermal heat flux in fault zones, while the latter is due to the surface warming, e.g. by large rivers. A key question to be answered by the models is existence of open taliks - a body of unfrozen ground connecting sub- and supra-permafrost waters - through which the gases can escape to the water column. We note that the modeling results by Romanovskii and Hubberten [*2001*] limits existence of open taliks to the areas of fault zones, occupying less than 5% of the Laptev and East Siberian Seas. At the same time, the modeling results by Zhigarev show existence of the open taliks outside of the fault zones by considering both the downward and upward degradation of permafrost within the Laptev Sea. We hypothesize that another possible mechanism for the formation of open taliks outside of the fault zones is the thawing of permafrost beneath thaw lakes submerged several thousand years ago during the ocean transgression.

We emphasize that because of the insufficient measurements of the thermal properties, salinity, unknown dynamics of the ocean regressions/transgressions, and lack of the prehistoric temperatures, all models of the sub-sea permafrost dynamics are based on some hypotheses and assumptions regarding the shelf properties and physical processes during previous glacial cycles. Thus, in order to construct the most sound set of parameters to simulate the permafrost dynamics, we review previous studies and modeling results. We highlight major assumptions by Fartyshev, Taylor, Romanovskii, and Gavrilov, combine their ideas, and develop a refreshed sub-sea permafrost model. We indicate that some structural geology influence the permafrost dynamics and its present temperature distribution. We show that degradation of the salt-bearing sub-sea permafrost can lead to formation of open taliks outside of the fault zones in the Laptev Sea Region. Note that in the presented model, we assume a static ground mineralization, excluding salt diffusion, salt fingering and buoyancy-driven flows. Pockets of soil with anomalous salinity are possible and would complicate any generalization of seabed soil salinity.

Numerical modeling technique

We model permafrost dynamics on the Laptev Shelf by computing the ground temperature on a grid of points spaced uniformly in longitudinal and latitudinal directions, with a resolution of 6 arc-minutes. To determine when a certain part of the shelf was dry or inundated by the ocean, we use the global sea level reconstructions. If at time t ϵ $(-\infty, 0]$ the sea level is below the ground surface at point x, we assume that this point is dry and then define the ground temperature by $T_g(t)$; otherwise the surface temperature is equal to the benthic temperature $T_b(d, \boldsymbol{x})$, where d is the ocean depth $d = d(\boldsymbol{x}, t)$ at point x on the shelf. One of the difficulties in the sub-sea permafrost modeling is to find the moment of time when the point x was inundated during the transgression. In all previous permafrost modeling efforts, it was assumed that the latest ocean transgression proceeded over the present-day bathymetry, and thus temporal changes in topography/bathymetry are not considered. In this work, we review major physical processes shaping the most recent transgression on the Laptev Sea shelf and numerically model changes in the bathymetry/topography in the Late Pleistocene [*Gavrilov et al. 2006*].

Following *Molochushkin and Gavrilyev; Danilov and Zhigarev* and *Fartyshev*, we consider a two-layer soil column. The top layer in our model is 30 meters thick and represent the Quaternary era sediments which presumably have originated during a series regressions/transgressions, and hence have the largest porosity and mineralization. The bottom layer is associated with the properties of either the pre-Quaternary clastic deposits or the undisturbed ground material. Following *Fartyshev*, we propose that the horsts and tectonic uplifts are primary composed of the undisturbed consolidated ground material - the bedrock, while the grabens are filled with the clastic deposits.

We assume that the layer of Quaternary sediments has the highest salinity, 40‰, due to diffusion of salutes to the near-bottom sediments during periodic ocean transgressions. Salinities of the ground material in horsts and grabens are assumed to be 10‰ and 30‰, respectively. Ground material with salinities of 40‰, 30‰, and 10‰ have the freezing point depression of −2.05C, −1.54C and −0.55C, respectively. As in [*Romanovskii & Hubberten 2001*], we parameterize the heat flux variability on the shelf by the lateral extents of the geological structures constituting the Laptev Rift System.

Results

Figure 1 shows possible locations of open taliks on the Laptev Shelf, based on the $70 \cdot 10^{-3}\ Wm^{-2}$ flux in case of two benthic temperature parametrizations with depth. The continental slope is characterized by high values of the geothermal heat flux as well as subject to the warm Atlantic-based ocean circulation, and is thus prone to widespread development of open taliks. The existence of such taliks can serve as pathways for gas in the sub-sea permafrost, providing an explanation for widespread methane observations in the Laptev Sea. We hypothesize that additional locations of open taliks may coincide with the active faults - the boundary between horsts and grabens - associated with abnormally high geothermal heat flux and also with pre-Holocene channels of large rivers such as the Lena and Yana Rivers. This consideration is out of the scope of the presented modeling study; the interested reader is referred to works by Romanovskii and Delisle, where some modeling attempts were accomplished.

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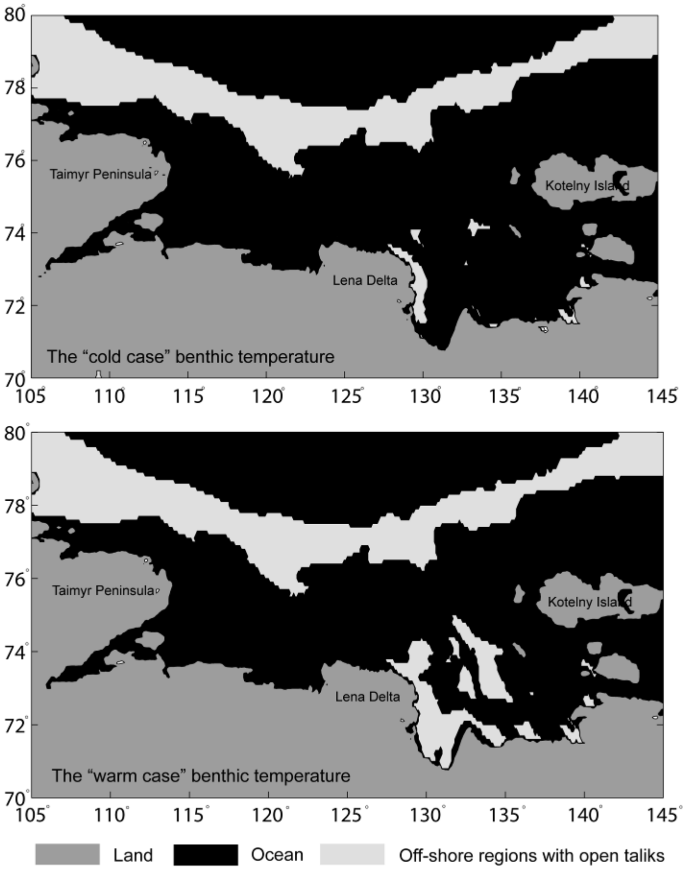

Figure 1. Modeled locations of open taliks in the Laptev Sea Shelf. Top and bottom plots show locations of the open taliks in the case of "cold" and "warm" parameterization of the benthic temperature, respectively. The geothermal heat flux within the Laptev Rift System is assumed to be $70 \cdot 10^{-3}\ Wm^{-2}$.

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The Results of Development of Cryological Research Innovative Infrastructure in Tyumen State Oil and Gas University

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Tyumen State Oil and Gas University founded 55 years ago is now the main supplier of specialists for oil and gas industry. The reason for establishing the university was the need to provide the developing industry of the region with engineering specialists. The university has been succeeding in this task up to the present day. Tyumen State Oil and Gas University is the largest research and education complex with a good resource base and a highly qualified teaching staff that includes 725 Candidates of Science and 213 Doctors of Science. The university provides 642 education programs and the total number of students in these programs exceeds 60 thousand.

At the university the training of specialists for ensuring effective management of natural resources in the oil and gas producing region is realized through the innovative program called "Incorporation and development of the cryological aspect in the major education programs of the university complex" and it is based on the integration of education, science and innovation.

In general, the issues of cryology are cross-cutting for the studies carried out by various departments of Tyumen State Oil and Gas University including geological, engineering, economic and arts departments. This is reflected in the following issues: road construction and struggle against glazed frost phenomena, topographic surveying in the Far North and the water supply system in the northern climatic zone, the social aspects of health and healthy lifestyle in the northern climate, the technology of conducting welding works and pipelines installation at low temperatures, and in the course of studying the particularities of motor starting at low temperatures. Over the last years, comprehensive studies aimed at assessing the impact of oil and gas facilities as well as the impact of infrastructure facilities on the fragile cryosystems were carried out; innovative technologies aimed at preserving them are being developed.

Within the university structure there are specialized structural units that actively study the impact of low temperatures on the processes of engineering, social, environmental and biological systems.

In 2002 the department of Earth Cryology was established in Tyumen State Oil and Gas University. In 2003 the Subarctic Scientific Center was established as a result of collaboration of the Earth Cryosphere Institute of SB RAS and Tyumen State Oil and Gas University.

The uniqueness of the Subarctic Scientific Center that is the only inter-university research and education center in Western Siberia is a possibility of organizing monitoring studies into the variability of climate and geocryological conditions of the area in a multi-year perspective. To date, a network of observation sites was established on the territory of the "Gazprom dobycha Nadym" LLC fields. These sites are equipped according to the unified principles and are located both in the southern regions of discontinuous permafrost distribution within the Nadym-Pur interfluve, and on the Yamal Peninsula with continuous permafrost and a wide distribution of saline grounds.

The basis for all monitoring sites are geothermal boreholes with the depth of 30 m that are equipped with autonomous automated systems for recording and accumulating information on the thermal regime of grounds through the entire depth. The research activities include performing a snow survey, i.e. spatial distribution of the thickness and density of a snow cover, its structure, as well as determining the dynamics of the seasonal depth of thawing and freezing. Geothermal boreholes are included in the database of the Council on Earth Cryology of the RAS Presidium and the International Permafrost Association (IPA).

During the International Polar Year (2007 — 2008) the International field courses on permafrost were held at the Subarctic Scientific Center for the first time in Russia. They were organized in the form of Student summer schools in collaboration with University of Hamburg (Germany), University of Delaware and Montana (the USA), and with the participation of Lomonosov Moscow State University. In recent years such educational centers for students became rather widespread. These centers operate with the financial national support and the participation of international scientific communities that organize competitions of scientific and educational programs among the leading scientists, who are engaged in conducting field and laboratory courses.

Modern research activities as well as the training of qualified specialists at university are impossible without the integration into the international scientific community and involvement of the Center staff and the active youth from undergraduate and graduate students in international research projects. In 2005 within the framework of the INTAS Infrastructure Action project the university was awarded a grant together with the University of Hamburg and Alfred Wegener Institute for Polar and Marine Research (Germany). The grant was received for «Developing and maintenance of the observational network of the Subarctic Scientific Center as the base for educational and scientific activity in environmental studies in Western Siberia» and used for purchasing an automated soil-climate station of the international standard that was installed on the territory of the Bovanenkovo gas field (the Yamal Peninsula). The main measurement parameters are air temperature and humidity, wind direction and speed, pressure and actinometric data including solar radiation, as well as long-wave radiation, precipitation rate and snow cover thickness in winter. The soil module involves soil temperature and soil moisture measurement in the main lithological horizons of the layer of seasonal thawing (7 horizons).

The complex structure of the cryolithozone in the north of Western Siberia provides researchers with not only practical problems of assessing and forecasting the state of permafrost, but also with fundamental questions about the origin of a surprising phenomenon — massive ice that is most widespread on the Yamal Peninsula. Since 2009 the Center employees have been participating in the project "Subsurface ice as a habitat for microorganisms" within the framework of the grant of the Russian Foundation for Basic Research (RFBR). In order to solve the task set we propose a creative approach, and that is to study the life of microorganisms directly in their habitat — subsurface ices of a different genesis – using methods of optical and electron microscopy.

The work of the Subarctic Scientific Center not only improves the quality of education, but also promotes the development of cooperation between Russian scientists and international scientific community in solving the fundamental problems of the modern world, in particular, understanding the trends of global climate change in the "CLIMATE-CRYOSPHERE" system.

In February of 2005 an applied institute (Research Institute for Cryogenic Resources) was created on the base of the department of Earth Cryology.

The main purpose of the Research Institute is the development of a resource approach in Earth cryology, and the realization of an innovative potential of promising scientific developments and advanced forms of integration of universities, specialized research institutions, as well as project and production organizations that solve practical problems related to various aspects of cryology as a science and a field of activity.

The main scientific fields of the institute are cryoecological resource studies and geocryobiology, cryotechnology, physics, chemistry and mechanics of cryogenetic systems, as well as geoecological monitoring in the cryolithozone. The institute studies the mechanisms of self-regulation and the limit states of cryogenetic systems, the impact of cryogenic factors on the dynamics of renewable resources, and the patterns of variability of the potential of the Earth cryosphere. It also develops and enhances the technical means and ways of rational use of renewable cryogenic resources, the technologies of improving the building properties of grounds and construction for ensuring the reliability of geotechnical systems in the cryolithozone, as well as the systems of background cryosphere and geoecological monitoring at the industrial and civilian facilities.

The institute operates in close cooperation with specialized units of Gazprom OJSC, the RAS divisions, specialized enterprises, as well as organizations and departments of universities.

At the time of creation of the institute it numbered seven scientific research laboratories: for cryoecological resource studies; background cryosphere monitoring; cryogeotechnologies; engineering ice studies; geoecological monitoring in the cryolithozone; geocryobiology; and biogeochemistry of permafrost soils. Moreover, there are also the analytical laboratory of physics, chemistry and mechanics of frozen grounds that was certified in 2006, and the laboratory of the cryolithozone microbiology. The institute is equipped with three large climatic chambers, special equipment and apparatuses for conducting thermophysical and geothermal research, equipment for conducting field geocryological studies, as well as equipment for sampling, studying and determining the characteristics of grounds in the field.

Since 2006 until present comprehensive studies have been conducted as part of the research at background cryosphere monitoring sites located in the areas of Khanty-Mansiysk, Surgut, Kogalym, Noyabrsk, Priozerny, Pravaya Khetta, Kharasavey, Tyurin-to, Zapadno-Tarkosalinskoe and Bovanenkovo fields, as well as in the Tyumen area.

In 2006 the research was conducted to study the particularities of adverse cryogenic processes development along the route of the gas main at the 0 - 115 km section and at the Baydaratskaya pump station site, and also to forecast the impact of technogenic loads on the geological environment state at the 1B and 2B sites of the Zapolyarnoe gas condensate field.

In resources studies a special place is occupied by the investigations of the Research Institute for general and applied cryology that are devoted to the impact on the speed of reparative processes of living organisms and biomedical characteristics of the ancient self-sustainable microbiota of the cryolithozone.

Experiments proved that the local short-term impact of the temperature factor can systematically influence and intentionally modulate the work of various physiological systems of an organism — immune, nerve, muscle, digestive and thermoregulatory systems. Local exposure to cold can have a positive effect on the speed of reparative processes.

One of the fields of studying the cryolithozone microbiota is researching the impact of cryogenic microorganisms collected from permafrost in Yakutia on the speed of reparative processes of wounds and on cytogenetic abnormalities in cells. Cryogenic microorganisms help to speed up the processes of wound healing and epithelialization.

Biological testing of the obtained species has recently started. This testing is the basis for the development of biotechnological technologies of obtaining the pharmacological substance with immune-modulating and geroprotective characteristics.

The focus and volume of the work in progress, as well as the provision of scientific research suggest that Tyumen State Oil and Gas University in conjunction with the Institute of Earth Cryosphere of SB RAS are one of the most active researchers in the field of cryology.

Analyzing Climate Change Indicators in the Himalayan Region from Satellite Observations

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Keywords: Climate change, Himalaya, MODIS, remote sensing, snow

The remote sensing snow cover data from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite from 2000 to 2007 have been used to analyze some climate change indicators in the Himalayan region. In particular, the variability in the fractional snow coverage with elevations, its temporal variability (8-day, monthly and seasonal) and its variation trends have been analyzed. The snow product used in this study is the maximum snow extent, which comes in 8-day temporal and 500 * 500 m spatial resolutions. The results showed a tremendous potential of the MODIS snow product for studying the spatial and temporal variability of snow as well as in the study of climate change impact in large and inaccessible regions like the Himalayas. This study also showed that the variation of the snow coverage with elevation is not always monotonous. It showed that in the studied area in winter the elevation zone 3000-4000 m receives more snow coverage than higher elevation zones, 4000-5000 and 5000-6000, and similarly the elevation zone 6000-7000 m receives more snow coverage than the elevation zone above 7000 m. This was consistently observed in all 8 years. Some important trends on the alternation of the snow cover extent are also observed. In particular, the decreasing trend in January and increasing trend in March for some elevation zones may be interpreted as a signal of a possible seasonal shift in the maximum snowfall from mid-winter towards late-winter or early spring. However, it requires more years of data to verify this conclusion.

The HOLOANTAR project: Holocene environmental change in the Maritime Antarctic. Interactions between permafrost and the lacustrine environment

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The objective of this abstract is to present the HOLOANTAR project, a multidisciplinary research funded by the Portuguese Government that has been recently approved. The project integrates 16 researchers from different international institutions (Portugal, Spain, Brazil and Uruguay) and will be developed between 2012 and 2015. The main purpose of HOLOANTAR is to infer the palaeoenvironmental evolution and associated climate variability occurred over the last millennia in ice-free areas of the Maritime Antarctica based on the study of lake sediments.

The South Shetland Islands (SSI) are located in the northwestern tip of the Antarctic Peninsula, one of the Earth's regions that have experienced a stronger warming signal during the second half of the 20th century. In the ice-free areas of this archipelago the terrestrial ecosystem is supported by permafrost, though its reaction to climate change is still poorly known. However, in the recent years a very important effort took place to monitor the thermal state and characteristics of permafrost in order to study its response to the recent warming trend. Many international teams are involved on several of these long-term monitoring projects, but HOLOANTAR, in addition, pretends to offer a new integrated approach aiming to bridge the gap between contemporary and past changes in permafrost environments.

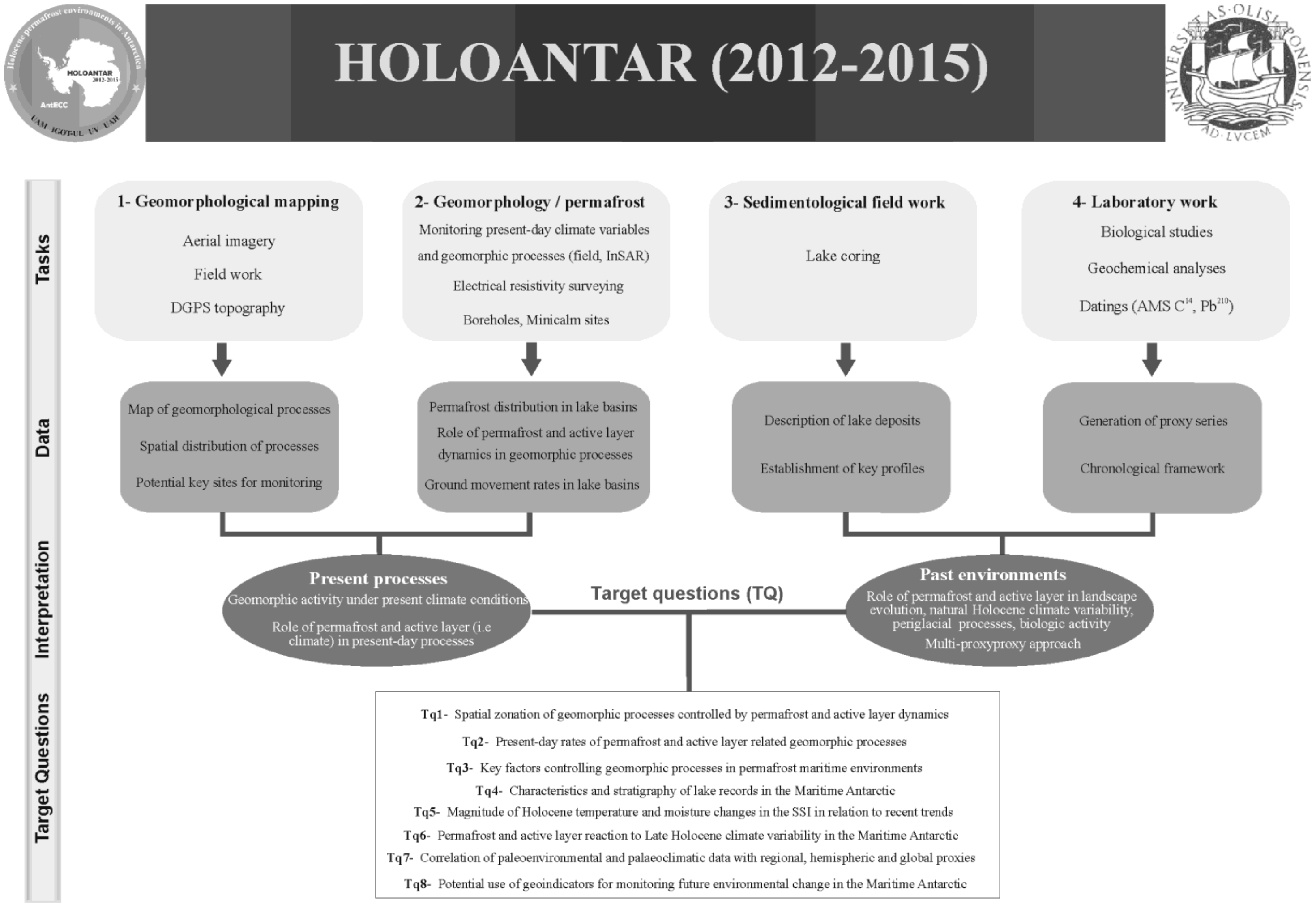
HOLOANTAR project is based on two main hypotheses:

A multi-proxy analysis of lake sediments will allow reconstructing the palaeoecological evolution in the Maritime Antarctic and the role played in it by permafrost and active layer dynamics,

The detection of activity rates, spatial patterns and geographical controls of contemporary key-geomorphic processes and permafrost distribution, will allow defining their limiting climatic conditions that will be used to interpret the sedimentary record.

This approach is innovative since it will focus on both present and past geomorphodynamics as keys for understanding the landscape evolution. In Byers Peninsula (Livingston), the largest ice-free area in the South Shetland Islands, where the environment is dominated by permafrost and active layer dynamics, climate variability should have induced modifications on the erosion rates at the slopes, mass movements, active layer thickness, biological activity, etc. In a context of fast rate of current change in mean annual air temperatures, it is possible that by studying similar features at different altitudes, different movement rates and an altitudinal/climatic boundary for their activity may be found, thus providing important applications for the palaeoenvironmental reconstruction. We will approach the two leading hypothesis in Byers environment by executing five main tasks:

Task 1 - Geomorphological mapping
Task 2 - Geomorphological monitoring and permafrost distribution
Task 3 - Sedimentological field work
Task 4 - Laboratory analyses
Task 5 - Palaeoenvironmental reconstruction



Tq1- Spatial zonation of geomorphic processes controlled by permafrost and active layer dynamics
Tq2- Present-day rates of permafrost and active layer related geomorphic processes
Tq3- Key factors controlling geomorphic processes in permafrost maritime environments
Tq4- Characteristics and stratigraphy of lake records in the Maritime Antarctic
Tq5- Magnitude of Holocene temperature and moisture changes in the SSI in relation to recent trends
Tq6- Permafrost and active layer reaction to Late Holocene climate variability in the Maritime Antarctic
Tq7- Correlation of paleoenvironmental and palaeoclimatic data with regional, hemispheric and global proxies
Tq8- Potential use of geoindicators for monitoring future environmental change in the Maritime Antarctic

Figure 1. Sketch of the HOLOANTAR project.

These tasks will be supported by state-of-the-art techniques both in the field and laboratory. The main purpose is to produce high resolution proxy data from lake sediments that will allow reconstructing past landscape changes and climate variability. By comparison with present-day geomorphological processes, we shall derive the role played by permafrost and active layer dynamics in the last millennia controlling the environmental evolution in the area. Results will be published in international journals and widely spread in national and international conferences. Several outreach activities will be conducted in order to collaborate in making aware the people of the uniqueness and the necessity to preserve and protect the Antarctic environment.

Acknowledgements

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Mid To Late Holocene Winter Warming In The Laptev Sea Region (Russian Arctic): Evidence From Ice Wedges

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Introduction

The Arctic as key region for the global climate system is more affected by ongoing climate change than most other regions and has experienced a strong warming in the recent decades. A better understanding and assessment of recent Arctic climate and environmental dynamics from a longer scale perspective require detailed information on past changes and their causes from climate archives. Of particular interest are climate variations in the Mid to Late Holocene, characterized by relative stable boundary conditions of the climate system and by a negligible anthropogenic influence in the preindustrial period. Studying these changes provides insight into the natural climate variability of present interglacial conditions.

In the wide tundra areas of Arctic lowlands ground ice contained in the permafrost sequences, in particular ice wedges, serves as valuable climate archive. Ice wedges are formed in polygonal patterns by the repeated (± annual) filling of frost-cracks by snow melt and can be studied by means of stable water isotopes. Their isotopic composition is indicative of past winter climate conditions even though also genetic aspects, i.e. melting and refreezing, have to be taken into account. Whereas mainly low-resolution information on Late Quaternary paleoclimate has been obtained from ice wedges so far, it has recently been shown for Alaska [*Meyer et al., 2010*] and Northeast Siberia [*Opel et al., 2011*] that ice wedges have the potential to provide up to centennial-scale climate information.

Here, we report results from three study sites in the Laptev Sea region in the Russian Arctic. We present stable water isotope and ^{14}C data derived from Holocene ice wedges, their paleoclimatic interpretation and put them into the context of the Mid to Late Holocene climate history of the Arctic.

Study Region

This study was carried out at three study sites in the coastal lowlands of the Laptev Sea Region in the Siberian Arctic: (1) on the Oyogos Yar (OY) coast of the Dmitrii Laptev Strait (72.7°N, 143.5°E) in a huge Alas in 2007 (2) on Muostakh (MUO) Island (71.4°N, 130.0°E) on the top of the Ice Complex in 2011 and (3) in the Central Lena Delta (LD; around 72.5°N, 126.5°E) on the first Lena River terrace in 2005 and 2010.

Material and Methods

In total, we studied 43 ice wedges, 8 on the Oyogos Yar coast, 6 on Muostakh Island and 29 in the central Lena Delta. The studied ice wedges were sampled by chain saw in horizontal profiles by cutting thin slices every about 10 (medium resolution) or 2 to 3 cm (high resolution), resulting in up to 100 samples per ice-wedge profile. The samples were cleaned, melted and bottled in the field. Additionally we cut blocks from the ice wedges. These blocks were transported in frozen state to Germany where they were sub-sampled in very high resolution (1 cm) in a cold lab leading to up to 200 samples per ice-wedge profile.

Organic material enclosed in the samples (plant remains, lemming coprolites) was carefully separated and collected for age determination (^{14}C AMS).

The ice-wedge samples were analyzed for their stable water isotope ratios by equilibration technique using a Finnigan MAT Delta-S mass spectrometer in the stable-isotope laboratory at the Alfred Wegener Institute for Polar and Marine Research Potsdam (Germany).

Organic material of selected ice-wedge samples was radiocarbon-dated using the AMS facilities at the Leibniz Laboratory for Radiometric Dating and Stable Isotope Research (Kiel University) as well as at the University of Cologne (both in Germany).

Results and Discussion

The results of radiocarbon dating of organic matter from the ice-wedge samples obtained so far show that the studied ice wedges are of Holocene origin and are mainly formed in the Mid to Late Holocene, i.e. between about 6 kyr BP and today. This indicates syngenetic growth associated with sediment accumulation. In general, ice wedge growth was particularly active in the past 2000 years.

The co-isotopic relationships of the ice wedges are generally close to the Global Meteoric Water Line pointing to no significant isotopic changes during snow melt and after ice-wedge formation and, therefore, to a good suitability for palaeoclimate studies.

The studied ice wedges exhibit a broad range in their stable-isotope composition with δ^{18}O values between about -27‰ and -20‰ and d-excess values ($d= \delta D-8*\delta^{18}O$) between about 5‰ and 11‰ indicating non-stable climate conditions.

The ice wedges show a marked variability in their stable-isotope composition reflecting highly variable winter temperature conditions and moisture transport patterns. However, a part of the variability might also be caused by irregularities during ice wedge formation. Generally, the lowest δ^{18}O values are observed in the older and the highest δ^{18}O values in the younger ice-wedge parts, indicating a general winter warming trend in the Laptev Sea region over the Mid and Late Holocene with superimposed short-term climate fluctuations (Figure 1).

The by far highest $\delta^{18}O$ values are observed in the most recent ice-wedge samples (Figure 1). This reflects the culmination of the long-term warming trend in the ongoing strong Arctic warming and is accompanied by marked changes in the moisture generation and transport patterns as indicated by the low d-excess values in these ice-wedge samples.

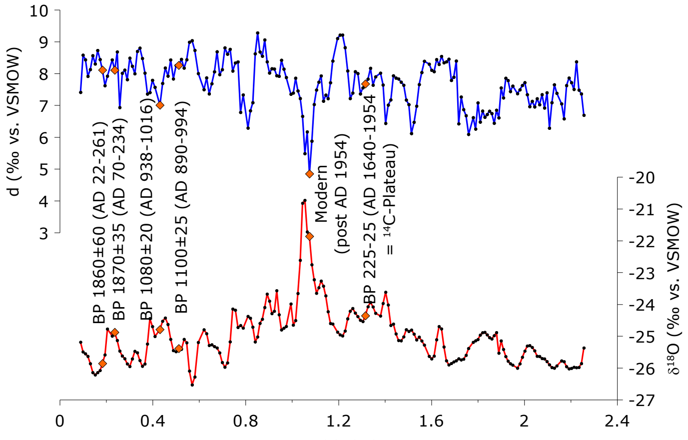

Figure 1. $\delta^{18}O$ (bottom) and d excess (top) data of the ice wedge Oy7-11 IW7 as example for high-resolution ice-wedge profiles. Large dots indicate ^{14}C-dated samples with their ages.

The general warming trend observed in our data (even though with regional differences between the study sites) is in contradiction to other Arctic temperature records that show a long-term cooling over the Late Holocene, e.g. the compilation of Kaufman et al. [*2009*]. However, this temperature reconstruction and many other Arctic climate records are mainly based on summer temperature indicators and reflect probably the decreasing summer insolation.

However, our ice-wedge based reverse winter-temperature trend in the Laptev Sea region might be related to an increasing trend in winter insolation and show that there is a strong need for a more seasonal view and that the study of ice wedges can contribute valuable findings required for a better understanding of the Mid to late Holocene climate dynamics of the Arctic.

The relation of stable-isotope values from ice wedges to that of fresh atmospheric precipitation in the Laptev Sea region is the topic of a paper by Meyer and co-authors.

Conclusions

This study reveals the potential of ice wedges to serve as mid-resolution (centennial-scale) archives of winter climate conditions in permafrost regions.

Our ice-wedge data show a Mid to Late Holocene winter warming in the Laptev Sea region (Northeast Siberian Arctic) which is in contrast to the long-term cooling known for the Northern Hemisphere and the Arctic.

The by far highest winter temperatures in the recent decades reflect the ongoing strong Arctic warming and are accompanied by variations in the moisture generation and transport patterns.

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Statistical Analysis of Simultaneous Start of Thermokarst caused by Permafrost Degradation

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Introduction

The significant attention is attended to exogenous geological hazards investigation nowadays. Also the influence of geohazards to the elements at risk is considered in up-to date researches. Thermokarst is specific for the East Siberia (Russia) region, also to south part of it.

The south part of East Siberia region is characterized with rather slow velocities of the permafrost processes. Velocities of the permafrost processes grow up caused by disturbance of the land cover, warming ground up and environment equilibrium disturbance.

The main reason of the environment equilibrium disturbance is building of the significant line structures, for examples oil and gas pipelines. Destruction of the nature land cover, is one of the main reasons of permafrost degradation and start of thermokarst.

Start of the thermokarst can be avalanche-like for the local parts of pipelines. Also flooding and other concomitant processes can accelerate thermokarst.

Modeling of the avalanche-like thermokarst is very important for thermokarst impact to the pipeline.

The aim of this work is to estimate the possibility of using of the mathematical model of landscape pattern of themokarst lake plains [*Viktorov 1995, 2005*] for non-stationary case of avalanche-like start of thermokarst.

Methods and Materials

The materials of this work were scanner optic autumn airborne images (0,2 m/pix). Images were made since one year after pipeline was built.

The interpretation of the morphologically homogeneous section of the pipeline was done. The length of interpretation section was 4,5 km, the width was 50 m. The round shape lakes and depressions were determined, these depressions are considered as thermokarst.

This section has linear morphologically homogeneity. The pipeline has same structure elements along the section (pipeline road, power line and pipeline). So section has no 2D morphologically homogeneity, but has 1D homogeneity. Numerous thermokarts lakes were noticed around chosen section in not disturbed conditions.

Mathematical model of landscape pattern of themokarst lake plains is based on several hypotheses [*Viktorov 1995, 2005*]:

- the appearance of primary depressions is stochastic process. The appearance of primary depressions at the disjoints time intervals and parcel is independent;

- the probability of appearance alone depression at the sample parcel depends only on its own area (Δs) and time interval (Δt). And this probability is much more then probability of appearance several depressions, that is:

$$p_1 = \gamma \Delta s \Delta t + \hat{\imath}\,(\Delta s \Delta t) \qquad (1)$$

$$p_k = \hat{\imath}\,(\Delta s \Delta t) \quad k = 2{,}3... \qquad (2)$$

expansion of the depressions (caused by thermo-abrasion) are independent from each other. This expansion is directly proportional for heat reserve in the lake and inversely for side surface of the lake.

There was shown [*Viktorov 1995, 2005*] that sizes (diameters, areas) of the thermokarst depressions would have lognormal distribution (in condition of synchronous start of the process).

So if we can show that sizes of the thermokarst depressions (in condition of synchronous start of the process) have lognormal distribution, we can prove justice of the model hypothesis for the case of anthropogenic start of the process.

Results

At the pipeline section with 4,5 km length and 50 m width was recognized 600 primary thermokarst depressions. Average depression area was 11,2 m^2, minimum area was 0,11 m^2, maximum area was 145,8 m^2.

There was done comparing empirical distribution with theoretical lognormal one. Critical value of chi-square criteria for 0,95 significance level and 21 degrees of freedom is 32,67 (StatSoft). Empirical value of the criteria was 31.81 (fig. 1).

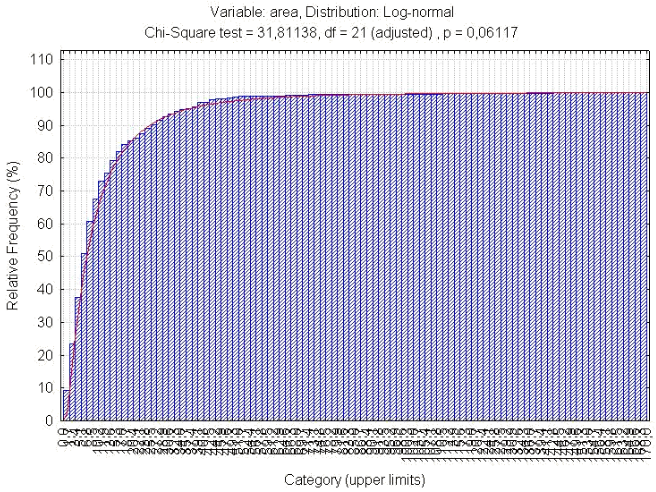

Figure 1. Theoretical and empirical distributions.
So distribution of thermokarst depression areas is lognormal with 0,95 significance level.

Discussion

There were several difficulties while airborne images interpretation:

- detection of morphologically homogenous sections;
- detection of minimum size of thermokarst depression;
- discrimination between thermokarst and overwetting process.

It is possible to solve these problems using images of different observation periods.

Conclusion

There was proved that primary thermokarst depression areas have lognormal distribution. Also this conclusion shows that determined depressions have thermokarst genesis.

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Rock Glaciers in the Altai and their Present State

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Rock glaciers are quite widespread in the Altai but remain poorly investigated. Some evidence of their geography and formation conditions can be found in few publications [*Agatova 2002; Zamoruev 1963, 1981; Ivanovsky 1977, etc*.].

In the course of the reported study, rock glaciers have been detected and assessed in terms of their present state and thermokarst processes, motion of their fronts and surfaces, as well as the temperature patterns of their upper part (to the permafrost table).

Rock glaciers are of two main types distinguished according to genetic and morphological features: rock glaciers proper (glacial rock glaciers) and rock flows (nonglacial or periglacial rock glaciers). The former consist of ice-cemented coarse material which can move by itself; they may be linked with present ice glaciers existing at their heads. Rock flows involve talus cemented with congelation ice and are likewise capable of independent motion. In this study the two varieties of rock glaciers are termed jointly glacial-periglacial rock flows.

Glacial-periglacial rock flows were identified using standard remote sensing and field methods of glacio-morphological analysis and mapping. Their principal diagnostic features include: convex flow morphology, U-shaped in map view; a frontal scarp with a debris train at the back and with pressure and impact ridges at the base; flow terraces that produce a characteristic trough-ridge topography; multiple rills and springs in the front part and marginal channels between the bed slope and the side scarp (in some rock glaciers and armored glaciers).

The discovered rock glaciers were described according to several parameters: location; type; heights of fronts; activity; slope direction; size (length, width, and surface area); available published evidence. These data made basis for a GIS map of rock glaciers of the Altai and the respective catalog. The map was compiled using LANDSAT images (28 and 14 m/pixel) of the whole territory and ALOS images (10 and 2.5 m/pixel) of selected areas, as well as published evidence and data collected by our team in the field.

The LANDSAT images shot at different times and in different seasons allow cross checking the flows distinguished in different conditions of vegetation, illumination, and geomorphic expression (the snow cover highlights landforms in winter images).

Of special interest is the use of a digital elevation model (DEM) for detecting glacial-periglacial rock flows. The modeling was by means of minimum curvature interpolation of ALOS stereopairs with a stepsize of 10 m. DEM-derived contour lines at every 5 m made the detection of rock glaciers more reliable. With this approach, the objects, including river networks, can be mapped in 3D to obtain high-resolution ortho-transformed satellite images.

Glacial-periglacial rock flows are especially abundant in the South Chuya, North Chuya, and Katun ranges of the Central Altai, in the South Altai range, and in the Ukok plateau (southwestern Altai), where 1210 flows have been detected, with a total area more than 398 square kilometers. Rock glaciers show a slope-direction dependence because of the predominantly W—E strike of the ranges and mostly western and southwestern wind directions. The greatest number of rock glaciers occur in northern, northwestern, and northeastern slopes (almost 70%), which are more favorable for the existence of permafrost, but they are few in southern, southwestern, and southeastern slopes.

The types of glacial-periglacial rock flows likewise depend on slope direction. Namely, glacial rock glaciers form mainly on northern and northeastern (shadowed and leeward) slopes while more rock flows appear on northern and northwestern (shadowed and windward) slopes. This dissimilarity is evidence of their origin and evolution in different conditions. Note also that rock flows are farther away from large modern glaciation centers (1200 m) than rock glaciers. Both types of glacial-periglacial rock flows exist at elevations between 2000 and 2600 m above sealevel.

Since 2003 the motion of rock glaciers has been monitored instrumentally (with a geodetic GPS of cm-scale accuracy and a tachymeter) in the Akkol River valley (South Chuya Range) at 2550 m asl (two flows) and at 2300 m asl (three flows). Over the period 2003 through 2011, the marks on the surface of the monitored flows moved 0.32 to 1.56 m downslope at a mean rate of 3-7 cm/yr. For the past two years, the flows have moved 0.9-2.1 cm/yr faster. The reason is that, besides moving downslope by themselves, they experience translation pressure from younger generations of flows up the slope, which also causes their lateral dispersal.

Continuous temperature monitoring has been run since 2003 in Akkol and since 2006 in Multa, with automatic loggers (sampling at every 1 hour) in different landscape-climate high-latitude conditions, on the surfaces and in vicinities of rock glaciers. Air temperatures have been measured in the Multa Valley (Katun Range), at 2 m above the ground surface at elevations from 2150 to 2350 m. Monitoring in the Akkol Valley (South Chuya Range) is both of air and ground temperatures, at 2 m above and below the ground surface, respectively, within the altitude interval 2300-2570 m above sealevel.

Acknowledgements

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Effects of Landscape Conditions on Active Layer Dynamics: Field Data from the Igarka Region

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Introduction

The interplay of landscape factors and depths to the shallow permafrost table is an important issue of permafrost studies. Relationships among the nonuniform patterns of plant communities, landforms (including nanorelief), and the most changeable seasonally thawing upper layer of frozen ground were studied in July 2011 by measuring the active layer thickness in different landscapes near Igarka town. The effects the permafrost experiences from vegetation cover and other landscape agents vary over the area due to considerable diversity in plant taxa and heights, as well as in terrain patterns. When studied simultaneously, vegetation, terrain, thaw depth, and climate parameters become better understood in their linkage and interaction.

In the course of this study, seven sites have been distinguished that differ in landscape conditions, depths to the permafrost table, temperature and moisture patterns, as well as in anthropogenic loads.

Methods

The study included description of all main forms of nanorelief in the area (polygons of different levels and vegetation patterns, cracks, and knobs of any origin) and the respective plant communities at each selected site.

The depths to the permafrost table were measured, to an accuracy of 1 cm, by means of probing and trenching. The thaw depths were measured at least three times at each site and at least twice at each point within the sites, in order to ensure the maximum accuracy. The sampling interval corresponded to the scale of mesorelief and vegetation studies.

Study area

The study area is located in the vicinity of Igarka, within discontinuous permafrost where thaw depths vary from 0.5-0.7 m (in peat soils) to 1.5-1.7 m (in mineral soils).

The climate in the area is subarctic, with a mean annual air temperature of -9.5°C and a mean annual precipitation of 500 mm/yr.

Most of measurements were performed on terrace II above the floodplain (deposited in Karga time), in tundra, forest-tundra, and northern taiga landscape systems.

Results and Discussion

The descriptions of seven landscape sites distinguished in the course of the study (their microrelief and vegetation) are synthesized in Table 1.

Table 1. Landscape sites

No.	Description
I	Northern taiga: plain surface, with a few minor streams and knobs of biogenic origin; birch-larch forest
II	Well drained knobby surface; birch-larch forest
III	Light larch forest upon a knobby surface
IV	Hummocky-knobby surface with heaves and thermokarst sinkholes; shrub-subshrub tundra
V	Frost heave with subshrub-sedge-moss communities
VI	Hummocky-undulated surface, with numerous gullies and tussocks: a former birch-larch forest after a fire; many fallen and partly burnt trees; grass-sedge communities
VII	Hummocky-knobby subshrub tundra after a fire

See below the photographs of all landscape systems listed in Table 1 (Figs. 1-5).

Fig. 1. Landscape I.

Fig. 2. Landscape IV, Fringed with Landscape II.

Fig.3. Landscape VII, Fringed with Landscape III.

Fig.4. Landscape VI.

Fig. 5. Landscape V.

The thaw depths (active layer thicknesses) were measured at each landscape site (Table 2).

Table 2. Active layer thicknesses at different landscape sites

Landscape site No.	I	II	III	IV	V	VI	VII
Average thaw depth, cm	-	-	93	35	32	77	34
thaw Maximum thaw depth, cm	-	-	150	46	58	138	44

Thus, measurements on 02.07.2011 failed to reach the permafrost table in northern taiga (it lies as deep as >217 cm). The permafrost thickness has increased at the site, in the Karga terrace, as the former forest burned out in a fire in 2004 (according to eyewitness evidence) and the area has been gradually re-vegetated with grass-sedge communities. Unlike the parameters of preserved birch-larch forest (forest tundra) where the permafrost table was not reached (>160 cm), the average active layer thickness measured on 07.07.2011 was 77 cm. Of course, the fire perturbed strongly the ground temperature regime. Taking into account the steady air temperature and summer moisture patterns, one may infer that this is the lack of forest vegetation, which also influences the thickness and density of snow, that is responsible for the thickening of permafrost and the respective active layer thinning.

In southern tundra, within a frost heave buried under peat, the largest thaw depth was 2 m (drilling on 07.07.2011) near the heave base occupied by subshrub communities. The site was highly moistened as meteoric water flew along the permafrost surface (which acts as a confining bed) from the heave top to its bottom. The shallowest thaw depth (19 cm) was measured near the top of the heave, in areas of moss-lichen vegetation.

In general, plant communities cause direct and indirect influence on the ground temperature patterns. In the former case, this is heat insulation of soil by moss, lichen, forest litter, and sod covers. The indirect effects include shadow, snow cover, and moisture of the thaw surface.

Conclusions

The active layer thickness is controlled by climate parameters and their interplay with vegetation and near-surface soils. No direct dependence on vegetation and topography has been revealed during the observation period.

Acknowledgments

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The Late Pleistocene Cryolithopaedogenesis and Grounds of the Central East European Plain

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Abstract

Gray forest and black soils of the Central East European Plain were studied. Patterned-fractured systems of various generations and shapes were formed in soil-forming grounds in the Later-Pleistocene age. They occurred at the modern day surface in the form of microrelief influencing the structure of modern and buried soil profiles. The soil formation in the Holocene age imposed on these strata and inherited and (or) transformed some of the relict indicators of periglacial soil formation and cryolithopaedogenesis. Multiple and various relict cryogenic phenomena differentiate the Holocene soil cover.

Keywords: buried blocks and intrablocks; cryolithopaedogenesis; paleocryogenesis; soil cover structure; wedge thickening.

The problem of soil and environment interaction is one of the most important ones in the modern soil science. It is especially important in the investigations concerning the study of the soil structure and the soil cover structure. Later Pleistocene loess-like clayey silts are the subject of the soil scientists' research as the soil-forming grounds for the Holocene soils. Multiple relicts of paleocryolithogenesis and periglacial paedogenesis attract a specific interest to clayey silts. According to our materials, they influence the modern (Holocene) soil formation process significantly. We think that various uneven-aged relict paleocryogenic indicators and phenomena are most informative, and relict patterned-vein structures among them are the ones influencing the Holocene soil formation process most noticeably.

The results of research into gray forest soils and black soils in the central East European Plain are reported. Black soils were studied in the Tula (key site *"Venev"*) and the Voronezh Regions (wildlife reserve *"Kamennaya step"*). Gray forest soils were studied in Moscow Region (key site *"Pushchino"*).

The studies on various types of soils in large sections-trenches showed that the soil-forming grounds and the soils buried in them represent cyclically built strata formed under the impact of lithogenesis, cryogenesis and paedogenesis. The paleocryogenesis indicators in these strata most frequently include cryoturbations, solifluction ground flow and frost cracks of various generations, including inhomogeneities in the spatial distribution of wedges (their thickening) identified by us [*Ovchinnikov 2009, Alifanov et al. 2010*]. Patterns formed by *wedge thickenings* with the height of 1-1.5 m have slightly smaller dimensions (microrelief with block dimensions of 15-20 m), as compared to patterns with pseudomorphs on ice veins or initially ground veins with the height of 2-3 m that form the microrelief with the dimensions of blocks equaling 25-40 m [*Alifanov 1995*].

Patterns with pseudomorphs on ice vein, or with 2-3 m high ground veins were formed in the center of the Later Pleistocene periglacial zone: pseudomorphs on ice veins were studied in the north of the Central Russian Upland (Moscow Region, 54.8323 N, 37.6272 E), and ground veins - in the east of the Smolensk-Moscow Upland (Vladimirovo Region, 56.1780 N, 40.5077 E). Wedge thickening was formed in the south of this zone (wildlife reserve *"Kamennaya step"*, Voronezh Region, 51.0361 N, 40.7359 E). The climatic conditions were probably less severe here, frost cracking was not so deep, and more active frost ground weathering occurred in fracture intersection zones under the impact of freezing and thawing (see Fig. 1).

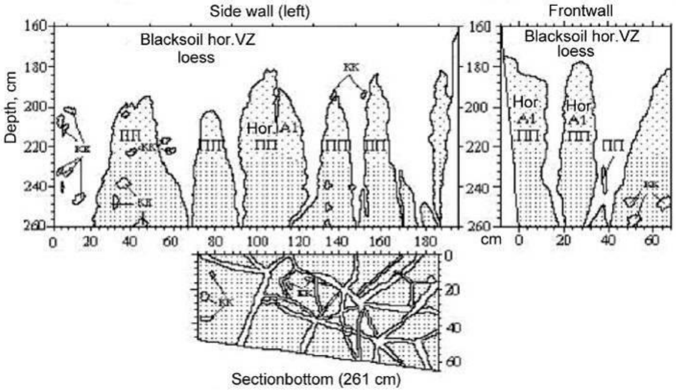

Figure 1. Diagram of wedge thickening in the black soil profile in the intrablock. Section 6-2005.
Wildlife reserve Kamennaya step, Voronezh Region

The microrelief formed by relict patterned structures on the modern day surface influences the formation of Holocene soil profiles significantly. The inhomogeneity of the genetic horizons structure is formed as a result of cryolithopaedogenesis: the depressions at the day surface formed above paleocryogenic fractures transform the soil morphology significantly. Genetic horizons can vary in thickness significantly and can even disappear from the soil profile; differentiation of physical and physical-chemical soil characteristics occurs above buried blocks and intrablocks. This causes the spatial inhomogeneity of the soil cover at the typical and the subtypical levels (see Fig. 2).

Small relict patterned structures are frequently observed in soil profiles in addition to relict patterned large structures (see Fig. 3). Their formation occurred in the process of burial of large patterned structures. The deposition of new material was evidently discontinuous. Each of the newly deposited layers existed at the day surface for some time and was processed by cryolithogenesis processes. The fact of existence of these layers at the day surface is confirmed by the presence of poorly expressed humus horizons in the leached black soil profile.

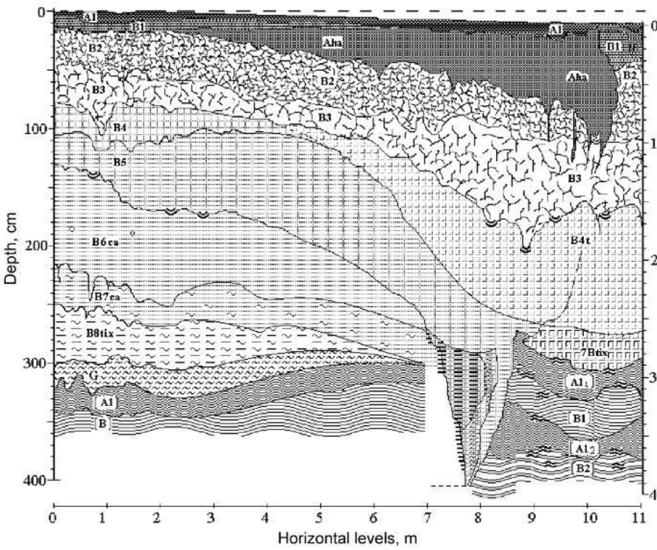

Figure 2. Diagram of the structure of gray forest soil profiles on various microrelief elements (block - section 1AG-2007 (on the left); intrablock – section 2AG-2007 (on the right).
Key site Pushchino. Moscow Region.

According to the latest data of the paleogeographers' group who studied large relict patterned structures for a long period of time, their formation occurred in the Yaroslav cryogenic stage at the end of the Later Pleistocene age, approximately 20-18 th. years ago [*Paleoclimates… 2009*]. Our preliminary studies of the age of these structures allow us to think that the earlier dating of the Yaroslav cryogenic stage suggested by this group (17-15 th. years ago) is more probable.

Acknowledgements

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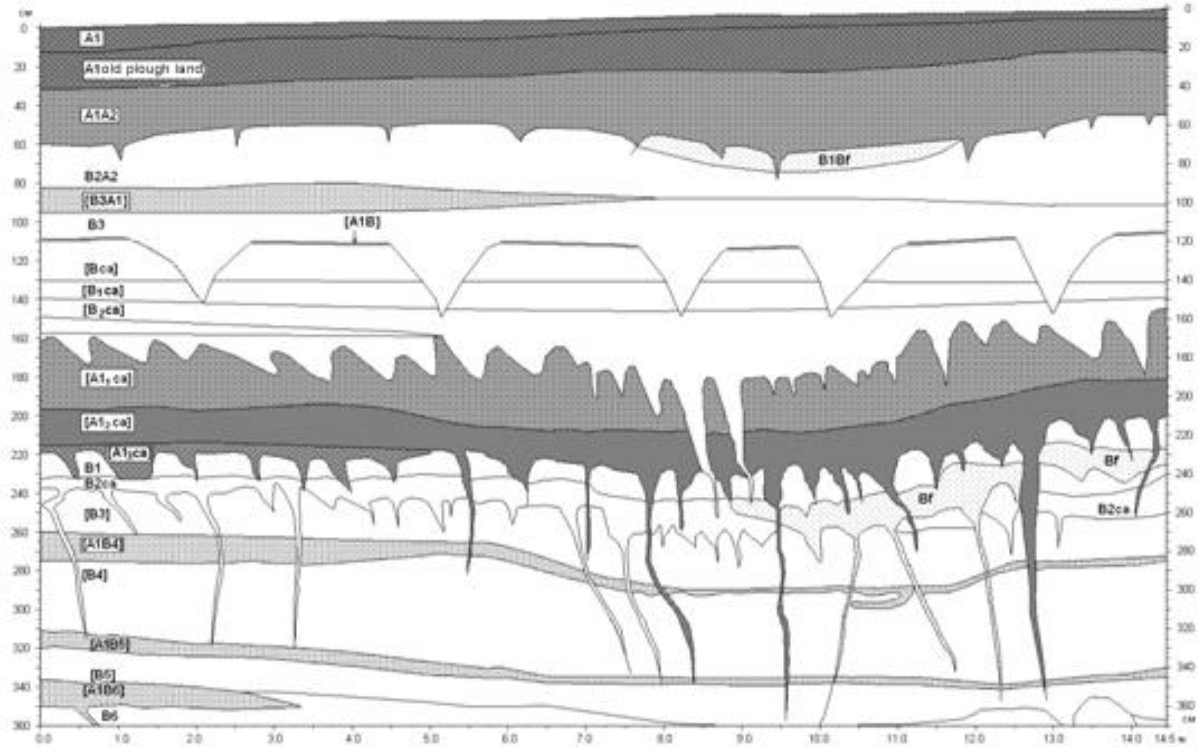

Figure 3. Diagram of the profile structure and paleocryogenic structures in the black soil northern subtypes. The section covers the block (on the left) and the intrablock (on the right). Section 1-2009. Key site Venev. Tula Region

The rate of subsea permafrost degradation in the 25 years following coastal erosion at Muostakh Island, Laptev Sea

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Submarine permafrost is usually created by the inundation of terrestrial permafrost by seawater. The inundation of permafrost follows coastal erosion or relative sea level rise. Low modern sea level rise rates in Siberia mean that coastal erosion is the main mechanism of formation of submarine permafrost. Coastal sections composed of fine-grained sediments that have high ground-ice contents, such as the long Yedoma coastline of eastern Siberia, are especially vulnerable to mechanical and thermal erosion processes [*Romanovskii et al., 2004*]. When such frozen soft sediments thaw and/or erode, then the state of the permafrost is determined by the transition from sub-aerial to submarine conditions, and the processes that accompany this transition. These include removal of the upper horizons of material, sediment dynamics along the beach and shore face profile, saltwater diffusion, changing thermal regime and sea ice dynamics. For example, driven by the influence of warm and salty seawater, permafrost begins to thaw once inundated due to thermal and chemical degradation. As a result, submarine permafrost degradation may be rapid near the coast, and shows a spatially variable dependence on this set of processes [*Overduin et al., 2007*].

Our objectives are to investigate changes in coastal geomorphology in combination with geophysical investigations of submarine permafrost distribution in the near-shore zone (< 10 m water depth), in order to infer which processes dominate permafrost degradation in this highly dynamic coastal setting.

Study Area

Muostakh Island (71°34' 30'' N, 130° 0' 40'' E) in the Central Laptev Sea is the most frequently studied location in East Siberia for coastal processes [*e.g. Grigoriev et al., 2009*]. Although observations exist from as far back as the 19th century, ongoing long-term observations of coastal change rates on the island started in the early 1950s. These observations are based on air- and space-borne imagery and yearly on-site measurements. Muostakh Island has local coastal retreat rates that are among the highest observed in eastern Siberia, with land-loss rates of up to 25 m per year [*Grigoriev et al., 2009*].

Off-shore permafrost was drilled along a transect of 6 boreholes north of Muostakh Island during field campaigns of the Mel'nikov Permafrost Institute Yakutsk [*Siberian Branch, Russian Academy of Sciences; Kunitsky, 1989*] in 1982 and 1983. Temperature and geochemical data are summarized by the same source, while granulometric, cryolithologic and mineralogic data are presented by Sladoga [*2004*]. These core data provide a baseline for the validation and interpretation of geophysical measurements data obtained in August 2011 by the joint Russian-German expedition Lena-Laptev 2011.

Materials and Methods

Coastal change rates and coring data

Coastline position was measured in situ at two key sites (NEC - northeastern coast; NC – Northern Cape) on the northern end of the island using benchmarks established on the coastal bluff from which distance to the upper cliff edge was recorded at irregular intervals between 1 and 14 years. Using on-site geodetic methods (theodolite), the upper and lower edge positions of the eroding cliff, its slopes and shape were measured. Historical bathymetric data was taken from available nautical (1964, 1:50 000) and topographic (1982, 1:100 000) maps of the island.

Sub-bottom electrical resistivity and bathymetry

Direct current electrical resistivity measurements in the submarine environment have been shown to be an effective means of detecting submarine permafrost based on the high contrast in electrical resistivity between highly conductive unfrozen, saline sediments and frozen, terrestrial. Geoelectric surveys of subsea permafrost were used to detect the depth of penetration of the salt front into the sediment, and to detect the upper surface of the ice-bonded permafrost within the sediment profile. An IRIS Syscal Pro™ system with 10 channels was used in August 2011 to record sub-bottom apparent electrical resistivity. We measured quasi-symmetric voltages around an electrical current injection dipole of 5 m size, using a floating electrode streamer towed behind a small boat. Electrode position, the injection current, measured electrode pair potentials and water depth were recorded continuously at intervals of at least 2 m as the streamer was towed. RES2DINV™ software was used to invert the apparent resistivity data via least-squares inversion for floating electrodes with a measured, fixed water layer resistivity.

Results

Coastal retreat and core data

The north end of Muostakh has retreated at rates of up to 25 m a^{-1} [*Grigoriev 2009*]. However, the rate has varied between -0.5 and -11.5 m a^{-1} at NEC and between -1.5 and -25.0 m a^{-1} at NC, depending on the observation period and time of measurement.

Kunitsky [*1989*] and Sladoga [*2004*] report on sediments drilled at 6 sites from the beach to a point 2.5 km from the coast during the springs of 1982 and 1983. Sediment temperatures measured after drilling lay between -12 and close to 0 °C [*Kunitsky 1989*], with coldest temperatures observed at the coastline. Sediment temperatures at 45 to 50 m depth, below the damping depth for seasonal fluctuations, were -9.2 °C at the beach, and -3.1 and -2.1 °C at positions 850 m and 2.5 km from the coast, respectively. The top of ice-bearing sediments was found at the ground surface (0 m b.s.l.) at the beach, and inclined downwards with increasing distance from the beach, reaching 16 m b.s.l. 2.5 km from the beach. Pore water salinities were observed in the ice-bearing permafrost only, where they were 0.2-2.4 ‰, with highest values from 0 to 10 m beneath the ground surface at the beach.

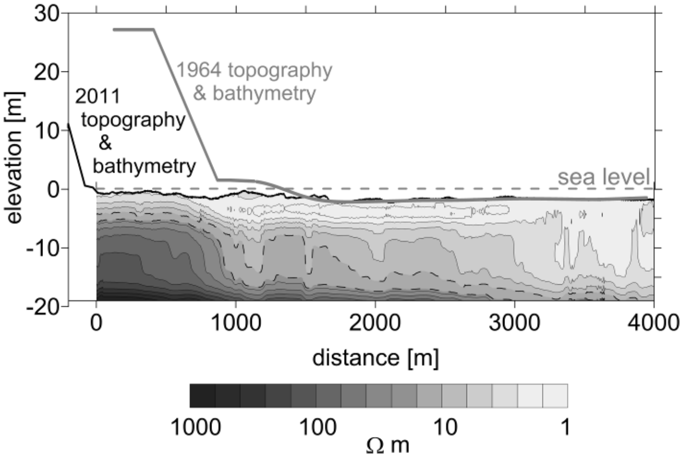

Figure 1. The bathymetry along in the drilling transect is shown for 1964 (gray) and 2011 (black) as well as the sediment electrical resistivity data from observations collected in 2011. The 10 and 20 Ωm isopleths are indicated with dashed lines. Vertical exaggeration is 42 times.

Electrical resistivity

Bathymetry along the resistivity profile lies between 1.6 and 3.8 m, increasing with distance from the shore. The modeled sub-bottom electrical resistivity from the sea bed to approximately 19 m b.s.l. lay between 1 and 1000 Ωm (Figure 1). Figure 1 also shows the coastal bluff positions and the bathymetries in 1964 and 2011. The coastal bluff has retreated almost 1 km along the measured resistivity profile, but crosses the profile at an acute angle. Higher resistivity sediment was found progressively deeper in the sediment column with increasing distance from the coast. The vertical resistivity distribution changes at about 1000 m along the profile, where the 10 and 20 Ωm isopleths descend from 5 and 7 m to 14 and 17 m over just 250 lateral meters. At the seaward end of the profile, the observed sediment column (down to 19 m b.s.l.) had resistivities of between 1 and 10 Ωm.

Discussion

NC is located on the cape, where the coastline is sharply curved. As a resulting, a wide range of angles of attack for waves impinging on the base of the coastal bluff are effective at removing material and causing thermo-abrasion. Rates measured here are thus not typical for larger stretches of coastline but the effect of local coastal morphology. NEC rates for the past 5 years are perhaps indicative of the coastal retreat rate and have varied between 7 and 12 m a^{-1}. The effect of this erosion is to remove the material above the water line and inundate the land surface. Over 1 km of the resistivity profile was inundated between 1964 and 2011 (Figure 1, 0 to about 1200 m), leading to warming and thawing of permafrost below sea level and to penetration of salt water into the sediment. These processes decrease the electrical resistivity of the sediment by increasing its liquid water content and the conductivity of its interstitial solution. Although Buor Khaya Bay is freshened by Lena River discharge, the brines that form below sea ice are probably the main cause of the latter. The downward inclination of the resistivity isopleths seaward is a result of the length of time of inundation: the longer the influences of warming and diffusion, the lower the resistivity and the lower the ice-bearing permafrost table. Overduin et al. (in press) showed ice contents increasing most between 10 and 20 Ωm; although there are differences in salinity, temperature and grain size between study sites, this resistivity range corresponds to the ice-bearing permafrost table observed at the 850 m and 2.5 km boreholes almost 30 years ago. Lowering of the subsea permafrost table at these positions over the past 30 years is probably too small to be resolved geoelectrically. The combination of on-site measurements of coastal change rates with observations of near-shore subsea permafrost by geophysical methods and drilling as performed at Muostakh Island highlights land-ocean-interaction processes in the arctic, and provides validation for the geophysical method.

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Application of Electromagnetic (EM) Resistivity Data for Near-surface Permafrost Mapping in a Pilot Study Area, Interior Alaska

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Introduction

Permafrost can develop in all types of geologic materials ranging from very fine clay to big boulders, and even in bedrock. The geophysical properties of the most geologic materials are altered by freezing, especially when the material contains pore water. For example, electrical resistivity of the geologic materials such as clay, silt, sand and gravel show a dramatic increase with decreasing below 0 °C temperature as their pore water freezes [*Hoekstra et al., 1975*]. The presence of ice in the frozen ground makes it more resistive to the flow of electric current compared to the unfrozen ground. In frozen state resistivity of silt, sand and gravel can be >10 times higher than their resistivity in unfrozen state [*Scott et al., 1990*]. This contrast in the electrical resistivity of geologic materials, in frozen and unfrozen conditions, makes electromagnetic (EM) resistivity method useful for permafrost mapping [*Hoekstra et al., 1975; Scott et al., 1990; Kellet et al., 2000*].

Study Area

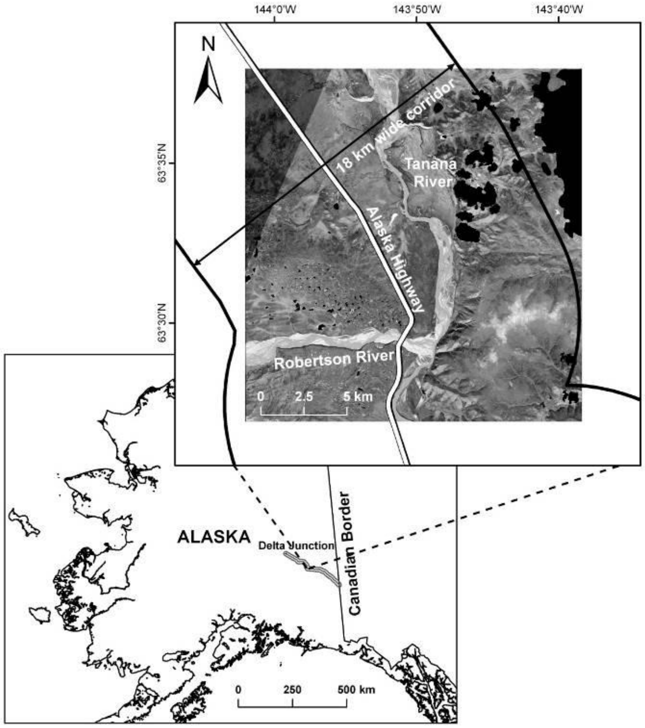

Figure 1. Study area. A small section (23 km long x 18 km wide) of the 320 km long Alaska Highway corridor that stretches from Delta Junction to the Canadian border (bottom). Top: a SPOT satellite scene acquired on 30 June 2003.

Purpose

The purpose of this study was to evaluate the potential of airborne EM resistivity data to map near-surface permafrost in the discontinuous permafrost setting of interior Alaska.

Objectives

Analyze EM resistivity data to determine the relationship between the recorded resistivity value and the surficial geologic units in different topographic settings.

Apply the above relationship along with frozen ground presence/absence data collected in the field to evaluate the potential of EM resistivity to map near-surface permafrost in interior Alaska.

Data

The EM resistivity data was acquired by Stevens Exploration Management Corp., Mining and Geological Consultants using a RESOLVE multi-coil multi-frequency EM system. The survey was performed from August 27, 2005 to January 16, 2006. Data was acquired at six different frequencies (400 Hz, 1800 Hz, 3300 Hz, 8200 Hz, 40000 Hz and 140000 Hz). For this study we used the resistivity data acquired at 140000 Hz only because we were interested in near-surface permafrost mapping and this frequency interacts with ground material nearest to the surface.

Methods

We sampled at 156 locations using a 1.6 m long hand-held soil augur in different geologic, topographic and vegetation settings in August 2008. Ground-sampled points were classified into seven categories based on topography and presence or absence of frozen ground. The seven ground-sampled point (GSP) classes were 1-low-lying frozen, 2-low-lying unfrozen, 3-north-facing slopes, 4-south-facing slopes, 6-low-lying possible frozen, 7-on ridge top, and 8-east-facing slopes. Mean resistivity values were extracted from raster resistivity maps for each GSP using a 100 m radius buffer zone.

Box plots of resistivity values for all the GSP classes were compared to find out how resistivity value discriminates between frozen and unfrozen ground in different topographic units.

Box plots of resistivity values of GSP classes were compared separately for each geologic unit in the study area to investigate the correlation between EM resistivity and frozen/unfrozen state of the ground in different geologic units.

Results

Resistivity Box-plot analysis of GSP classes

The median resistivity value and resistivity value distribution of the GSP classes were compared. For low-lying valleys, floodplain and outwash plain the median and resistivity value distributions were very similar for permafrost present and absent classes. However, for north-facing slopes and south facing slopes a significant difference in resistivity values was found. Slopes are generally underlain by rock with little or no soil cover. Assuming little variation in rock type on north-facing versus south-facing slopes, the significant difference in resistivity values between the two slopes was interpreted to be due to the presence/absence of permafrost. Hence, the findings suggested that permafrost could be mapped on slopes using EM resistivity data.

Resistivity Box-plot analysis of GSP classes in geologic units

In alluvium deposits the material type ranges from silt to gravel with presence of pebbles and cobbles. The resistivity of unfrozen alluvium can range from 100-1000 ohm-m [*Scott et al., 1990*]. For all the locations we sampled in alluvium units, the resistivity values were less than 1000 ohm-m which suggested that alluvium units were generally devoid of near-surface permafrost in the study area.

In retransported silt and sand, and low-land loess units, the resistivity value for low-lying permafrost present GSP class was ~1000 ohm-m which is representative of frozen silt and sand [*Scott et al., 1990*]. Thus, for these geologic units resistivity value greater than or equal to 1000 ohm-m imply presence of permafrost.

Slackwater flood deposits chiefly contain organic sandy and silty back swamp sediments [*Regeret et al., 2008*]. Ground resistivity values of all the locations sampled in this unit were higher than 3000 ohm-m which suggested frozen ground and hence the presence of permafrost. Similarly, for swamp deposits which contain locally woody, autochthonous peat with organic silt and sand, the median resistivity value for all locations sampled were higher than 4000 ohm-m. In this unit as well the resistivity values were suggestive of permafrost.

In glacial deposits, the sediment size varies widely from silt to big boulders and so does the resistivity value. We found that resistivity values for locations sampled in low-lying permafrost present and low-lying permafrost absent GSP classes were very similar, and consequently resistivity data failed to discriminate between permafrost presence or absence in glacial deposits of low-lying areas. However, significant differences in resistivity values between north-facing and south-facing slopes suggested resistivity data can be used to map near-surface permafrost on uplands.

Conclusions

Resistivity of ground to the flow of electric current is a function of material type, amount of ground ice, and unfrozen water content. In alluvium deposits, resistivity values at all the sampled locations were less than 1000 ohm-m suggesting either alluvium deposits were generally devoid of permafrost in the study area or permafrost was present in isolated small patches that were too small to influence the ground resistivity.

In retransported silt-sand and lowland loess, swamp, and slackwater flood deposits resistivity values were well in agreement with field observations of permafrost presence. Hence, for these geologic units resistivity can be used to map near-surface permafrost.

In low-lying areas, which are majorly glacial (till and moraine) and glacio-fluvial (outwash plain) deposits in this region, the material types vary widely and so do the amount of ground ice and frozen ground conditions. Resistivity values of all the locations sampled in low-lying permafrost present and absent areas were very similar, hence it was difficult to delineate permafrost areas in glacial and glacio-fluvial units based on resistivity data only.

A strong correlation between resistivity, north-facing and south-facing slopes showed up in all geologic units except one, which is in agreement with the widely accepted generalization that north-facing slopes are generally underlain by permafrost and south-facing slopes are devoid of permafrost in the study area.

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Determining the Density of Frozen Grounds in Laboratory Environment

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Abstract

Determination of physical properties of frozen grounds is one of the key stages in comprehensive determination of physico-mechanical properties in the process of geotechnical site investigations. This paper presents new methods of the frozen ground density determination, along with some laboratory test results.

Keywords: ground density; ice cover; physical properties; physico-mechanical properties; vacuumization.

Determination of physical properties of frozen grounds is one of the key stages in comprehensive determination of physico-mechanical properties in the process of geotechnical site investigations. Incorrect determination of physical properties causes errors in mechanical characteristics. Therefore, providing more precise determination of physical properties of frozen grounds at the stage of geotechnical investigations, one can reduce possible mistakes at the engineering stage, as well as possible negative effects at the stage of construction and operation of the buildings and utilities. This paper presents some results of laboratory experiments conducted by the authors in order to determine such physical property as the density of frozen grounds.

Currently, for certain cost and technical reasons, the studies into most properties of frozen grounds and the determination of their characteristics are conducted in laboratory settings. According to GOST 5180-84, frozen grounds density is determined by two ways, depending on the type of grounds and their state, that is by a “cutting ring” method and by weighing in a neutral liquid.

The “cutting ring” method used to determine the frozen ground density consists in the determination of the mass of the ground placed in a cutting sampling ring relative to the internal volume of this ring. In terms of frozen ground density determination, this method has several disadvantages.

- According to the requirements presented in Table 2 of GOST 5180-84, a sample ring used for loosely frozen sand soils and frozen silty clays should have internal diameter not less than 70 mm and 80 mm, respectively, with the sample ring’s wall thickness from 2 mm to 4 mm. Taking into consideration the longitudinal shear of ground along the monolith 15 mm thick and more, the “cutting ring” method can be used to study the frozen grounds’ structure in the frozen ground monoliths with diameters not less than 85 mm and 99 mm, respectively.
- GOST 5180-84 does not provide for the use of this method for frozen grounds with coarse-fragmented aggregate and coarse grounds.
- The “cutting ring” method significantly corrupts the results of investigations with frozen icy grounds and grounds with high ice content, as well as those with ice inclusions of the size more than 2 mm, since numerous tests show that ice inclusions are unevenly distributed in the monolith.
- The “cutting ring” method corrupts the results of investigations with fissured frozen grounds, as well as those with high porosity value.

The method of determining the density of the ground by its weighing in a neutral liquid (kerosene, ligroin, etc.) consists in the determination of the frozen ground mass in the ambient air and in the neutral liquid with regard to the neutral liquid’s density. In terms of frozen ground density determination, this method has several disadvantages as well.

- This method is applied to the frozen ground samples with the mass from 100 to 150 g. This leads to significant corruption of the results of investigations with frozen icy grounds and grounds with high ice content, as well as those with ice inclusions of the size exceeding 2 mm, due to the small size of samples.
- This method significantly corrupts the results of investigations for frozen grounds with coarse-fragmented aggregate and coarse grounds.
- This method uses only the samples of frozen ground without open pores and fissures.
- In case of pore grounds (peated soils, peats, coarse grounds, etc.), the neutral liquid absorbing into the sample may impact its mechanical, thermophysical and chemical properties.

There are also some other laboratory methods used to determine the frozen ground density, but all of them are either labor-intensive or require special equipment. The methods of frozen ground density determination developed by the authors are free of the above-mentioned disadvantages. These are:

1) determination of the density of frozen ground in an ice cover.

2) determination of density of frozen ground by means of vacuumization.

1) *determination of the density of frozen ground in an ice cover* includes the determination of the mass of the whole ground monolith, gradual short-term freezing of an ice cover onto the monolith, and the determination of the full volume of the ground monolith based on the volume of displace liquid in the volumetric glass. Neutral liquid or water of corresponding temperature can be used in this test. Numerous experiments conducted by the authors showed that short-term freezing of ice

cover on the ground monolith and further determination of its volume led to changes of the monolith surface structure to the depth from 0.3 to 1.5 mm. Such changes are minor and can be neglected, as they do not cause any significant changes of other properties. This method can be used in the determination of density of frozen sand soils, silty clays, grounds with coarse-fragmented aggregate and coarse grounds, peated grounds and peats, samples of regular or irregular shapes and various volumes.

2) *determination of the density of frozen ground by means of vacuumization* consists in the determination of the mass of the whole ground monolith, consequent placing of the monolith into a leakproof cover, and the determination of the volume of the ground monolith based on the volume of displace liquid. Neutral liquid or water of corresponding temperature can be used in this test. According to the tests conducted by the authors, the determination of the volume of a ground monolith leads to the changes of the structure on the monolith's surface to the depth from 0.1 to 1.0 mm. Such changes are minor and negligible, as they do not cause any significant changes of other properties. This method can be used to determine the density of frozen sand soils, silty clays, grounds with coarse-fragmented aggregate and coarse grounds, fissured grounds and grounds with open pores, peated grounds and peats, samples of regular or irregular shapes and various volumes.

The conducted tests showed that ground density values determined by the proposed methods differed from those obtained with the standard method within the range from 2% to 12% (upward or downward). This range of ground density values changes mechanical and thermophysical properties by 3 – 9 %. For example, the clayey ground sample taken from the depth of 9 meters has ground density determined with the "cutting ring" method ρ_f=1.75g/cm^3, compared to ρ_f=1.59 g/cm^3 with the proposed ("ice cover") method. Taking into consideration the data presented in Table 3 (Appendix 1) of SNiP 2.02.04-88, the heat transfer coefficient of the frozen ground will change from λ_f=1.96 W/(m·°C) to λ_f=1.78 W/(m·°C). The corresponding difference will be approximately 9%.

Results of the tests conducted with the proposed frozen density determination methods showed that these methods could be used as alternatives to the existing ones or, in some cases, as the only possible options in studying frozen ground properties in laboratory environment. The proposed methods allow to reduce the duration of the works by 1.5 – 2 times, to prevent the disturbance of the monolith's integrity, and to determine the density of the monoliths with smaller size and volume, compared to the conventional methods.

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Physical Essense of the New Approach to the Thermoluminiscence Dating Technology for Absolute Age Identification of Permafrost

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Introduction

Absolute age identification of permafrost is one of the most important tools used in geocryological studies. Today, investigations into identification of the absolute age of the cryolithozone's objects are very popular, since in terms of age determination the studies of permafrost on key sites often face difficulties. The use of thermoluminiscence (TL) dating for identification of the absolute age of grounds by quartz can be helpful in terms of the solution of the problem of dating the samples taken from the Quaternary series within the cryolithozone. Maximal ground age that can be determined by this method is approximately 300 thousand years. This is enough for studying geocryological objects, since most of them were formed in the Late Quaternary period. Most of the permafrost objects do not contain the material that could be dated by any other methods. That is why TL dating based on wide distribution of quartz (which is used in this case as a timing mineral) often represents the only possible method of age diagnostics. Also, compared to other methods, TL dating is a relatively simple and cheap way of age identification that can produce results with minor deviations.

For a long time the traditional TL dating practice has been using extrapolation of TL signals by simplified dependency of the TL dose output and the models based on the 2nd order kinetics equations for the processes of electronic transitions on the energy traps. However, this process often leads to errors that significantly exceed those allowed by the traditional procedure (10%). This is primarily caused by non-linear dose dependence of a TL signal for quartz, where, according to [*Shlukov 2005 and Sheinkman & Melnikov 2011*], the second order of kinetics is predominant.

The objective stated by the authors is to present theoretical analysis of new physical approaches that, using a radiation-indicating mineral, take into consideration more subtle mechanisms of electronic transitions related to the 2nd-order kinetics.

Physical Basis of the Proposed Method

In TL dating, the grains of quartz contained in the studied ground samples play the key role of a stable timing mineral. They are well preserved, as quartz is a solid mineral with high resistance to the impacts generated by the surrounding ground. The age value is determined by the energy of natural radiation field absorbed by quartz in the form of excited electrons caught by energy traps. Quartz is good as a timing mineral, because SiO_2 crystals contain and preserve unchanged the sufficient amount of energy traps during the period of time exceeding the maximal dating period that, in practice, is equal to 10^{13} s (300 thousand years). The velocity of the molecules diffusion in quartz (with regard to diffusion coefficient equal to 10^{-20} cm^2/s) has the value of approximately 1 micron per 10 million years. So, one can assume that diffusion does not cause significant shift and loss of energy traps. As for the removal of the diffusion layer about 1 micron thick, it takes place all the same when grains of quarts of the separated fraction of size 100-200 micron are cleaned by acid pickling.

Concentration of trapped electrons is determined by means of TL lab tests. The device registers the TL curve that reflects the relation between the photon impulse counting rate and the temperature of the tested sample. Experimental data interpretation aims to determine, based on the TL splash value, the concentration of trapped electrons and, consequently, the age of the sample.

Therefore, two physical processes should be considered. These are: accumulation of electrons on energy traps of quarts grains, and thermoluminiscence in a laboratory environment.

Accumulation of Electrons

The process of electrons accumulation on the energy traps can be presented in the form of a diagram in Figure 1. At first, a grain of quartz on the Earth's surface, impacted by the sunlight or high temperature, is decolorized (Fig. 1, B). As a result, electronic traps are emptied to certain residual concentration (Fig. 1, C). After that, quartz grains contained within the newly-formed depositions will be protected from the impact of the sunlight. During the dated time interval (Fig. 1, D) the only impact suffered by them is that of natural radiation with constant power of gamma radiation exposure E that is *usually equal* to 15-20 micro-roentgen per hour. As a result, each year the grains absorb dose D equal to approximately 0.5 Gy [*Wagner 2006*]. Accumulation of electrons in traps is described by the *n – B* dependence. It is non-linear (Fig. 1, D), and it is called "dose function" in the academic papers [*Pagonis, 2006*].

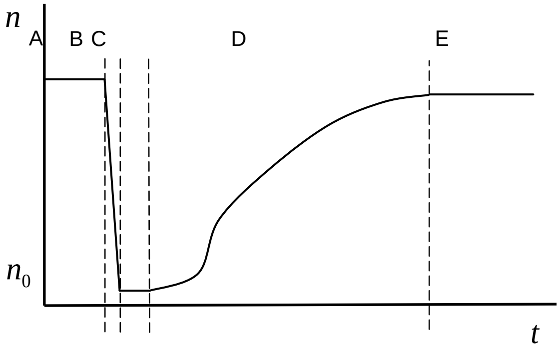

Figure 1. Accumulation of electrons on energy traps

The dating interval (Fig. 1, D) is physically limited by time (Fig. 1, E) to 10^{13} s – the ultimate saturation of electronic traps. However, at the level of ultimate saturation, not all traps of a quartz grain are filled, but only a small part of them [*Shlukov 2005*]. At the level of ultimate saturation, concentration of all electronic traps of a quartz mineral is significantly higher than that of the filled traps. With regard to the presented experimental results, one can conclude that saturation (Fig. 1, E) occurs regardless of the concentration of traps in a SiO_2 crystal, being caused by dynamic equilibrium between inflow-outflow of electrons at a given energy level.

The inflow of electrons onto the trap's energy level is a consequence of natural gamma radiation. The concentration of trapped electrons n rises in proportion to the cross-section of capture reaction ξ, the concentration of free traps $(N\text{-}n)$ and power of exposure E.

Spontaneous outflow of electrons from an energy trap is caused by heat fluctuations described by Boltzmann distribution. In case of an energy trap with energy of activation 1.6 eV, the calculation using the Boltzmann equation for temperature 273 K gives the typical time value 10^{20} s that exceeds the time of saturation by 10^7 times. Based on this estimate, one can assume that heat fluctuations do not affect the saturation of electronic traps and are not a significant factor able to change the dose dependency pattern (Fig. 1, D).

So, the outflow of electrons from the traps can occur only as a consequence of natural gamma radiation. The release of electrons is proportional to outflow probability w_E of electrons from the traps due to the exposure dose and to squared concentration n due to the fact that this process is recombinational and is described by the 2nd-order kinetics equations [*Chen, McKeever 1997*].

The dose function is the solution to the differential kinetics equation:

$$dn/dt = - wE\, n^2 + \xi E(N\text{-}n), \qquad (1)$$

where t is time of accumulation and N is the concentration of traps. At the moment of time $t=0$, the concentration of electrons $n=n_0$ is determined by residual post-decolorization concentration. The maximal time of dating $t=t_\infty$ corresponds to the ultimate trap saturation $n=n_\infty$. It seems that this moment comes when the velocity of electrons capture becomes equal to the velocity of their outflow due to gamma radiation. This differential equation is solved by the s-form function of tangential saturation (Fig.1 , D).

Thermoluminiscence

The concentration of accumulated electrons n is determined by thermoluminiscence of quarts in laboratory environment using special equipment. Usually the concentration of accumulated electrons is represented by the total light sum, accurate measurements of which are difficult. The authors use the method presented in Shlukov 2005. This method is based on the determination of the n value by temperature T at the maximal level of elementary TL peak on the TL output diagram. For traps with energy of activation ε, this maximal level shifts along with reduction of n to the high-temperature range. Natural quartz samples are characterized by stable traps with energy of activation of about 1.6 eV that determine the predominant peak value 300°C. According to Shlukov 2005, the trend experimentally determined for this type of traps based on natural samples of various ages is represented by the following equation:

$$n = n_\infty \left(\frac{T_\infty}{T} \right)^2 exp\left(\varepsilon/k(1/T - 1/T_\infty) \right), \qquad (2)$$

where k is Boltzmann constant, n_∞ is the concentration of electrons in the ultimately saturated timing mineral, T_∞ is maximal temperature of the ultimately saturated timing mineral, ε is energy of activation.

The newly proposed physical approach allows to calculate concentrations of trapped electrons based on previously measured T_∞ and n_∞ of an ultimately saturated sample. According to this method, it will be enough to carry out the most precise measurements of the maximal temperature of the predominant TL peak and, with trend function (2), to calculate the concentration of trapped electrons. Then, using the reverse dose function obtained from equation (1), one can use the absorbed dose value and to calculate the age of a sample by a simple equation $t = D/E$.

Conclusions

At this stage of investigations, the authors have managed to set the task of the improvement of the TL dating method in terms of its use in permafrost studies. Also, the results include the formulation of the differential dose dependency equation and present the trend function describing the shift of TL maximal peak from the concentration of trapped electrons for natural quartz samples. It is shown that, based on the natural TL signal, one can determine the concentration of electrons accumulated in the traps using not optical, but thermal properties of the timing mineral. The key advantage of the new physical approach lies in the fact that it does not require complex calibration or precise spectrometric instruments.

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The spatial distribution of SOC in the forest tundra of the European North-East

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The study area (2.5° × 1°) was located in the forest-tundra ecoclimatic zone within the Usa River Basin, Northeast European Russia. The study describes the spatial variability of soil organic carbon (SOC) (kg/m^2), measured in 153 points that were aggregated to 83 observation points, according to the chosen scale (grid mesh 300 m). Measured mean and standard deviation of SOC at observation points were 24.1 ± 39.3 kg/m^2. Previously estimated mean was 38.3 kg/m^2 [*Hugelius & Kuhry 2009*].

The purpose of this study was to study the relationships between SOC and environmental factors (soils, topography, and climate) at a regional level. If corresponding correlations are strong, one may use these factors to predict SOC by environmental factors both in space and time.

The prospective dynamics of subarctic ecosystems and shifts of their carbon balance in a changing climate are actively studied [*Dormann et al. 2007; Kolomyts 2011*]. The main focus of the study was to present a methodology for determining carbon pools in phytobiota and in soils, as well as to create a database on the current and forecasted SOC for a region with different soil types. The study used the extended system of quantitative topographic attributes [*Shary et al. 2002*]. Our data on SOC for different soil types, in a conjunction with digital elevation model (DEM), derived from it topographic attributes, and average temperature and precipitation (Hijmans et al. 2005) were statistically combined for spatial modeling that permitted to calculate predictive grids (and maps) of SOC. Calculations of topographic attributes and statistical data treatment were performed using software packages «Analytical GIS Eco» and «R2» [*developed by P.A. Shary 2004*] for finding out the relationship of SOC to the environmental factors.

The statistical analysis of interrelationships between SOC and environmental factors was performed using non-linear multiple regression and revealed that 89% of SOC spatial variability in tundra and forest-tundra of Usa River Basin was explained by soil types (three groups of them), topography (slope, exposure, and terrain dissection), and climate (mean December precipitation and July temperature). Verification of the model was carried out using Allen's cross-validation technology that demonstrated very low (1.2%) degradation of the model for predictions at new observation points, as compared to the criterion of 50%.

The results can be represented as raster maps for the current time, as well as be used for the spatio-temporal prognoses of SOC for various climatic scenarios in the future (such as E-GISS or HadCM3).

The correlation between SOC and environmental factors (soil types, topography and climate) was extremely high ($R^2 = 0.886$, $P<10^{-6}$), so that SOC may be predicted directly by these factors. In contrast to "pure" simulation models, real field data were used for spatial modeling, instead of various theoretical approaches that were used in simulation models. Our approach of predictive modeling may, first, minimize the influence of subjective opinions in the model, and second – be used at a regional scale as in a most objective way.

Our study has shown that meso-scale studies for SOC spatial predictions appear very effective, and that topography is an important and significant factor for such studies.

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Assessment of the Effectiveness of Drainage Systems for the Solution to Hydrogeoecological Problems of the City of Yakutsk

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Introduction

As the construction experience in Yakutsk shows, most construction sites, particularly in the areas of demolished dilapidated housing as well as in undeveloped wetland areas, are characterized with complicated geotechnical and hydrogeocryological conditions. These sites are characterized byincreased irrigation of foundation grounds in places that continuouslyserve as thaw cups under buildings and as drain wells. Salinized, plastic frozen, sandy-clayey ground of these areas with temperatures close to 0 °C often contain suprapermafrost and intrapermafrost cryopegs. In such hydrogeocryological conditions operational reliability of the foundations without special geotechnical maintainance procedures is very low.

One of the methods of melioration of weak grounds and of improvement of their properties for purposes of further construction is diversion of underground waters of closed suprapermafrost taliks by means of various drainage systems.. Unfortunately, in Yakutsk the lack of methods for dewatering procedures in complex hydrogeocryological conditions, the lack of knowledge on filtration properties of grounds in the aeration zone, and of water-absorbing, loose, alluvial deposits hinder the introduction of drainage systems, widely used outside the permafrost zone. To assess the potential of drainage use and its effectiveness in building development of the territory, experimental sites were selected where drainage systems were installed. Experimental filtration operations were conducted.

Discussion of results

Vertical well drainage

Testing of vertical well drainage was conducted at the demolished site within the city of Yakutsk in 2010-2011. Before the testing at the planned site for construction thawed water-saturated grounds were deposited at the depth of 1.5-4.2 m. The thickness of the irrigated layer varied from 0.7 to 4.5 m, and in some areas it reached 7.4 m. Water-absorbing deposits are clayey silts, silty sand and fine sand. The ground water of the suprapermafrost talik had mineralization equaling 1.8-2.3 g/l and was characterized by the chloride-hydrocarbonate sodium-magnesium-calcium composition.

A experimental cluster of four perfect wells was sunk in order to study the filtration properties of grounds and assess the possibility of well drainage use on the site with a maximum thickness of water-bearing talik (the interval of deposition is in the range of 1.8-9.2 m). A complex of experimental filtration operations was carried out twice: in January, when there is no infiltration alimentation of suprapermafrost ground water and in August, after thawing of the seasonally frozen layer. The analysis of the data from cluster dewatering enabled calculation of water-transmitting capability of the grounds, calculation of the influence radius of dewatering and assessment of water influx in drainage working in different seasons of the year. Experimental procedures at the hydrogeological wells were followed by dewatering operations to drain foundation grounds with their subsequent freezing by means of seasonal cooling devices. Artificial cooling of the grounds combined with fast track dewatering operations allowed us to reduce the volume of gravitational waters in the talik by 8.8 times.

Drainage pit

The drainage pit is placed on one of the typical areas with cryopegs. It should be noted that often it is rather difficult to remove technogenic cryopegs. This has to do with the specific hydrogeocryological structure of the alluvial stratum, i.e. the lenses of negative-temperature high-mineralized water are separated by layers of salinized solid frozen or plastic frozen grounds. Currently, installation of "cold" piles and cooling thermosyphons under the buildings provides the main method to control cryopegs and strengthen foundation grounds. However, natural or artificial freezing of water-saturated grounds is complicated by the migration capacity of cryopegs, while mineralization of porous solution above 20 g/l makes these methods ineffective.

The experimental site contains suprapermafrost cryopegs deposited within the interval of 2.0-4.5 m, their mineralization equals 14-18 g/l. The chemical composition is sulfate-chloride magnesium-sodium, the temperature is minus 0.6-1 °C. The drainage pit installed in 2010 was sunk as deep as the permafrost table and has perforated sides and bottom. Development of cones of depression was observed at 5 specially designed wells during experimental operations performed in August 2010 and June 2011. The conducted studies allowed us to determine the radius of the area affected by the drainage pit, to recommend water discharges that provide for the most effective melioration, as well as to prove the effectiveness of water extractions on local sites with shallow deposition of cryopegs. The study showed that the highest water influx into the drainage pit occurs in late spring-early summer, which is due to high cryogenic water yield of talik grounds in the course of its maximum seasonal freezing.

Tubular drainage

Tubular open-cut drainage with water intake pit is mounted in a wetland depression that constitutes a part of an ancient flow gully. The lithological composition of the grounds down to the depths of 1.0-1.5 m is represented by sandy and clayey silts underlain with fine and silty sands. The depth of seasonal thawing of the grounds equals 1.5 m. The drainage system consists of a perforated pipe of 30 cm in diameter, laid in a 1.5 m deep trench over the 30 cm thick layer of rubble that is also laid above the pipe up to the day surface level. The water from the perforated pipe enters the water intake pit with a solid bottom and walls through a special opening.

The experimental work performed at the site showed low efficiency of this type of drainage for the purposes of drainage of the seasonal thawed layer grounds. The low water influx is associated both with inconsiderable thawing of the seasonal thawed layer grounds on the wetland area and with considerably lower filtration coefficients of sandy silt-clayey silt deposits by comparison with those of rubbly fill in the trench. However, the tubular open-cut drainage may be recommended for regulation and diversion of surface water.

Conclusions

In general, the conducted research confirms that the use of drainage systems within the city of Yakutsk is conceptually possible. The effectiveness of a type of drainage depends on hydrogeocryological conditions of the targeted areas and on the possibility of their transformation resulting from technical melioration of grounds. For that reason, when developing an area, it is necessary that geotechnical research should include hydrogeological studies that would make it possible to determine filtration parameters of the soil in field conditions by means of extractions.

The problem arising during dewatering operations has to do with the diversion of highly mineralized water. The extracted fresh suprapermafrost water may be discharged into the urban channel or surface water reservoirs (in this case, the maximum permissible level of water in them must be preliminarily calculated). On the contrary, highly mineralized water must not be discharged into open water bodies, while their release into the municipal sewage system is only possible if it is negotiated with the corresponding supervisory authorities.

The Use of Mineral Sorbents for Sludge Pit Reclamation in the Far North

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Abstract

The prospects of development of the oil and gas production in the cryolithozone of Tyumen Region are analyzed. The following is studied: impacts on the lithosphere, the chemical pollution of the relief and of drill sludge, and particularly its neutralization with the use of silicic sorbents: diatomite and glauconite. The work technology for drill sludge neutralization with sorbents is suggested.

Keywords: cryolithozone; diatomite; drill sludge; glauconite; neutralization; sorbents

It is hard to overestimate the economic value of the permafrost area, or the cryolithozone (as geocryologists call it). Moreover, it occupies 65% of the area of modern Russia. More than 30% of the explored reserves of all oil in Russia, about 60% of natural gas, innumerable hard coal and peat deposits, most of hydraulic energy resources, non-ferrous metal, gold and diamond reserves, and huge wood and fresh water reserves are concentrated within the Russia's cryolithozone.

The explored hydrocabon reserves of the North West Siberian Cluster, the fields of Yamalo-Nenets Autonomous District and the Caspian Sea shelf make up about 27 billion of reference fuel, including 74% of explored gas reserves on the dry land. It is obvious that the West Siberian cluster is the main one in terms of gas production. The level of gas production from these fields can fully provide for the assumed capacity of the gas pipeline system equal to 100 billion m^3. The liquid hydrocarbon production will make up 50 Mtpa [*Grigorenko 2008*].

The provision of the geoecological safety of natural-technical complexes in the process of development of raw hydrocarbon resources in the Far North is based on the complex analysis of the oil and gas industry conditions, rating of the levels of technogenic impact on geosystems, and the environmental impact assessment.

Drill sludge is one of the factors of exogenous (technogenic) impacts on the Far North lithosphere in the process of hydrocarbon fields development. The adverse impact of drill sludge on the environment is preconditioned by the presence of oil and chemical agents in it, heavy metals in particular.

It is reasonable to use silicic grounds – diatomites and glauconite with high sorbate activity – for reduction of the oil, toxic and oncogenic elements content in drill sludge prior to the biological reclamation stage [*Arens & Gridin 2000; Kamenshchikov & Bogomolny 2005*].

Diatomite is sedimentary ground consisting mainly of diatomitic algae shells. It is usually unconsolidated or poorly cemented, light-gray or yellowish. 96% of the chemical composition of diatomite is represented by aquatic silica (opal). Diatomite has high porosity, is capable of adsorption, has low heat and sound conductivity and is refractory and resistant to acids.

Glauconite (monoclinal dioctahedral ferric-magnesian mica) consists of: up to 28 % of Fe_2O_3, up to 9.5 % of K_2O, 8.6 % of FeO, and 4.5 % of MgO. The sorbate activity of glauconite is associated with ion-exchange properties and the developed specific surface.

Sludge neutralization consists of the following stages:

1. Polluted substance sampling, determination of the presence and the concentration of pollutants in samples and determination of the maximum permissible concentrations (hereinafter – MPC) in accordance with the standards regulating the scope of laboratory studies and their assessment.
2. Calculation of the quantity of silicic ground for object processing and bringing of the pollutant concentrations to MPC norms are carried out in accordance with the developed algorithm. It provides for determination of the specific quantity of the sorbent required for sludge neutralization by means of study of the polluted sludge samples and also the samples of sludge mixed with silicic materials in different proportions.

A natural sorbent is added to polluted sludge for neutralization until the set concentration of the pollutant in the sludge is achieved. The type of the pollutant and its concentration in the polluted sludge sample are defined prior to the sorbent addition to the sludge. Then the pollutant concentrations are measured in the process of mixing of the polluted sludge samples with a sorbent. After that the weight of the sorbent is defined in accordance with the demand for mixing with the sludge polluted by the earlier determined pollutants with the known concentration, and for achievement of the set pollutant concentration in the sludge.

3. The chosen composition of sludge with silicic grounds is mixed in the 250 l forced mixer till homogeneous state during 10-15 minutes.

The results of study of water-soluble, mobile and bulk forms of pollutants show that sorbents well bind and retain heavy metals and oil, hindering their migration in the soil profile and further into ground waters.

The temperature range of work execution with the use of sorbents is from 5 to 50 °C.

The sorbent is not extracted from the ground after neutralization. The neutralized ground can be used for reclamation, solid household waste filling on waste burial polygons etc.

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Climate Change Aspects in the New Report on the “Social-Economic Development of Arctic – 2014” (*in Russian*)

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The elaboration of the first report on the social-economic development of Arctic had been initiated in 2002 by the Arctic Council. It had been issued in 2004, and undoubtedly had become an important event among the scientific community involved in Arctic problematic. The project on arctic social indicators and the project “Econor” occurred to be its immediate continuation. Due to these two projects, the information on the social-economic processes in the arctic regions of the world was for the first time consolidated and represented as a single format. One could consider that the Russian Report on the circumstances in Arctic (elaborated by the council of experts under the Chairman of the Federation Council of the Federal Assembly in 2010) became the worthy continuation and development of the first «Arctic Human Development Report».

Ten years after the elaboration of the first Report on social-economic development of the circumpolar zone, the working group of the Arctic Council on stable development has initiated the elaboration of the second Report. The period of its preparation is 2012-2014. The basic idea of the new Report is to represent those trends in social and economic processes that have been outlined in the Polar countries during the period since the elaboration of the first document.

The elaboration of the project of the climate changes and their influence on the arctic regions and countries on the whole and on the fortunes of the north small primorye communities and settlements in particular is the most important prevailing task put before all the authors of the chapters of this document. Thus the impact of climate upon the various levels of the administration and different “dimensions” of economics (operations of the major companies, functioning of small and middle business, social service facilitations and so on) must be revealed. The project of climate changes along with the gender problematics and the problem of globalization ought to be prevailing and wide-covering through all the chapters of the Report.

In the process of our work, the empirical material on social and economic expenses and profits for aboriginal and migratory communities due to the climate changes has been accumulated. The scientists of Alaska, North Canada, North European countries and Russia adduce evidences and theoretically interpret the new phenomenon for arctic economy, the impact of which has constantly increased during the last two decades. In the reports of congresses of the International Association of the social investigators of Arctic one can hear the “human dimension” – the very social-economic effect due to the ice cover reduction in the Arctic Ocean and the diminution of the permafrost area during the last two decades. Adduced are the solid evidences, that the climate changes and associated processes in Earth’s biosphere, ecosystems and cryolithozone are not only the objects of investigations of the natural phenomena and technological decision making but first of all - the factor requiring the immediate elaboration of the comprehensive social programs.

Thermoluminescence Dating of Permafrost: New Approaches, Methods, and Instruments

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Introduction

New approaches to dating of permafrost need a solid instrumental and methodological support. Work in this line is underway at the Earth Cryosphere Institute SB RAS (Tyumen), where an advanced tool is being designed for dating permafrost according to thermoluminescence (TL) of fine-grained sediments (quartz). The work is important because, although TL dating has been broadly used in geology since long ago and its principles are quite well known [*Vagner 2006*], the alternative dating approaches [*Sheinkman & Melnikov 2011*] require special facilities, and there are no appropriate TL dating tools available in the Russian market. Below we report the results of preliminary research and design and give a description of the new TL dosimeter.

Unlike the classical dosimetry with counting the light sum of samples, the alternative dating technology we suggest employs the dependence of the basic TL peak temperature on the radiation dose received by quartz grains. The basic TL peak is meant as an elementary high-temperature peak in the dose curve of a timer mineral. Quartz peaks at about 300°C, which corresponds to an electron trap with an activation energy about 1.6 eV [*Shlukov & Sheinkman 2007; Sheinkman & Melnikov 2011*].

Method

The dating procedure begins with preconditioning of samples. First, fine particles (0.1-0.2 mm fraction) are separated by sieving from the selected sample; then they are rinsed and etched in HCl and HF in order to extract quartz grains and to remove their contaminated surface layers of a few micrometers.

The aliquots are spread thinly on the pad of the experimental cell, where an electronic system automatically runs the technological process. TL in quartz grains is stimulated by heating, at a constant rate, to 400°C and the luminescence is recorded by counting output photons from a photomultiplier per time unit.

As a result, one obtains a TL glow curve which represents the temperature dependence of the photon count for the analyzed sample. The TL curves are processed with a special software using a reference interpretation model to derive the age of the sample.

Instrument construction scheme

The new TL dosimeter (Fig. 1) consists of the following units:

1 – experimental cell (EC);
2 – microprocessor (MP);
3 – photomultiplier (PM);
4 – high-voltage pulsed power supply (PPS);
5 – amplifier (A);
6 – discriminator (D);
7 – light filters (LF);
8 – heater (H);
9 – transistor switch (TS);
10 – thermocouple (TC);
11 – analog-to-digital converter (ADC);
12 – light-tight housing (LTH);
13 – computer (PC).

The preconditioned quartz grains are charged into a brass capsule with a fused silica window (the experimental cell). The cell is connected to the heater with its one side, and the window side faces the photomultiplier (Fig. 1).

A differential thermocouple junction (copper-constantan, type T, or chromel-alumel, type K) is set inside the capsule (TC in Fig. 1) and is the principal precise temperature meter. This thermo-junction configuration provides the best contact with quartz grains and reduces errors in temperature readings to no more than 0.1°C. The reference junction is placed in a thermostat. Thermal voltage data are digitized in the ADC unit. The digitized code from ADC comes to the microprocessor which calculates temperatures according to a polynomial function with specified calibration coefficients.

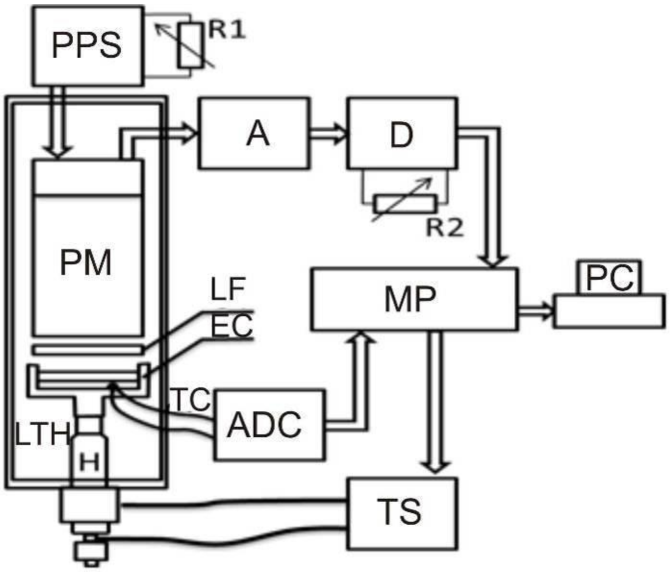

Fig. 1. Operation scheme of new TL dosimeter.

The heater (H in Fig. 1) is made out of an NGK spark plug used in motorcar diesel engines, which can heat up to almost 1000°C for 30 seconds consuming no more than 100 W. The spark plug is connected to a transistor switch (TS in Fig. 1), and the latter is driven by the microprocessor (MP) which regulates the consumed power from 0 to 100% by means of pulse-width modulation of current through the plug. The microprocessor ensures heating at an almost constant rate in the cell, with no more than 0.5% departure from linearity at rates from 1 to 15°C/s. The supply power to the heater is from a 150 W transformer with a constant output voltage of 12 V. TL recording is possible at temperatures no higher than 400°C:

otherwise the background IR radiation from the brass cell exceeds considerably the signal.

The electronic circuit includes several units, namely: an ADC, a heating control unit, an amplifier (A) and a discriminator (D) of photomultiplier signals, and a microprocessor (MP). The electronic circuit has a separate constant +20 V voltage supply.

There are blue-green filters (LF, types BGL-21 and BGL-25) between the cell window and the photomultiplier to filter out infrared bandwidths and to highlight the 300-400 nm TL signals emitted by quartz.

The photomultiplier is operated in a single photoelectron state [*Photon Counting 2005*]. The power supply to the photomultiplier is from a pulsed ADC with a regulated constant voltage to 2 kV. The resistor R1 maintains the operation voltage of the photomultiplier in the middle of the response plateau (Fig. 1).

The output signals from the photomultiplier come to the amplifier and the discriminator which provide the required gain, amplitude selection, and generation of pulses of preset amplitudes and lengths. The discriminator response level is set with the resistor R2 (Fig. 1) during photon counting at the receiver ADC.

Signals from the discriminator arrive at the input of the microprocessor counter, which counts pulses per unit time and calculates the count rate maximums according to their periods. The microprocessor unit translates the digitized temperature and photon count data, as well as the count rate peaks, to the PC via a USB port. Recording is discrete at every 100 points per second, which corresponds to the temperature stepsize 0.1°C/s in the TL curve. The TL data are processed by a program integrated into WINDOWS. The ages of the samples are derived via functions which are, in turn, obtained through solving differential equations that simulate the dose function [*Pagonis et al. 2006*].

Conclusions

Using the more strict thermal parameters of timer minerals instead of their absolute optical characteristics allows simplifying greatly the design of the new TL dating tool and reducing the instrumental error, as it requires neither the radiating calibration procedure of the optic channel nor sample weight control.

In the optic channel, it is enough to measure relative luminescence to highlight the basic elementary TL peak in the dose curve. The measurements in the temperature channel, however, have to be highly precise. The high precision is possible due to special calibration of the heating system and to a tight contact of the thermocouple junction with the analyzed quartz grains. The advanced tool has a more compact design than its previous counterparts and can be a handy portable device for field work.

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Plant Matter Decomposition and Net Primary Production Rates in Russian Tundra under Contemporary Climate: Regional Patterns and Key Controls

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Introduction

To forecast spatiotemporal patterns of climate change, the mechanisms involved and ecosystem feedback are to be studied at any scales. Amongst biotic and abiotic ecosystem characteristics the carbon balance is the integral parameter to study dynamics of production and destruction of organic matter. Basing on the balance between the Gross Primary Production (*GPP*) and the Ecosystem Respiration (*ER*) the ecosystem is concerned sink or source of atmospheric carbon. Despite the rise of anthropogenic impact to temperature, biota driven carbon exchange between the surface and the atmosphere dominates on the Earth. The observed short-term temperature growth specifically leads to predominant growth of *ER*, making ecosystems not only dependent on climate, but being climate regulators as well.

Special attention is paid here to tundra biome due to its third highest pool of carbon in plant and soil matter after boreal and tropical forests. Tundra is at the temperature and precipitation tolerance limits of all ecosystems, thus making the micro- and mesotopography one of the primary factors in distribution of resources. However, further temperature increase will evidently force different species of autotrophs and heterotrophs to react specifically, with total effect of low predictability. Thus, important is to increase the predictability of the future carbon balance of tundra.

Under this goal we tried to find specific rates of production and decomposition of dominant tundra species and their fractions, dependent on the same resources and factors but to various extents. This was used for assessment of Aboveground Net Primary Production (*ANPP*) and decomposition rates. Second objective was to estimate the “hidden” carbon fluxes, i.e. important but hardly measured components of carbon budget, namely belowground Net Ecosystem Exchange flux (NEE_{below}).

Field Observations and Research Design

Field data were collected in the North-East European dwarf shrub tundra at the site Talnik (67°20’N, 64°44’E, 120 m a.s.l.), which represents 1 ha square plot, with nods marked every 10 m, in which the standard measurements are held. It has monitoring record since 1996, and is a part of Circumpolar Active Layer Monitoring program (CALM). Significant climate warming is observed in the study area during the last 50 years, with air temperature growth rate of 0.03C yr^{-1}, and precipitation increase by 0.5% yr^{-1}. The active layer was also increasing during 16 years of monitoring.

Aboveground Respiration of heterotrophs (Rh_{above}) was estimated by mass loss with litter-bags technique and by direct measurements of CO_2 emission from litter bags. The *ANPP* was estimated independently using: (a) the so called method of “minimal estimates” by Titlyanova [*1977*], applied to interannual periods; (b) sums of aboveground productivities of every plant species and their components; (c) regression modeling [*Gilmanov 1996*].

The record of aboveground phytomass random sample plots within the study site covers 1996-2011. Litter bags for all major vegetation fractions with freshly collected debris were placed in the nods of the site with long record of known parameters. Plant fragments were put in bags of nylon mesh with openings of 100 μm at bottom and 1 mm at top side after drying at +60C and scaling. Before and after installation C and N content was analyzed (“Vario EL”) to estimate debris quality.

NEE, *ER* and *GPP* fluxes were estimated by multiple regression equations [*Karelin & Zamolodchikov 2008*] based on surface CO_2 fluxes measured *in situ* (1996-99), by «bottom-up» chamber technique and LiCor-6200.

Results and Conclusions

All our independent estimates of ANPP do not differ significantly (1.82 ± 0.09, 1.85 ± 0.17, 2.07 ± 0.3; paired differences are insignificant, t-test, P > 0.05). Coincidences of the results approve the correctness of the approaches. Comparison with analogous estimates (Bazilevitch 1993) shows both the aboveground phytomass (8.61±0.56 (1996-2011) > 6.31 ± 1.07 (1969-1985) tdw×ha^{-1}, differences are significant, t-test, P<0.05) and production rates (1.82±0.09, 1.85±0.17, 2.07±0.3 (1996-2011) > 1.19±0.13 (1969-1985) tdw×$ha^{-1}yr^{-1}$; paired differences are not significant (t-test, P > 0.05) to be less than in our study.

The estimates made for 1969-85 period are character for stable temperature and precipitation [*Zukert & Zamolodchikov 1997*]. The mean annual temperature averaged for 1969-1985 of -6.06 ± 0.27°C is significantly lower than -4.98 ± 0.45°C of 1996-2011 (t-test, P=0.036). Growth of the annual maximal thawing depth of permafrost, which is an integral measure of climate change through correlation with the sum of above-zero temperature (r=0.5) further support recent warming.

During the study period the tendencies to increase in both vascular plants green mass (R^2=0.48) and mortmass (R^2=0.34) were observed. Subtracting the decomposition losses, according to the mean annual decomposition coefficient 0.26 t×$ha^{-1}yr^{-1}$ weighted for the annual decomposition rate of every plant species and their parts from the ANPP estimate of 2.07 t×$ha^{-1}yr^{-1}$, the residual from all the litter cohorts during the whole period of study is 1.36 t×ha^{-1}. Estimation of the litter pool accumulation from the linear regression returns the close value of 1.26 t×ha^{-1}, which provides the cross-validation of the results, and proves the correct use of the production and destruction models.

The fairly pronounced trend of increase in annual decomposition rate (R^2=0.25) is found. This attributed to higher contribution of the easily decomposed parts of the vascular plants, first of all from shrub leaves, in litter. The reason for this is the lengthening of the warm season. The stepwise multiple regression analysis shows another significant factor is nitrogen concentration in litter components. The higher the nitrogen content in the plant species or their parts, the faster it decomposes (R^2=0.63). Modeling shows that during the 1996-2011 period the storages of carbon (R^2 = 0.31) and nitrogen (R^2 = 0.35) in aboveground phytomass and mortmass grow, forming a possible side effect of the warming, which favors debris decomposition. However the observed increase of decay rate is not enough to compensate for higher rates of production, which result in litter accumulation.

According to the model the average age of the mixed litter is 4 years, while the total decomposition of the litter cohort lasts for 9 years. Among the old litter the slowly decomposing components prevail, with mossess and woody parts of vascular plants dominating.

Having the data on carbon fluxes, the belowground part of the annual net ecosystem flux NEE_{below} was estimated, as follows:

$$(GPP-ER)-(\sum_{i=1}^{S} ANPP-\sum_{i=1}^{S} Rh_{above})=(\sum_{i=1}^{S} BNPP-\sum_{i=1}^{S} Rh_{below})$$

$$NEE-NEE_{above}=NEE_{below}$$

The modeled dynamics of carbon fluxes shows the linear trend during the study period of warming with strengthening carbon sink (R^2=0.34). This is also evidenced from observed litter storage growth and higher aboveground production. In the studied ecosystems NEE_{below} appears to be normally the source of carbon, while the NEE_{above} is the carbon sink. Both fluxes vary widely on an interannual timescale, nevertheless the average absolute values for the entire period of study doesn't differ significantly (t-test, P=0.3).

That means the total balance is based on ratio between above- and belowground parts of the ecosystem, and more precisely on that of vascular plants. Strengthening of the carbon sink in the ecosystem is mostly attributed to gradual decrease of the belowground source, tending to have carbon sinks to both components of *NEE* possible under further warming. However such tendency could only last under continuous temperature growth. The new equilibrium will be reached when temperature factor will stop acting.

The relationship of NEE_{below} and NEE_{above} is actually dependant on the period of carbon exchange we study. The more appropriate way is to study ecosystem in a C-equilibrium state. This C-equilibrium period was estimated using NEE integral value with 1 year step starting from 1996. As it crossing the zero line of C-balance in 2007, the equilibrium period was than estimated as 1996-2007. As it could be seen from Figure 1, within the equilibrium by C-balance period of 1996-2008, an

increase of C-sink in shrub tundra is mostly due to *NEEbelow* emission decrease (r=+0.71, P=0.05), rather then to the growth of NEE_{above}, which is relatively more stable (correlation with *NEE* r=+0.49, insignificant at P=0.05). The mechanism involved is not yet clear. The smaller increment of NEE_{above} is due to strong positive linkage between *ANPP* and decay rates (R^2=0.6).

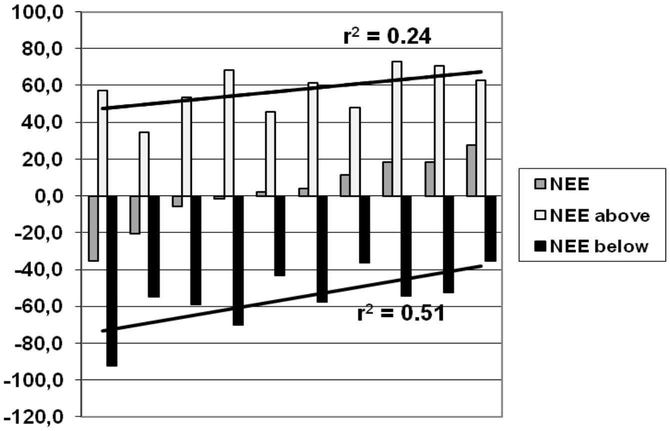

Figure 1. *NEE* (gC m^{-2} yr^{-1}) vs. NEE_{above} and NEE_{below} dynamics during equilibrium by C-balance period (1996–2007). Fluxes are in ascending order by NEE.

Acknowledgments

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Permafrost Occurrence in Cold Scree Slopes at Low Altitudes (Detunatele, Apuseni Mountains, Romania)

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Detunata Goală (1158 m) as well as Detunata Flocoasă (1258 m) peaks in the Apuseni Mountains, Western Carpathians, present important debris deposits, only partially covered by trees, at the base of their rocky slopes, which prove to be „cold scree slopes" [*cf. Delaloye et al., 2003, Gude et al., 2003*]. The problem of sporadic permafrost existence at Detunata Goală was first taken into account when observations were made about low temperatures of the water spring during summer and highly negative thermal values at the base of the snow cover (BTS values), the main explication issued until now being the quasi-total shading topographically imposed on the basal debris deposits [*Urdea, 2000; Urdea et al., 2004*]. Nevertheless, the importance of rock deposits porosity and its correlation with the slope has not yet been quantified, and we assume that it defines the ideal air circulation model that allows ice preservation in this area.

Within this study, new investigations were made, in order to: a) detect the cold and warm sectors on the debris surface (thermal mapping of the scree – BTS – in two different time intervals), b) multiannually record the air and debris thermal regimes (in different points on a longitudinal profile and at multiple depths), c) observe the snow funnels appearance, d) monitor the air circulation within the snow funnels by instant measurements at different depths, e) detect the internal structure of the basal debris (geo-electric tomography). In the same time, debris textural analyses were made by measuring the dimensions and orientations of the basalt clasts, in the attempt to identify the processes that determine the highly negative thermal anomaly from the lower sectors of the „cold scree slopes".

The main finding was that the dimensions and forms of the clasts (basalt columns fragments) impose a high porosity of the debris deposit, which favours the intense air circulation during winter that consists in cold atmospheric air infiltration in the basal part of the scree, simultaneously with the evacuation of the warm air in the upper part. This circulation remains active even in the time intervals with a thick snow cover. This circulation is responsible for the overcooling of the lower third of the scree slope at Detunata and for the formation of some massive ice structures which, due to their large sizes, preserve (with significant volumetric reduction) until the end of autumn, when the ice-formation process re-initiates between the boulders. This process dictates the strong difference between the mean annual air temperature (6.9 °C) and the temperature of the air within the debris (0.5-1.5 °C) in the time interval of our investigations (2009-2011). In the same time, the BTS maps show the position of the cold surfaces and of the cold air infiltration sectors respectively, designing the pump of the „thermal engine" responsible for permafrost existence. In this context, the presence of perennial ice is highly probable at Detunatele. Nevertheless, extending the geophysical investigations (GPR, electric resistivity) between the rocky slope (source area for the debris) and the forest is necessary for providing supplementary information about the permafrost extension, the thickness of the debris deposit and the structure of the active layer.

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The Analysis of the Temporal Structure of Conditions on the Territory of the Urengoy Oil and Gas Field (the Case of the Southern Forest-Tundra)

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Abstract

The preliminary analysis of the data of the Novy Urengoy weather station was carried out. The daily conditions typical of the southern forest-tundra were identified on the basis of the primary data with the help of N.L. Beruchashvili's methodology for study of the contribution of daily conditions to the annual functioning regime of natural territorial complexes (NTC).

Keywords: NTC (natural territorial complex); stex; temporal structure.

The following aspects of the natural territorial complex structure are currently identified:

- morphological (horizontal) structure - ordered NTC systems of lower range being a part of a larger one;
- vertical structure – storied positioning of the components forming the NTC;
- temporal structure – daily and seasonal rhythms and centuries-long fluctuations of nature conditions [*Pashkang et al. 1986, Beruchashvili 1986*].

Daily dynamics. The day-night biorhythm causes temperature, humidity and air movement fluctuations during a day. The change of lighting and weather conditions determines the daily dynamics of the landscape biota. Unlike plants, among animals it is not limited by physiological alterations in the organism, but is frequently supplemented by daily migrations. The daily rhythmics is also typical of geomorphological processes ongoing in landscapes. It is most noticeable in the areas with the dominance of physical weathering, but also occurs in this or other form in other zones. [*Khromykh 2006*].

The methodology of study of the daily conditions contribution to the NTC annual functioning cycle was initially suggested by N.L. Beruchashvili for the Great Caucasus. In the cryolithozone the annual cycle (spectrum) of NTC daily conditions depends much on such parameters as air temperature, humidification temperature and humidification regime. The hydrothermal regime in the surface layer (air - soil and vegetation cover - seasonally thawed layer) defines the intensity of the biological circulation, the energy balance of the NTC and its development (conditions alternation). This, in its turn, significantly influences the nature of permafrost distribution, its thermal regime and seasonal thawing depth as well as the manifestation intensity of cryogenic processes. The high degree of inter-landscape relations allows us to use the annual cycle (spectrum) of NTC conditions as the indicator of the seasonal thawing dynamics and the permafrost state in cryolithozone conditions.

V.V. Bratkov suggested the methodology of N.L. Beruchashvili on the basis of the earlier conducted station studies for investigation of the temporal structure of the Great Caucasus landscapes. This methodology allows us to simulate the daily conditions – stexes – on the basis of the reference weather station data. These stexes are the key ones in the NTC dynamics understanding [*Burym 2010*].

According to N.L. Beruchashvili, the NTC condition is some correlation of parameters characterizing it during a time period in which the specific input impacts (solar radiation, precipitation etc.) are transformed into output functions (discharge, some other gravity flows, phytomass increment etc.).

The results of analysis of the NTC temporal structure are of theoretical interest. They allow us to compare the temporal NTC structure of this area with the NTC of other areas in order to define similar and different features. The assessment of landscape stability is another important task of theoretical and practical interest.

The understanding of the processes flowing in the NTC allows us to register and analyze the space-time variability of NTC conditions qualitatively and quantitatively. The NTC structure must be understood to solve the task set. For this reason, the field works were continued on polygons in 2011. They were aimed at metering the thickness of the seasonally thawed layer and the permafrost temperature on the territory of the Urengoy field. We will try to use and adapt the methodology suggested by N.L. Beruchashvili for NTC structure understanding.

The identification and the designation of stexes should be conducted with regard to the gradations of: 1) the thermal regime, 2) humidification conditions and 3) trends in the vertical structure change.

Stexes characterized on the basis of the same trend of the vertical structure change, the commonality of the functioning processes flowing and the maximum duration during a month are united by him into groups. The preliminary analysis of the weather data was made for the southern forest-tundra, from the station in the town of Novy Urengoy. It made it possible to identify the approximate set of stexes and unite them into the following groups. The summer season groups were identified on the basis of humidification conditions: Izb – a group with overhumidification, Dos – a group with sufficient humidification, Um – a group with moderate humidification, N – a group with insufficient humidification, Sk - a group with poor humidification. U – groups of the transitional period; they are identified on the basis of the temperature: from 0 to +15°, the functioning is associated with formation and/or complication of the phytogenic structure (spring period, U+), or with its destruction and/or simplification (autumn period, U-). Winter season groups: Z – snowless conditions of the cold period; H – nival conditions.

The weather data on the daily and monthly mean temperature, precipitation, the number of days with snow and the snow cover height for the period of 2006-2011 were used as the basic materials. The MS-Excel software was used for basic material processing. It allowed us to identify the conditions.

The average values show that nival (H) conditions are characteristic of the biggest part of the year - about 60%, and 35% falls on the transitional period (Fig. 1).

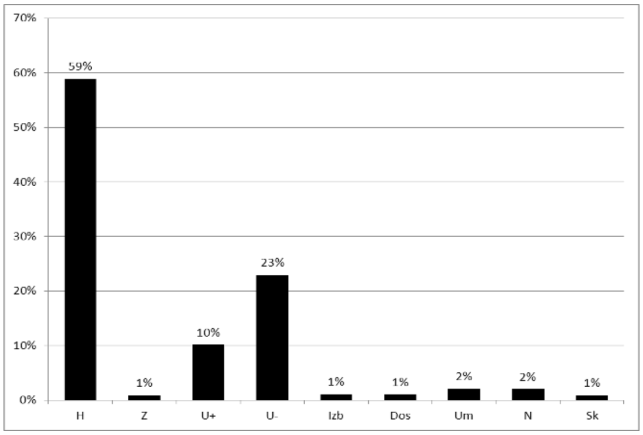

Figure 1. The average occurrence of condition groups in the southern forest-tundra (the area of Novy Urengoy).
Legend: Z – snowless conditions of the cold period; H – nival conditions, U – transitional period groups, Izb – a group with overhumidification, Dos – a group with sufficient humidification, Um – a group with moderate humidification, N – a group with insufficient humidification, Sk – a group with poor humidification.

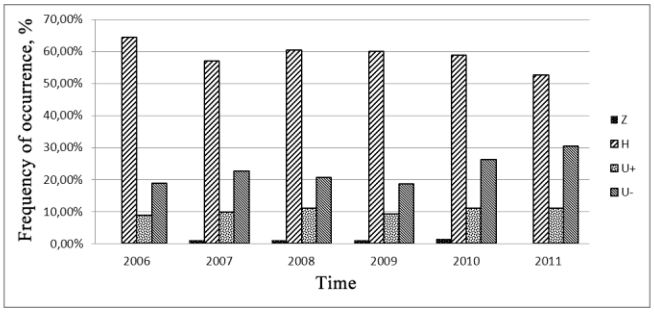

Figure 2. The occurrence of groups of the nival and the snowless conditions of the cold and the transitional periods in the southern forest-tundra (the area of Novy Urengoy) between 2006 and 2011.
Z – snowless conditions of the cold period; H – nival conditions, U – transitional period groups.

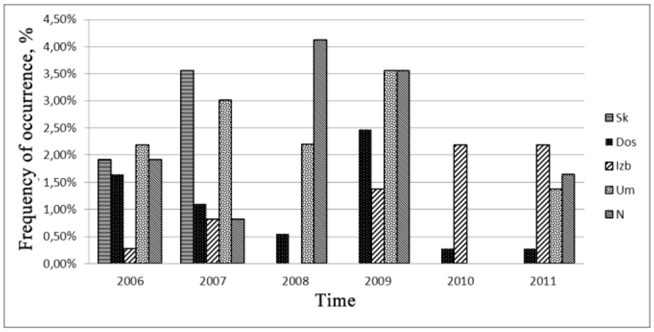

Figure 3. The occurrence of groups of the summer conditions in the southern forest-tundra (the area of Novy Urengoy) between 2006 and 2011.
Izb – a group with overhumidification, Dos – a group with sufficient humidification, Um – a group with moderate humidification, N – a group with insufficient humidification, Sk – a group with poor humidification.

Although the analysis of the groups by years allows us to speak of rather a high mobility of these conditions, except for the spring transitional period that is relatively stable and occupies 8-11%. The summer season that is usually the shortest has the highest variability - from 2% to 11% (Fig. 2, 3).

The preliminary analysis showed that it is competent to use the methodology for the cryolithozone area in order to receive the reliable results. Field research, the increase in the number of weather stations and larger time periods are required for that.

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Physical and Mechanic Properties of Perennially Frozen Ground in the Chayanda Oil-Gas-Condensate Field

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Southwestern Yakutia has been lately a rapidly developing producer of petroleum, coal, and base metals. The Chayanda oil-gas-condensate field is one such area under development.

The Chayanda field lies among perennially frozen slope wash (talus) and eluvium deposits. The present slope-wash facies consists mainly of clay and lies over older eluvial dolomite and marl weathered to different degrees.

The frozen ground of the area has low contents of ice (i_i < 20 %) which is mostly massive. Locally there occur layered ice-rich soils (i_i = 30 – 40 %).

Our principal objective has been to study physical and mechanic properties of soils in laboratory with implications for modeling parameters. Special attention was given to grain sizes which were important for further determination of mechanic properties.

The physical properties of soils measured in laboratory were:

- density, in g/cm³;
- total moisture content and moisture at the fluidity and plasticity limits, in % or fraction of a unit;
- grain size composition, in %;
- salinity, in %;
- relative organic matter contents, in % or fraction of a unit.

On this basis, input model parameters were determined.

The density of soils was estimated by inverse distance weighting (IDW) in 0.78 g/cm³ neutral liquid (kerosene) at -1.5 ºC. The obtained density values were in the range 1.95 to 2.40 g/cm³. The high density is due to the eluvial origin of the soils with relatively low percentages (15 - 20 %) of coarse >10 mm clasts.

The total moisture was from 10 to 30 %, or locally up to 54 – 72 % (in boreholes 31, 60, 65, 67). The samples were collected from the active layer, and their high total moisture indicates the presence of groundwater in the active layer at the time of freezing.

As for the grain size composition, over 80 % of particles are smaller than 0.1 mm.

According to salinity and organic matter, the soils are weakly saline or non-saline and have low peat contents. Laboratory analyses for the latter properties were applied to a few selected samples.

All measurements of the physical properties of soils were performed following the State Standard regulations (GOST 5180-84: Soils. Methods of Laboratory Measurements of Physical Properties).

The mechanic properties of frozen ground were studied proceeding from its grain size compositions. The soils consisting of ≤ 10 mm particles were tested using compression, ball stamp, and single-plane shear methods, in frozen state at -1.5 ºC.

Strong semi-rocky and rocky soils were tested by means of uniaxial compression in water-saturated and air-dry samples. Some heavily fractured semi-rocky and rocky soil samples were subjected to the uniaxial compression tests at a negative temperature of -1.5 ºC.

All measurements of the mechanical properties of soils were performed following the State Standard regulations (GOST 12248-96: Soils. Methods of Laboratory Measurements of Strength and Deformation Properties).

Formation of the Temperature Regime of Foundation Grounds and the Assessment of Engineering Facilities' Stability at the Zapolyarnoye Field during Current Climate Fluctuations

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The standard procedure of regime geothermal observations during geotechnical monitoring in spring and summer provides the basis for the assessment of the foundation grounds condition at the moment of geothermal measurements. However, in view of the developing climate fluctuations, this procedure is not sufficient in terms of timely identification and tracking of the trends in the thermal state of the grounds within a long-term cycle.

In order to solve this problem at the Zapolyarnoye field, monthly geothermal monitoring in background wells of various engineering facilities has been carried out since 2004 at large production sites with the most complex geotechnical systems.

The principle used to choose the monitoring points is similar to that used for choosing key sites for permafrost geotechnical site investigations. 28 thermometric wells characterized by a particular set of natural and technogenic factors were chosen for this purpose.

According to the results of current investigations in the background wells, foundation grounds are divided into two main types based on the formation of their thermal regime.

1) Foundation grounds of site engineering facilities with ventilated crawl spaces (gas treatment and dewatering workshops; auxiliary and maintenance buildings; car garages; warehouses).

Heat transfer conditions on the surface of foundation grounds of such structures are the most optimal for annual maximal cooling of grounds.

2) Foundation grounds of engineering facilities with different levels of on-surface snow accumulation (masts; racks; open sites with different types of equipment).

The decisive factor in terms of thermal regime formation of such structures is represented by the type of snow accumulation on their surfaces.

Depending on the design solutions concerning the use of seasonally operating cooling units (SOCU), and in order to increase the bearing capacity of grounds, the above-mentioned types of foundation grounds are divided into the following subtypes:

"a" - without SOCU

"b" – with SOCU

The existing results of investigations allowed to determine the thermal regime development pattern and to assess the maintainability (sustainability) of the mentioned types of engineering facilities.

1a) Foundation grounds of site engineering facilities with ventilated crawl spaces, without SOCU, Figure 2.

Thermal regime of the grounds is characterized by seasonal amplitude fluctuations. Minimal values t_{av}.min = – 4.0 ÷ – 6.0°C (in April and May), maximal values t_{av}.max = – 1.5 ÷ – 3.5°C (November). Within the period of observations, the geothermal regime can be characterized as stably satisfactory.

1b) Foundation grounds of site engineering facilities with ventilated crawl spaces, with SOCU, Figure 3.

Thermal regime of the grounds is characterized by clearly expressed seasonal amplitude fluctuations. Minimal values t_{av}.min = – 7.0 ÷ -10.0°C (in March and April), maximal values t_{av}.max = – 2.5 ÷ –3.5°C (November). Maintainability of foundation grounds and foundations of these facilities is very high with additional reserve of cold in ground. The cold-accumulating potential of the grounds is not exhausted.

2a) Foundation grounds with various on-surface levels of snow accumulation, without SOCU, Figure 4.

With snow cover thickness more than 0.5 m, most of the winter heat exchange is screened. So, the grounds annually suffer from insufficient cooling. Due to the lack of annual cooling, foundation grounds on such sites can shift to the parametric failure state. The geothermal regime can be characterized as potentially non-stable.

2b) Foundation grounds with various on-surface level of snow accumulation, with SOCU or with a possibility to clean the territory from snow, Figure 5.

Along with the reduction of snow cover thickness due to regular cleaning of the territory from snow or the use of SOGU, the thermal regime demonstrates a clearly expressed amplitude pattern. T_{av} fluctuations vary within a wide range from 1 to 5°C. Every year in the winter period foundation grounds absorb the dose of cold required to maintain the design thermal regime.

The presented calculations evidence that, given the initially favorable engineering-geocryological conditions, natural cold resources in the region in question are sufficient to ensure the maintainability of the structures according to conventional construction solutions (ventilated crawl spaces). However, with regard to pessimistic estimates based on climate warming (according to opinions of some experts), the use of SOCU for additional accumulation of cold in foundation grounds becomes a reasonable solution.

At the current stage of operation and engineering of new facilities at the gas-producing complexes in similar natural and climate conditions, one should pay special attention to the elaboration of new methods aimed to ensure sustainability of the second type of engineering facilities (2a, 2b).

Monthly geothermal monitoring in the background wells of the production sites of gas-producing complexes ensures higher-quality assessment of the current state of foundation grounds along with the determination of their development trends. This, in turn, helps to make timely decisions on thermotechnical management and to provide the optimization of expenditures aimed to ensure reliable operation of foundation grounds and foundations in complicated geocryological conditions.

Thermoisopleth diagrams showing the development pace of winter and summer heat exchange in foundation grounds of the engineering facilities in question

Figure 1. Average monthly air temperature t, °C

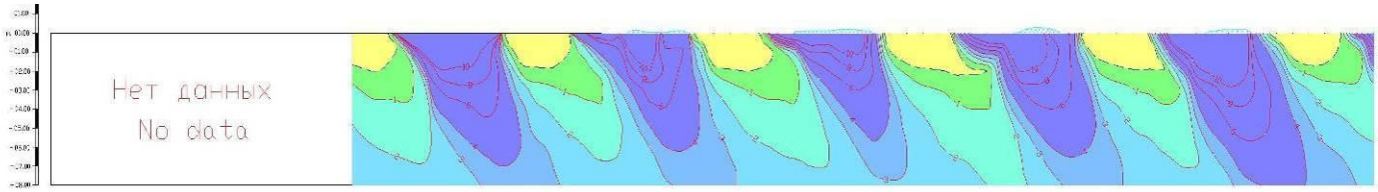

Figure 2. Foundation grounds of site engineering facilities with ventilated crawl spaces, without SOCU, **type 1a**

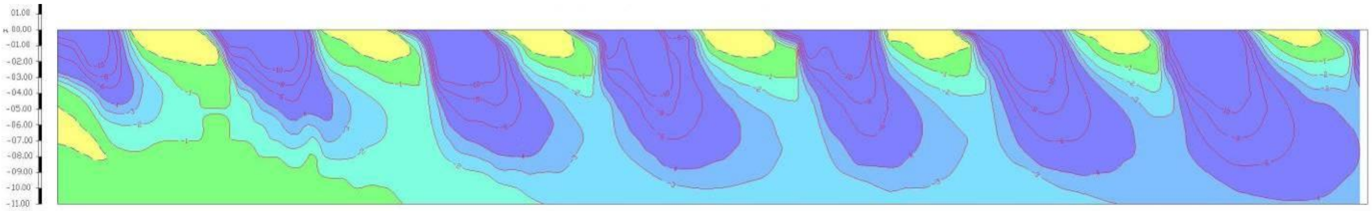

Figure 3. Foundation grounds of site engineering facilities with ventilated crawl spaces, with SOCU, **type 1b**

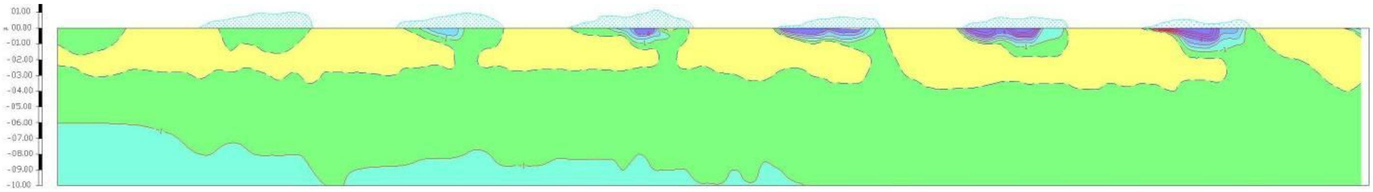

Figure 4. Foundation grounds of engineering facilities with various on-surface level of snow accumulation, without SOCU, **type – 2a**.

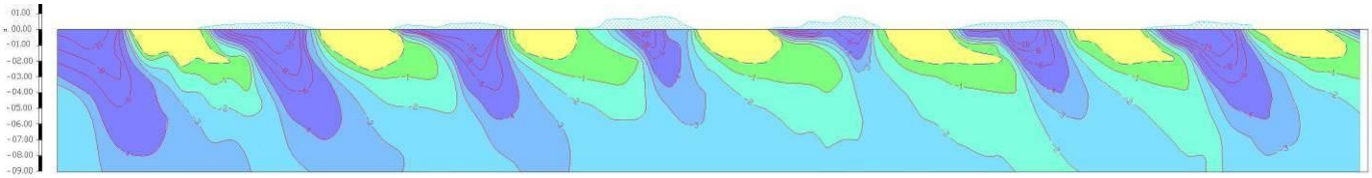

Figure 5. Foundation grounds of engineering facilities with various on-surface level of snow accumulation, with SOCU or with possibility to clean the territory from snow, **type – 2b**.

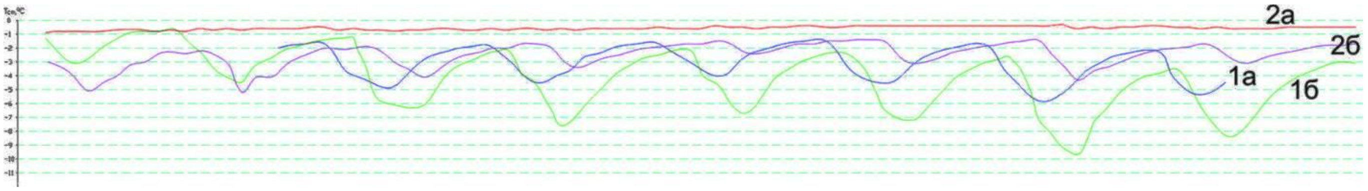

Figure 6. Dynamics of average ground temperature values within the operational range of the pile foundation from 2 to 10 m.

The Experimental Study on the Convection Process of Crushed-rock Layer

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As an important engineering measure for actively cooling embankment constructed on frozen soil, the crushed-rock embankment reduces the embankment temperature by adjusting its heat convection. The in-depth study about air flow characteristics in the crushed-rock layer is elemental to optimizing its structure and improving its performance. In particular, significance is the air flow characteristics and micro-wind speed measurement in the crushed-rock layer under various temperatures. Utilizing statistics-based simulations and laboratory & field experiments, researches have been conducted previously for the cooling effect, mechanism and influence factors of the crushed-rock layer in the crushed-rock embankment [*Cheng et al., 2007; Zhang et al., 2006*]. However, because of limited experimental conditions the convection process and air flow characteristics are only speculated based on the temperature or calculated through simulation [*Lai et al., 2005; Sun et al., 2006*]; such special phenomena as asymmetrical changes in temperature has not been effectively explained [*Xu et al., 2003*], and there are no detailed research or discussion on the relationship between the convection process and the temperature changes and influence factors. Forced convection does exist in the crushed-rock embankment when it is exposed [*Wu et al., 2006*], and through studying ventilation performance of the crushed-rock layer under strong wind pressure it is discovered that there is a nonlinear relationship between the convection speed and wind pressure, and the causative factors [*He et al., 2007*]. However, there is no published research information on natural convection caused by temperature difference or micro-pressure and the interrelationship when the embankment is closed. So the model experiment on convection process in crushed layer is conducted for the first time.

For the purpose of the unprecedented discovery of the air flow characteristics in the crushed-rock layer when the embankment is closed, in the model test of the crushed-rock layer, using high-precision measurement of micro-wind velocity to determine the natural convection velocity in the crushed-rock layer, the crushed-rock sample of which is sized 0.8×0.8×0.9m (length × width × height) with sealed and adiabatic boundary covered by the insulation material 20 cm thick (the coefficient of thermal conductivity is 0.02 $W.(m.K)^{-1}$) . Detailed experimental process and methods are described in the reference QIAN et al., 2012.

In the top of sample, the cyclical fluctuation of boundary condition was set as follow:

$$T = 1.2 + 14.5\sin(\frac{\pi}{12}t)$$

which controlled by the Ultra-Low Refrigerated Heating Bath Circulators (XT5702ULT, made in China, the accuracy was ±0.1ºC).

From the analysis of the natural convection process and temperature change process in Fig. 1, the cooling process in the crushed-rock layer is closely related to its natural convection process. As the airflow velocity is not zero, the convection cooling process appeared and the temperature decrease gradually, otherwise the convection cooling process disappeared. Under the scenario that there is cyclical temperature fluctuations on the top of the crushed-rock layer, temperature continues to decrease with concurrent occurrence of air flow in the layer, and the timing of convection accurately correlates to the cooling process at that particular location; in contrary, there is no obvious air flow when the temperature rises and the air is basically still. The alternation of the temperature-rising and -dropping states exist in the whole experiment to achieve the cooling process. In the crushed-rock layer, the temperature difference of that the top being lower than the bottom is the determinant of whether there is natural convection in the crushed-rock layer, and its air flow velocity. As shown in Fig. 2, as temperature difference increases, natural convection increase linearly, and a critical temperature difference is presented in the air flow. In light of the viscous resistance of the crushed-rock layer itself and its inner air flow process, the critical temperature difference is the equinoctial point of corresponding air gravity difference, and is associated with the diameter and type of the crushed rock, and the connectivity and size of air flow channel [*QIAN et al., 2011*] . The convection process of different depth in the crushed-rock layer is shown in Fig. 3. and descried as follows: firstly, partial convection is produced by the temperature difference of the top, the heat transfer process is intensified with the convection; secondly, a temperature difference is produced at the bottom, i.e. heat convection process; and lastly, the process is passed down herefrom to complete the entire heat transfer process. According to the analysis results in Fig. 3, the air flow mainly occurs in the area closer to boundary fluctuations, and its intensity weakens with increasing depth and decreases quickly at the bottom area. So the more thick of crushed-rock layer is not more cooling effect, there is an optimum thickness. At some time, the time difference of the air flow occurs indicate that the transitivity of heat transfer exists from top to bottom.

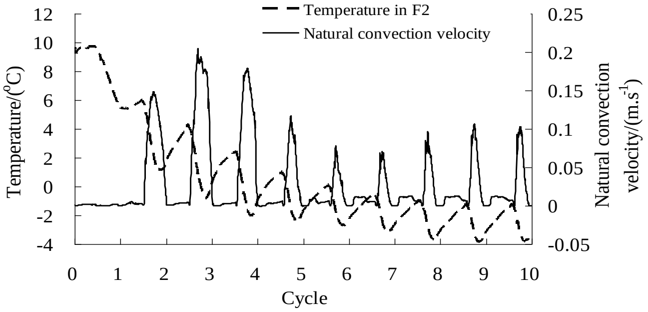

Fig.1 the change relationship between natural convection speed and temperature in F2 position, the F2 position is in middle of crushed-rock layer

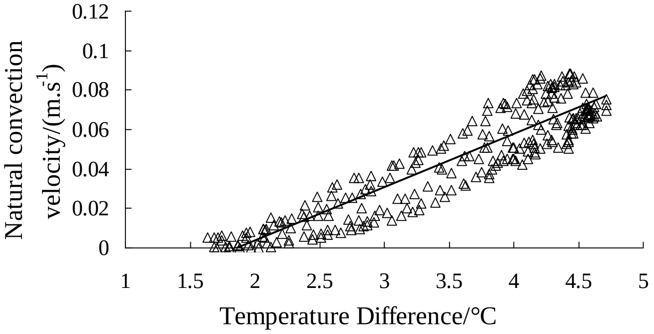

Fig. 2 The relationship between natural convection speed and temperature difference

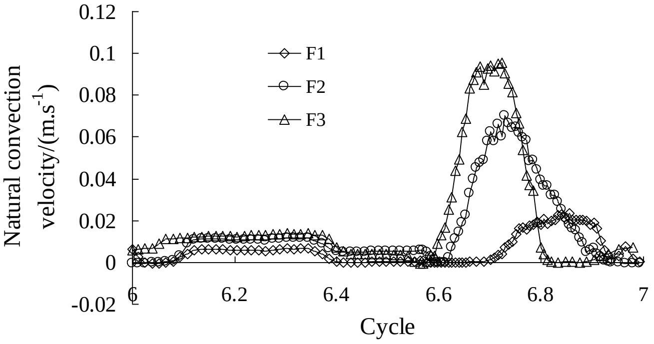

Fig. 3 The change process of the natural convection speed different position with time in crushed-rock layer. The F1, F2 and F3 stand for the natural convection speed in top, middle and bottom of crushed-rock layer

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Analyses on Thaw Settlement of Conventional Embankments in Warm Permafrost Regions

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Introduction

Some measures for protecting permafrost under an embankment were adopted to cool roadbed and lower permafrost temperature in unstable regions, particularly in ice-rich and warm permafrost regions along the Qinghai-Tibet Railway, however, there were still some sections of the embankment constructed traditionally, called as conventional embankments [*Wu et al.*, *2007; Mu et al.*, *2012*]. They performed a passive role of preventing permafrost from thawing by simply increasing thermal resistance [*Cheng 2005*]. Under global warming, the permafrost underlying roadbeds will be thawed inevitably, and then the embankments will generate great thaw settlement in warm permafrost regions. Therefore, the large strain thawing consolidation theory is proposed by combining large strain consolidation theory with UL (Updated Lagrangian) description and thermal conduction equation with phase change. Then thermal regimes and thawing settlements of earthen embankments with various heights in warm permafrost regions are researched according to the theory. Furthermore, an expeditiously and practically method is explored to obtained thawing settlement. The research works above could provide some scientific guidelines to future construction.

Results and Discussions

Based on the temperature, mechanics and geology conditions on the Qinghai-Tibet Plateau [*Qin 2002; Xu et al., 2010*], the thermal and deformation characteristics of the conventional embankments are analyzed for 50 years.

Thermal analyses indicate that permafrost table moves upwards slightly beneath the embankment with reasonable height in first few years after embankment construction in warm permafrost regions, but the uplifting amount is less than 15cm. However, the underlying permafrost warms significantly; the magnitude of warming is around 0.2°C in 5 years. Then owing to climate warming, the permafrost table begins to decline quickly after 4~6 years of embankment construction. The lower the embankment is, the larger the table's decline is. In 50th year, the permafrost table under the embankments of 2m high, 4m high, 6m high decline to depths of 4.15m, 3.7m, 3.3m, respectively, which exerts serious impacts on the embankment stability.

Fig 1 is the vertical deformations of embankment surface with various heights within 50 years after conduction. The deformations performs as ladder-type with years, also in a freezing and thawing cycle, the embankment deformation develops quickly during the warm seasons but slowly in cold seasons. And the higher the embankment is, the larger the thawing settlement is, the more remarkable the ladder-type phenomenon is.

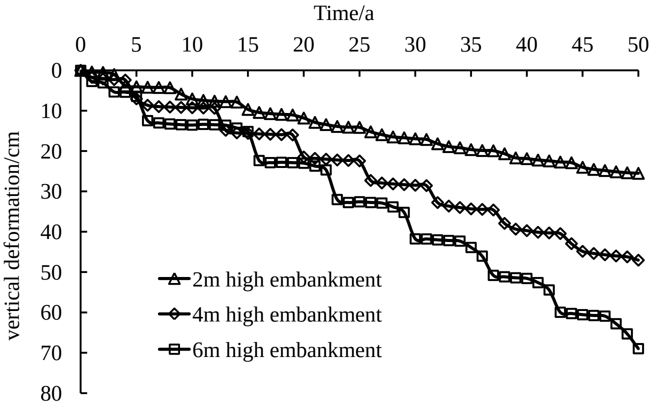

Fig1 Deformations of embankment surface with time

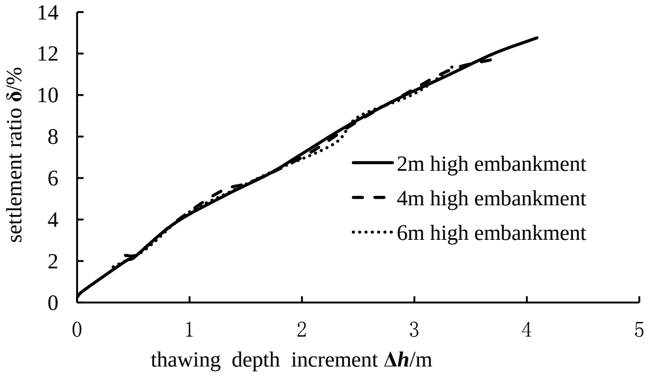

Fig 2 Relationship between settlement ratio and thawing depth increment

In order to investigate the complicated relationship between deformation and thawing depth, a settlement ratio, defined as embankment thaw settlement to its height, is proposed. It is found that this ratio is lineal proportional to the time, and will increases with a decreasing embankment height. Another variable, thawing depth increment, is defined as permafrost table underlying the embankment at present subtracting the standard table when it began to decline. Fig 2 shows the some functional relationship between settlement ratio and thawing depth increment. We find the three curves are greatly consistent, although each curve matches along with different embankment height. It indicates that settlement ratio is a function of thawing depth increment and is independent with embankment height. The function is as follows:

$$\delta=f(\Delta h) \qquad (1)$$

Thus, the thaw settlement of embankment surface can be obtained by:

$$S= f(\Delta h)H \qquad (2)$$

We could attain thawing settlement with different embankment height quickly and practically if the settlement ratio function is ready. Regression analysis is a useful access to seek the connection, the analysis results between settlement ratio and thawing depth increment is shown in the table 1. Taking into consideration of accuracy and practical applications, the linear equation should be selected.

Table 1 Regression analysis between settlement ratio and thawing depth increment

Equations	Parameters			R^2
	a	*b*	*c*	
$\delta=a(b-e^{-c\Delta h})$	31.262	1.0135	0.1241	0.99856
$\delta=a+b\Delta h$	0.8893	3.0699	——	0.99645
$\delta=a+b\Delta h+c\Delta h^2$	0.4490	3.7984	-0.1877	0.99854

Acknowledgments

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Pore Structure Change of Seasonal Frozen Soil Caused by Moisture Migration

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Introduction

In China, there is about 75% percent covered by permafrost and seasonal frozen soil, the percentage of the seasonal frozen soil can be more than 50%, which may occupy ten percents of the world's frozen ground area.

The characters in hydrogeology and engineering geology are very different in frozen ground region and none-frozen ground region. In nature, moisture migration is a very important part of the water-cycling. The structure of soil will be influenced significantly when moisture migration happens. So, in order to make sure that engineering, like road, house-building can develop smoothly, we have to study the change of pore structure in seasonal frozen soil caused by moisture migration.

Laboratory test

The moisture migration is the process that moisture distributes again in the soil. For unsaturated soil, when it is freezing, the outer weak bound water freezes first and with the effect of the temperature gradient, the bound water migrate to the freezing front. At the same time, the adjacent thick hydration film adds moisture to the thin hydration film, and moisture migrates to the freezing front, completing the process of moisture migration.

In the effect of moisture migration, unfrozen water migrates to the frozen area by driving force, and then the water becomes ice and has a 9% amount of frost heave, with the influence of the frost heave force, the pore in the soil changes.

There are many factors influence the moisture migration, like the initial moisture content, particle size composition, salinity etc. in order to find the pore structure change in the soil in the moisture migration, we do the test in macro and micro aspects.

The test material is from Sanzhigou district in Baicheng city of Jilin province in China. First we do the physical and chemical analysis including particle size composition, moisture content, and salinity, and then micro-structure tests of SEM.

Particle size composition measurement

The soil particle size is one of the basic properties of the soil. The finer the particle is, the larger the surface area will be and the stronger the water-holding capacity is, and the film of the water is easier to presence and migrates. In the condition of no dispersant, we do the test of particle analysis used the soil samples taken from Sanzhigou district. In the end, we get the conclusion that contents of the silt in the soil is 65%, the test soil belongs to silt clay group.

Moisture content and salinity measurement

Moisture content influences moisture migration obviously. It reflects the size of the pore structure, moreover, when the test soil column has high initial moisture content, there will be sufficient unfrozen water provides the ice crystals come into dense ice, and then the path of the moisture migration is lengthened and it is not conductive to moisture migration.

For salinity, the ice point is linear decrease with the salinity increases. When the salinity increases, the moisture content increases rapidly, this will make the path of the moisture migration longer and it is not beneficial to moisture migration. (The data of moisture content and salinity are shown in table 1).

Besides the factors we consider seriously above, we also consider the influence of the density that effects the moisture migration. Density can reflect the compaction of the material, and increase the density will improve the continuity of the film of the unfrozen water, and then it can provide more chance of moisture migration. If density keeps on increasing, the contact among soil particles will become closer and closer, then the moisture migration will be cutting off, at last, the migration flux will be lower.

Moisture migration test

In order to analyze the changing process of the soil's pore structure in the moisture migration, we make the soil samples to 170cm high and 95% density, and then we put it into the moisture migration instrument. Moisture migration instrument is a temperature control box, in the middle of the instrument is used to place the soil samples. At the bottom, there is constant water supply, The body of the instrument can be divided into three levels from top to bottom, every level can be identify like: high level ranges from170cm to 130cm for simulating the temperature-15°C, middle level ranges from 130cm to 80cm for simulating the temperature -10°C, low level ranges from 80cm to 30cm for simulating the temperature -5°C. In order to improve the precision, after we connect the soil columns, we use blowing agent sealing the round holes. We make the test soil samples operate in the moisture migration instrument for three months, then we consider the moisture migration process comes to an end, and next step we will do the electron microscopy test to find the changes in the pore structure.

Table 1. Data of moisture content and salinity in the density of 95%

Height(cm)	Temperature(℃)	Moisture content(%)	Salinity(%)
30	Room temperature	16.39	0.2315
80	-5	21.44	0.3065
130	-10	18.28	0.331
170	-15	19.97	0.4415

Electron microscope scanning

When the process of moisture migration completes, we cut sample into four sections from 30cm, 80 cm, 130cm, and 170cm, respectively, and then coat film for the soil on section and use electron microscope scan the section of the soil (the density of 95% is shown in Fig.1). In the density of 95%, the average pore diameter is 4.357, 2.866, 3.462, 3.674 (the unit is micrometer) under room temperature, -5°C, -10°C, -15°C, respectively. For the variance of the average pore diameter is too high in some condition of temperature, we do the pore micro-analysis and find that on the temperature of -10°C, the content of the micro-pore(<1μm) is 68.25%, larger than other condition. So, we can see, the pore structure in 130cm is smallest. So, in the density of 95%, the discipline of the changes ranges from 30cm to 170cm is smaller first, and then become bigger.

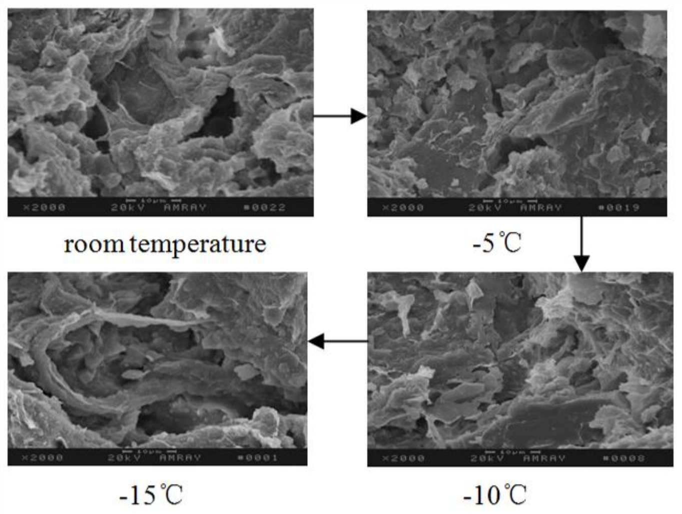

Figure.1 Soil pore structure scanned by SEM

With the analysis of the 2000 times SEM (scanning electron microscope) photographs above, we can see the style of the pore structure is loose. in the condition of room temperature, the pore structure of the soil samples is large, on the condition of -5°C, -10°C,-15°C, the size of the pore structure is larger and larger. With the temperature become lower, the micro-structure in the soil samples becomes smaller and the degree of the aggregation among the particles becomes bigger as a whole.

For the density of 95%, when the height is 30cm, pore structure is big; the degree of the aggregation is big. With the height higher, pore structure becomes small gradually, this is because, when the temperature decrease, the unfrozen water freezes into ice partly, when the ice crystals increase to a certain extent, it will produce displacement to the structure unit of the soil particles, and the displacement of the structure unit leads to the pore become dense. But, when the height comes to 170cm there will appears a new change, pore diameter becomes larger slightly, because of the high-density and lowest temperature, the frost heave caused by the moisture migration will be obvious.

Conclusions

I. The seasonal frozen soil in Sanzhigou district is mainly constituted by silt particles, so the frozen-heave character and moisture migration is intensified.

II. In the density of 95%, the pore diameter first become smaller then larger with the height ranges from 30cm to 170cm, moreover, because of the high-density of 95%, the path of moisture migration is hard to form, so the total moisture content is not high, the change of the pore is not obvious.

III. For the density of 85% and 90%, their laws are similar, their pore structure both become smaller first and then larger again smaller ranges from 30cm-170cm, and the maximum pore structure comes in 130cm, this is because the moisture in the top area migrate down by the gravitational potential. With the data of moisture content, we can see that most of the location is higher than the initial moisture content, this means the density of 85% and 90% are appropriate to moisture migration.

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Influence of heat balance components on permafrost dynamics in the Sytykan waterwork

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Abstract

Heat transfer on the permafrost surface and heat-and-mass transfer in bypass filtration have been studied in terms of their influence on permafrost stability, by means of nondestructive testing.

Keywords: Bypass filtration; heat transfer; nondestructive testing.

Waterworks are the least secure engineering structures built in permafrost as they perturb the geological environment, mainly by inducing permafrost degradation. The degradation process deteriorates dams (key elements in any hydraulic structure) and their junctions from which frozen ground receives most of mechanic and heat loads. Furthermore, thawing of permafrost interferes with the natural kinetics of intra-permafrost groundwater and may trigger large-scale bypass filtration.

Bypass filtration occurs at many hydraulic structures in Western Yakutia (e.g., Sytykan or Viyui Hydro I-II) and has been a subject of several research projects at the Institute of Permafrost (Yakutsk). Currently studies in this line have been run at the Vilyui Permafrost Station, by a joint team of the Institute of Permafrost and the Department of Geography, Moscow University, under the leadership of S.A. Velikin. The studies include qualitative assessment of surface and subsurface heat exchange as a control of the permafrost thermal state at the right-side junction of the Sytykan dam.

The sharply continental Subarctic climate in the area is very dry, with long (about 7 months) cold (t_{Jan} = –41.7ºC) poorly snowy winters and short, dry, and often rather cold (t_{July} = +14.8ºC) summers [*Gavrilova 1970*]. The mean annual air temperature is –13.2ºC, and daily amplitudes may reach 34ºC.

The Sytykan waterwork is located in the Daldyn-Alakit Plateau. The terrain in its vicinity consists of higher or lower hills and ridges; the river valley is U-shaped, with a flat bottom. Geologically the site is composed of Lower Ordovician limestone with lenses of weathered marl. The rocks are heavily fractured (30 % crack space on average) and have low ice contents (5 to 10%). Cracks are either bedding-parallel or are thermal contraction features making columnar jointing.

The area belongs to the zone of continuous permafrost, up to 500-600 m, under a 0.7-3.1 m thick active layer. Prior to the dam construction, the ground temperature at 5 – 10 m below the surface varied from minus 5 to minus 10ºC.

Perennial epigenetic ground ice is either massive or is associated with thermal-contraction cracks or karst. The lower section of the permafrost consists of frost-bound rocky ground. The river floodplain was composed of syngenetic wedge ice before the reservoir lake appeared, and the valley right side was perennially frozen, except a talik underneath the river bed. The talik has been growing since the onset of damming, and currently almost the entire valley side is unfrozen.

Groundwaters in the area are of three types: highly saline sub-permafrost, intra-permafrost, and supra-permafrost waters. The confining pressure comes from the frozen rocky-soil dam, which is actually unfrozen. The design presumed that the dam and its right-side junction would be impermeable for water due to a permafrost curtain maintained by air and liquid cooling systems, but their operation failed to lead to the wanted end.

Filtration flows responsible for heat exchange between the permafrost and the underlying subsurface were investigated using geoelectrical tomography in which the geoelectric pattern was obtained by processing measured apparent resistivities. Resistivity variations have implications for geology as well as for the state of rocks: frozen, frost-bound, unfrozen, or water-saturated.

The linkage between the reservoir lake and intra-permafrost water was studied with statistical methods, namely, by means of the correlation analysis of water levels in nineteen pressure-observation wells and in the lake.

The landscape approach was applied to study heat exchange on the permafrost surface. Five landscapes as indicators of permafrost conditions were distinguished in a *Google Earth* image, following Klimovsky & Gotovtsev [*1994*] and Gotovtsev [*1996*], and proceeding from our field data. They are, namely, taiga-like, forest-tundra, and anthropogenically disturbed landscapes, as well as roadways as a separate landscape variety. Then the thermal data were correlated with the geoelectric tomography results.

Interpreted jointly, the obtained data reveal a mostly destructive effect of filtration flows. The frozen ground above the filtration depth interval was expected to be stable being beyond the degradation temperature limit (below -1ºC). Therefore, the riverside warmed up unevenly after the dam lake was filled. Warming involved mostly the lower parts of the slopes and flooded plains with high ice contents. As the ice thawed out, the unfrozen ground became moistened which, in turn, caused further warming and opened the pathways for filtration (note that unfrozen ground is heavier than the frozen one, and moreover the rocks are limestone).

The ice-poor areas off the riverside pose no barrier to filtration, this being evident from high water level correlation between the dam lake and the piestic wells. Furthermore, the filtration flows lie within annually and seasonally active permafrost in their upper part. The filtration-induced heat input into the active layer changes the temperature patterns both below and above it, and deprives the ground of the cold it stores. This accelerates permafrost degradation and increases the filtration rate.

The climate- and vegetation-controlled temperature variations on the surface are of secondary importance and do not show up in the resistivity pattern.

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Thermal Interaction of the "Vertical Flare - Permafrost Foundation Ground" System with Regard to Radiation and Vaporization

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Flares for emergency gas burning are an integral part of any oil and gas field today.

Most of the hydrocarbon deposits in Russia are located in the range of permafrost. The work of flares has a negative effect on permafrost, on the foundation of a flare itself, and on the foundations of the buildings and structures located within its influence.

Therefore it is important to find the ways of predicting the interaction in the "flare – permafrost" system and to develop technical solutions aimed at preserving the carrying capacity of the foundations of flares as well as of other surrounding structures [*Dmitrieva et al. 2011*].

Taking into account that the radiation of a burning flare forms high temperatures on the ground surface (well above 100°C), the processes of not only melting, but also of vaporization are taking place in the ground. Typically, in the existing programs of thermal calculations the "water – steam" phase transition is not taken into account, as well as the changes of ground moisture in the process of steam generation.

This paper evaluates the impact of evaporation in grounds under the influence of the radiation of a burning flare. This study was performed using a special program based on the method of thermal resistance designed by L.A. Duginov and M.Kh. Razovskiy [*Kutvitskaya et al. 2011*].

This program allows to take into account such parameters as the height of a flare, flame size, heat flux, the speed and direction of wind, surface temperature as well as phase transitions "ice - water - steam", and the changes of ground moisture during the phase transitions. These factors significantly affect the depth of thawing, the distribution of temperatures in ground mass, and, consequently, the technical solutions related to the provision of a flare stability.

As an example, a flare with a following mode of operation was considered: one year continuously, then 10 days a year throughout its lifetime (30 years). In the mode of combustion the temperature on the surface at the foundation of a flare stack is 200°C.

A geological cross-section at the foundation of a flare used in the calculations is compiled of confluent permafrost and represented by sandy and clayey silty grounds. Ground temperature at the depth of zero annual amplitudes is set at minus 1.4°C.

The zone of a maximum heat load within 50 m from the flare is examined in the predictive thermotechnical calculations.

Calculation results showed that the consideration of the "ice – water – steam" phase transitions and consequent changes of ground moisture significantly affect the ground temperature regime. This is clearly confirmed by the dependences presented in Figure 1: the depth of ground thaw is increasing directly below the flare stack during a 30-year operation period with the above mentioned mode of operation, and in Figure 2 – by comparing the depth of the location of the "water - steam" front during the period of continuous flare burning in the first year.

Depending on the type of flares (vertical or horizontal) and their parameters (temperature and the duration of burning, height, flame size, etc.) the temperatures on the ground surface can be much higher than those in the example (over 300 ... 600 degrees). In this case, the contribution of evaporation and ground moisture changes to the formation of the foundation's thermal state becomes bigger.

In order to reduce the influence of thermal radiation from a burning flare some technical solutions are suggested and substantiated by calculations. These technical solutions ensure the preservation of the bearing capacity of the pile foundation of a flare for the entire operation period.

These solutions are conventionally divided into two groups:

- design measures that reduce the radiation flux from the flare to the ground surface;
- heat-insulating elements being laid in ground foundations in order to reduce the depth of thawing in the zone of flare influence.

In the first group reflective screens that are installed near the flare and (or) foundations are considered. The screens allow to reduce the influence of radiation in the local areas of the surface, which, in addition to reducing heat flow to the ground, is necessary for the functioning of various types of seasonal cooling devices (e.g., heat stabilizers).

The second group includes horizontal or inclined layers made of thermal insulation materials (heat shields) placed into the ground to protect permafrost from multi-year thawing and subsidence.

Whereas the measures from the first group are expensive and their effectiveness may decrease during operation (due to the contamination of reflecting surfaces), heat shields are easy to use, and their heat-shielding properties are practically permanent.

The latter refers to modern extruded polystyrene foam materials that have low thermal conductivity, high durability and low water saturation, which makes them effective for the use in ground foundations.

However, the use of these materials is limited by temperature range – the maximum allowable temperature should be not more than 60…80°C. At higher temperatures at the foundation of a burning flare traditional materials such as keramzite gravel cannot be used because of the shortness of their work in the conditions of changing moisture and temperature.

The most effective solution under the conditions of high temperatures is a variety of materials including, for example, foam glass.

In this paper we developed a solution using two types of heat shields laid at the depths where the materials are capable of withstanding a ground temperature created by a flare. Thus, the results of predictive thermal calculations of the foundation that take or do not take evaporation into account are crucial for estimating the economic efficiency of technical solutions in a foundation.

As one can see in Figure 2, the difference in the depths of "water – steam" phase transitions (boundary temperature 100°C) at the calculation with or without allowance for changes in moisture content is about 1.5 m only after the first year of flare functioning. The consideration of the "water – steam" phase transition allows to lay heat shields made of, for example, polystyrene foam plates that can withstand the temperature of not more than 60 degrees not at the depth of 3.5 m (if the "water – steam" phase transition is not taken into account), but at the depth of 2.0 m. At higher ground temperatures the effect is more substantial.

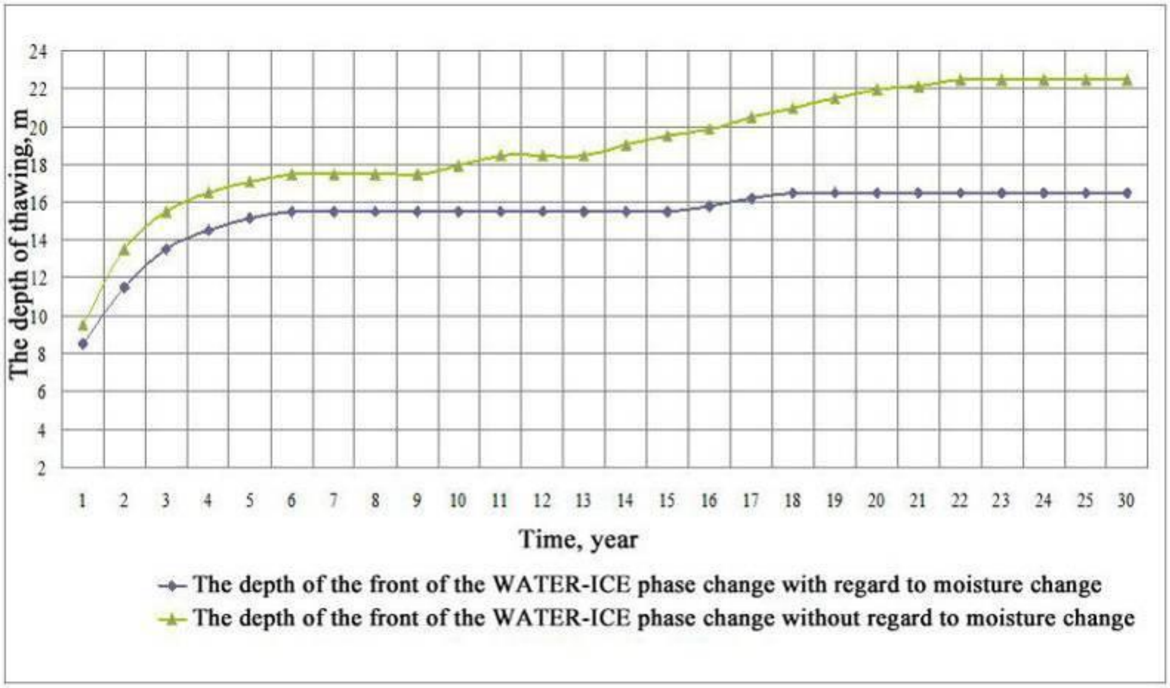

Figure 1. Comparison of the dynamics of ground thawing with or without consideration of moisture changes during "ice - water" phase transition

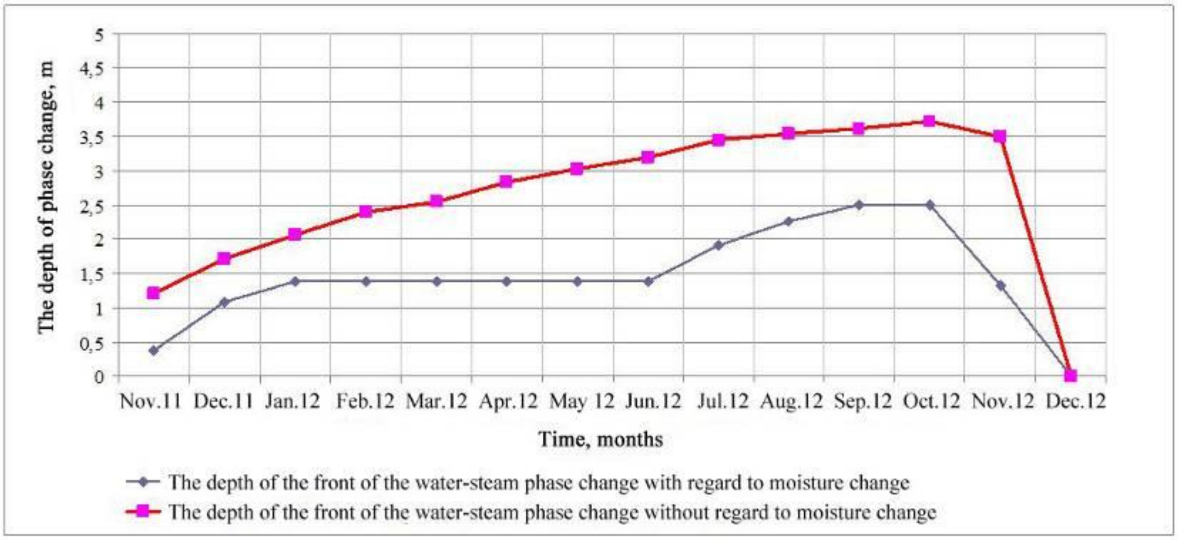

Figure 2. The depth of the front of the "water-steam" phase transition at the surface temperature of 200°C

To ensure the preservation of the bearing capacity of a pile flare foundation during the whole period of its operation one can also use traditional methods such as setting adjustable supports at the feet of the flare and a reflective canopy.

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Application Efficiency of Arctic Backfill Systems in the Intervals of Occurrence of Frozen Grounds

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Abstract

The requirements to improve the quality of well casing in permafrost cause the necessity to use complex backfill systems. This work describes the laboratory studies and the field application of backfill systems for well casing at the Kharvutinskaya area of the Yamburg Field. The purpose of the work is to develop dry backfill blends that contain not gypsum as the main hydraulic-active component but various functional additives (microspheres and expanding additives). These multicomponent blends are more practical and do not require additional operations for transfer and mixing of individual components in drilling units before well casing. They do not lose their technological properties during long-term storage on open sites. It is noted in the work that introduction of the developed complex backfill blends leads to the improvement of the quality of the tubular annulus filling and to the cohesion coefficient in the system "casing - backfill stone - ground" equaling up to 0.7-0.95 within the permafrost interval.

Introduction

Most of gas and gas condensate fields discovered in the Far North areas are characterized with the occurrence of massive permafrost layers in the geological section. The main complications occurring in the process of well drilling and casing within permafrost intervals include intensive cavern formation, wellhead cone formation, backfill solution non-lifting to the wellhead and unsatisfactory cohesion of the backfill stone with the ground. Low static temperatures within permafrost intervals lead to an increase in the setting time and hinder the formation of the backfill stone with the required bearing and insulating capacity.

The problems of high-quality cementing of casings within the permafrost interval are significantly worsened by the presence of massive gas hydrate deposits in the permafrost structure.

This is primarily referred to gas and gas condensate fields of the Yamal Peninsula (the Bovanenkovo, the Kharasavey, the Malyginskoe fields etc.), to the Urengoy, the Yamburg and the Zapolyarny gas condensate fields, and also to the territories located in the Obsko-Tazovskaya Bay water areas where the geological section in the descending and support intervals of conductor string and of structural casing includes several complication zones. The upper levels covered by the conductor string (up to 40-120 m) represent frozen sandstones with a high ice content from 40 % to 80 %. The intervals from 120 m to 180 m are characterized with a lower ice content, while the presence of gas hydrates, cryopegs and taliks is noted. Deeper intervals - below 300 m - represent alternation of ice-poor sandstones and clay that is characterized with positive values of static temperatures and can include gas-saturated interlayers of natural or technogenic origin (the Berezovskaya suite).

Therefore, the load on light backfill solutions located from the depth of 200-300 m to the wellhead grows during the support of conductor string and structural casing in permafrost intervals.

Thus, the complex approach is required for the development of light backfill solution compositions for conductor string and structural casing support: on the one hand, measures should be taken to improve the cold endurance of the stone, minimize the emitted cement hydration heat, reduce the backfill stone heat-transfer coefficient and minimize the difference in the values of strength characteristics of the backfill stone located at the bottom and at the wellhead. On the other hand, it is necessary to reasonably improve the resistance of the solution and of the backfill solution stone to gas showings, i.e. improve its gas-blocking properties, similarly to the technologies of cementing of the intermediate and the production strings.

The solution for the problem of the backfill solution uplifting to the wellhead and for the problem of formation of a continuous, low-permeable cement stone in the annulus seems possible with the help of light backfill compositions displaying increased hydraulic activity, a high bulk share of the solid phase and absence of shrinking deformations. Moreover, such compositions must be as simple in use as possible. All the required additives should be introduced into the factory-made dry blend composition.

This article is dedicated to the experience of development and application of such unique composition.

Development of an Alaska Thermokarst Lake Survey (ATLAS) Using Object-Oriented Classification of High Resolution Satellite Images

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Thermokarst lakes are common features and important ecosystems in Alaska [*Arp & Jones 2009*]. Understanding the dynamics and evolution of thermokarst lakes at the landscape level has important implications for the carbon budget in permafrost regions [*Walter et al., 2007*], hydrologic change that accompanies permafrost degradation, and habitat character and distribution [*Martin et al., 2009*]. In addition, thermokarst lake types vary across Alaska, differing in habitat character as well as impact on permafrost and carbon cycle [*Arp & Jones 2009*].

Currently available lake datasets for Alaska include the Global Lake and Wetland Database [*GLWD; Lehner and Doll, 2004*] with a minimum lake size of 10 ha and a revised version of the National Hydrologic Dataset (NHD) from Arp and Jones [*2009*] with a minimum lake size of 1 ha. However, these datasets represent historical lake cover, are constrained by spatial scale, exclude lakes that are smaller than 1 ha, and do not indicate thermokarst lake type. Our study attempts to map state-wide thermokarst lake distribution of Alaska using object oriented classification of high resolution satellite images and additional thematic geospatial data. In contrast to pixel-based classification method that classifies individual pixels solely based on its spectral property, object-oriented classification method aggregates spectrally homogenous pixels into image objects and, similar to a human image interpreter, can use spatial, textural and contextual parameters of individual objects to improve classification accuracy [*Liu & Xia 2010*].

As base dataset, we selected ortho-rectified and pan-sharpened SPOT-5 data currently processed by the Geographic Information Network Alaska (GINA) within the Alaska Mapped initiative that aims at providing a full coverage with high-resolution imagery for all of Alaska during the period 2008-2013. The raw SPOT-5 data is processed into ortho-tiles and a first set of tiles was available for lake classification tests in ATLAS.

Here we describe our approach for the lake and pond mapping for an area of approximately 62 km^2 south-west of Fairbanks, Interior Alaska, covering portions of the Bonanza Creek Long Term Ecological Research (LTER) site (Figure 1). The pansharpened SPOT-5 image of 2.5m spatial resolution for this area was acquired in the summer of 2009. The study site is characterized by thermokarst lakes and ponds, boreal forest, peatlands, and severe burn scars from recent fires.

In a first step for the lake classification, we pre-processed the image tile for better spectral separation of various surface types using visible and near infrared (NIR) bands. Particularly, spectral properties of water bodies and burn scars are similar in the visible range. Therefore, we performed a spectral transformation on green, red and NIR bands utilizing Principal Component Analysis (PCA) embedded in IDRISI image processing software to reduce data noise and increase the spectral separability between water and burn scars. PCA component 1 primarily contained information from the NIR band without noise and captured water bodies best. Water bodies in the first PCA component exhibited a very low value and thus were more distinct from burn scar.

We then used eCognition Developer 8.64 to perform an image segmentation and classification on a combination of PCA component 1 along with all the visible and infrared bands. We used a multi-resolution segmentation algorithm and utilized spectral properties, size and shape of image objects, which were produced by image segmentation, to map lakes with a minimum size of 0.1 ha. Even though separating burn scars from water bodies was a challenge, overall, our classification approach performed well in identifying lakes with an accuracy of 94.54% (Figure 1) compared to a manually digitized dataset of lakes for the same area that served as our ground truth dataset. The error of commission was 3.77%. This is because burn scar pixels were misclassified as water body. The algorithm had a smaller error of omission of 1.89%. Additionally, we visually compared our results with the NHD dataset for Alaska [*Arp & Jones 2009*]. Our classification method detected all thermokarst lakes and ponds (≥ 1 ha) that are present in NHD dataset for our test site. Our study shows that application of object oriented classification methods on high resolution satellite images is a promising tool for automated mapping of thermokarst lakes of Alaska. One of the major challenges will be coming up with generic lake classification methods on regional levels that can capture the large variability of lake types in different regions of Alaska to produce accurate thermokarst lake maps.

Next steps beyond this initial work will involve (1) the extension of this objected oriented classification approach to other regions of Alaska using the SPOT orthodata, (2) the implementation of additional ancillary data layers and parameters in the eCognition workflow, such as elevation, slope, land cover, permafrost distribution, and object texture, and (3) the development of region specific thermokarst lake-classifications to better suit the understanding of thermokarst lake dynamics in a variable landscape.

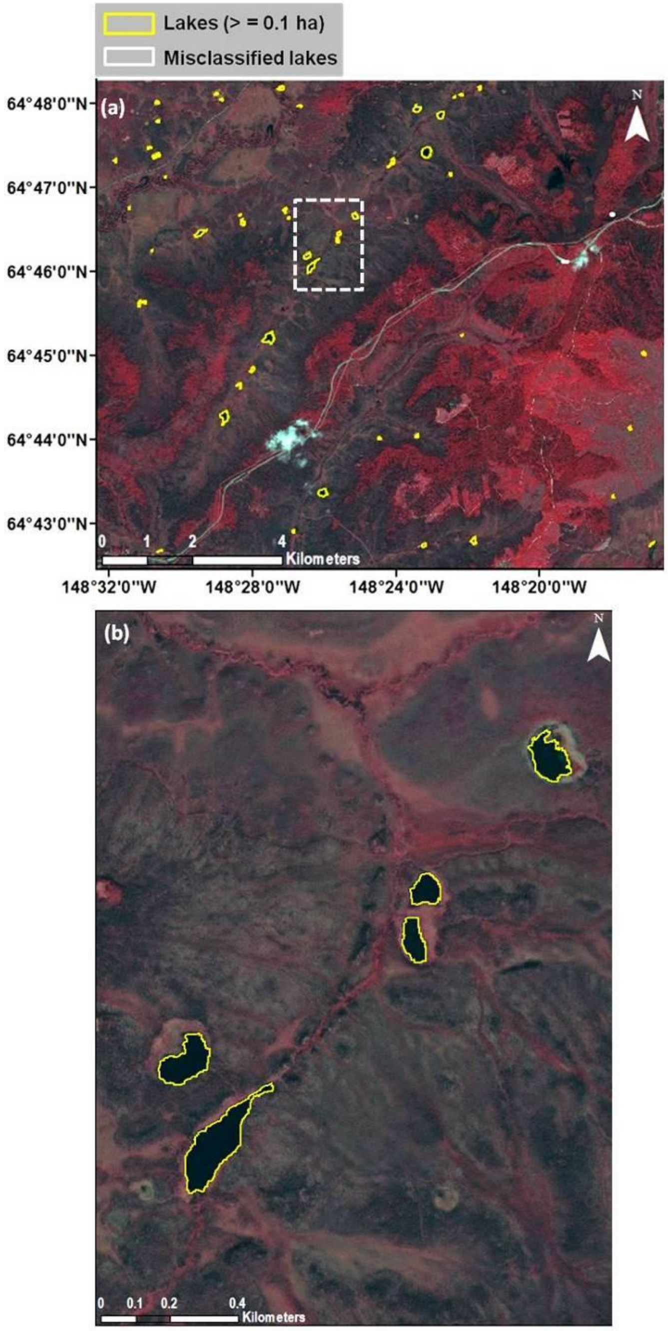

Figure 1. (a) Final classification result showing thermokarst lakes and ponds overlaid on pan-sharpened SPOT-5 image in false color composite of NIR, red and green bands and (b) zoomed area of the test site, highlighted in dotted white box.

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Geotechnical Maps in the Structure of Information Support of Engineering Research

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Abstract

Geotechnical maps in the structure of information support of engineering research in permafrost area are the final element of a thematic maps album. Their purpose is the interpretation of the results of engineering research in the form of suggestions for design solutions. Geo-information component of geotechnical maps based on spatial analysis allows to perform a quantitative and cost valuation of recommended projects.

Keywords: engineering-geocryological mapping, geotechnical mapping, geo-information mapping models, matrix system of zoning.

Introduction

Engineering-geocryological conditions largely determine the technical solutions adopted in the design. The creation of functional links between geotechnical conditions and adopted technical solutions allows to obtain direct information (spatial, quantitative, financial) concerning the results of the use of certain design options. The solution to this problem is always the goal of a complex of works in engineering research and design. Special maps for geotechnical purposes are one of the methods of solving this problem. Their analysis makes it possible to substantiate the choice of a certain design relying on quantitative data about the diversity of natural conditions and on the estimation of cost for different options of technical solutions.

The main principles of the method

The geo-informational support of engineering research is methodologically based on the creation of a system of stepwise mapping modeling of engineering-geocryological conditions that is implemented through the compilation of an album containing specialized maps of different scales. The content and structure of the album are defined both by the complexity and diversity of natural conditions as well as by the specifics of an object being constructed and the level of research detail. Geotechnical maps conclude the album of specialized mapping models and are developed on the basis of a standard map, which is a map of engineering-geocryological zoning [*Rivkin et al. 2011*].

The maps of engineering-geocryological zoning are developed based on the matrix schemes of zoning. The principle of their construction is based on the differentiation of factors and functional relations in the structure of the matrix that are pictured in each map. Moreover, the structure of a matrix should include both the factors determining the main regional formation patterns of engineering-geocryological conditions and the factors that determine the specificity of a designed object (including the particularities of its construction and operation). Thus, in order to create an album of mapping models of special and geotechnical content, the structure of the matrix should be differentiated with regard to the complex of natural and technogenic factors (including technological ones) [*Rivkin et al. 2003, Rivkin et al. 2004*].

In this aspect the matrix system of zoning is not only the form and method of organizing information, but it is also the basic element of the legend of geo-information mapping models.

Results

The solution of practical information support problems in engineering research for the construction of extended (transcontinental) pipeline systems and for the development of oil and gas fields allowed to develop techniques employed to create several types of geotechnical maps:

- Zoning map of the route with respect to the conditions of construction development;
- Zoning map of the route with respect to the physical and mechanical properties of frozen grounds;
- Zoning map of the route with respect to the value of the potential settlement of frozen grounds during thawing;
- Zoning map of the route with respect to the engineering solutions of pipeline laying (with cost estimate).

The first three types of maps are, as follows from their content, geo-information mapping models of the second level. They contain information obtained both in the course of geotechnical research and laboratory studies, as well as the information based on geotechnical processing. Thus, they are created on the basis of the analysis and transformation of basic information. As noted above, the role of a basic mapping model (the first level of geo-information mapping modeling) is fulfilled by a map of engineering-geocryological zoning developed on the basis of matrix analysis of the data of engineering-geocryological research. A zoning map with respect to the technical solutions of pipeline laying is a geo-information mapping model of the third or higher levels, since it is based on the results of geotechnical transformation of mapping models of the first and second levels.

Figure 1 shows the basic structure of geotechnical mapping model development, namely, a zoning map of the pipeline route with respect to technical solutions of its laying (block A in Figure 1). Based on the basic mapping model a database of major technical solutions was formed (block C in Figure 1). Other maps were used for this purpose in addition to the basic map: a zoning map of the route with respect to construction development, a zoning map of the route with respect to the physical and mechanical properties of frozen grounds, the map of ground settlement during thawing. The purpose of this phase is to develop an algorithm of the selection of technical solutions for pipeline laying. As a result of a complex analysis, a matrix analytical scheme of a route zoning with respect to the technical solutions of pipeline laying was developed, which is the main element of the map's legend (block B in Figure 1). A matrix analytical scheme defines only a range of technical solutions used in various engineering-geocryological conditions. The map shows their spatial distribution (quantitative). All this allows to obtain, on the basis of specialized calculation modules, the cost valuation of the application of chosen technical solutions and to quickly correct them. The combination of geo-information mapping models, calculation modules, and the database of technology solutions allows to provide information support for the project as a whole, ensuring the adoption of optimal solutions to adjust research and design.

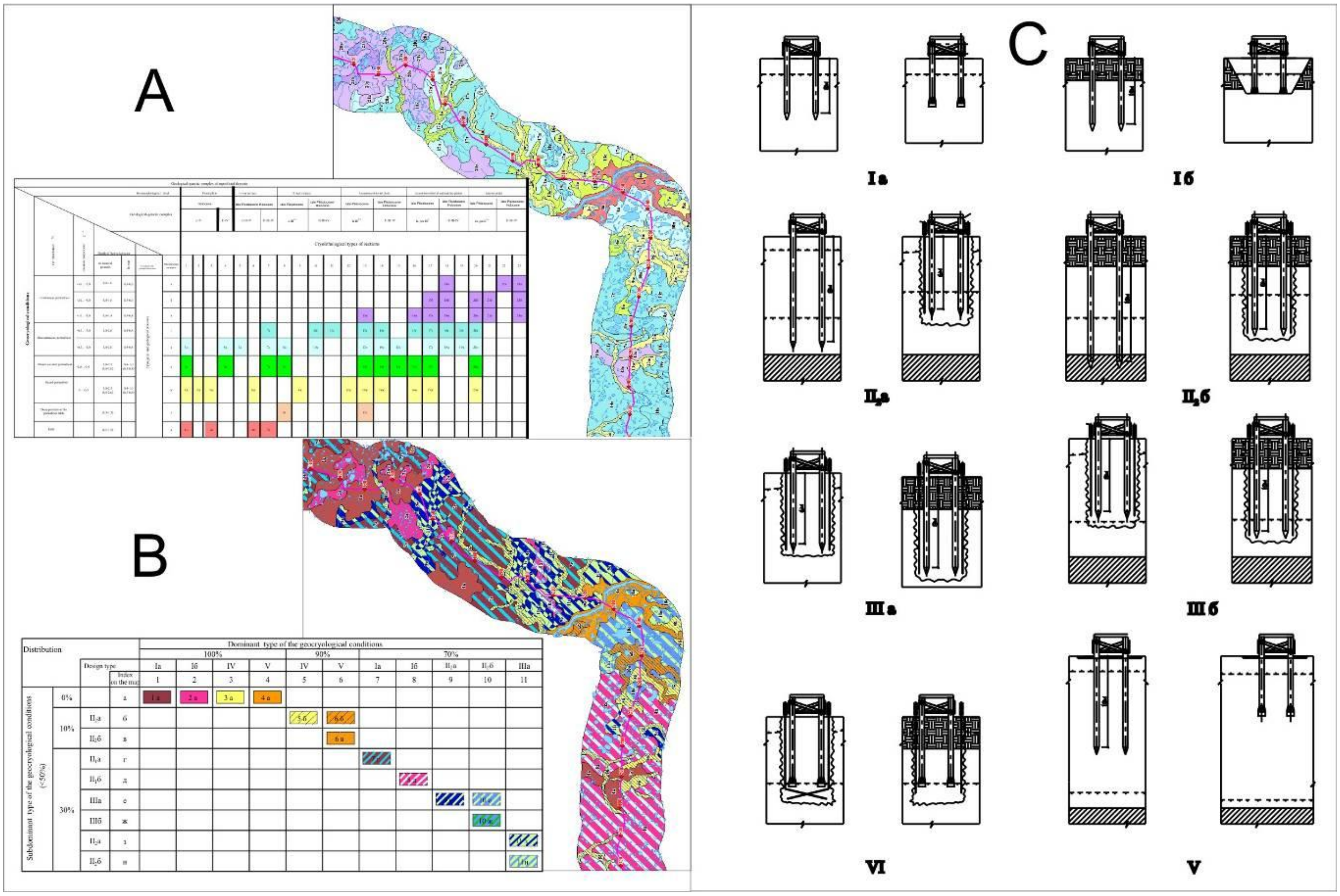

Figure 1. The basic structure of the creation of a geotechnical mapping model: A - a basic geo-information mapping model (a map of engineering-geocryological zoning and a matrix analytical scheme), B - a geotechnical mapping model (a zoning map of the route with respect to pipeline engineering solutions (with cost estimate)), C - a database of technical solutions of pipeline laying.

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The Study of the Thermal Regime of the Upper Part of Permafrost in Order to Ensure Geo-Environmental Stability of Oil-Producing Facilities: The case of the Ardalin Oil Field

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Oil production has a negative impact on environmental components, in particular, on geological environment. In the conditions of the Far North the features of the geological structure of the upper part of a section that are mainly preconditioned by the presence of permafrost largely determine the stability and reliability of the operation of oil and gas facilities. The violation of permafrost thermal regime can lead to the decrease of grounds stability, hence, the stability of engineering structures located on their surface. It is therefore necessary to carry out the research and analysis of the temperature regime of the upper part of permafrost in order to minimize the thermal impact of oil-producing facilities.

The Ardalin oil field is the site where this kind of analysis of the thermal state of the components of the upper part of geological environment under technogenic influence was carried out for the first time in the European part of the Far North. Regular monitoring of the state of permafrost tundra grounds that are located at the foundation of production facilities, sites, and other structures are carried out at the Ardalin oil field [*Rogach 2010*].

The monitoring is conducted by taking sensor readings in thermometric wells located at operational site "A", operational site "B", industrial sites of central production facilities (CPF), as well as in the wells of the landfill of drilling waste. The first three sites have sand filling that helps minimize the thermal effect on the upper part of permafrost. This is confirmed by the analysis of temperature regimes in thermometric wells.

Producing wells and three thermometric wells were drilled at operational site "A". Besides, there is a background thermometric well located at the distance of 150 meters from the edge of the site. Starting from the depth of 0 meters (initial soil surface is taken as zero) the grounds are in the year-round frozen state.

In operational site "B" the process of the injection of stratum water takes place. Due to the constant thermal influence of the mass of hot water the temperature of the upper part of permafrost undergoes increase. The comparison of two thermometric wells located at various distances shows a significant reduction of thermal impact as the distance from the injection well becomes bigger.

At the CPF site there are no producing wells, but the operating procedures carried out on its territory also have a thermal effect. To determine the thermal regime, the readings of a number of thermometric wells with the same spacing between temperature sensors were analyzed. In these wells, starting from the depth of 2.5 m (the thickness of sand filling is 3 m) the grounds are in the year-around frozen state.

The monitoring of the condition of buried drill cuttings is carried out through measuring thermal sensor readings in wells drilled in the body of sludge storage pits and in background thermometric wells [*Makarskiy, Gubaydullin 2009*]. From the depth of 3.5 m the grounds are in the year-around frozen state. The same depth is typical of background wells. This indicates that the thermal regime of grounds in the body of the sludge storage pit is restored to the background values.

The summarized results of the observations of the thermal state of the upper part of permafrost provide reliable characteristics of the heat exchange in frozen and seasonally frozen grounds and allow to find methods to improve the geo-ecological stability of near-surface grounds during the operation of oil-producing facilities.

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Three Decades of Changes in Permafrost Temperature along the Alaskan Permafrost/Ecological Transect

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Introduction

The impact of climate warming on permafrost and the potential of climate feedbacks resulting from permafrost thawing have recently received a great deal of attention. Expected increase in air temperatures and possible increase in winter precipitation, as indicated by all General Circulation Models for the 21st century, will have a pronounced effect on permafrost characteristics and stability. However, uncertainty in these climatic projections and complex relationships between changes in climate and permafrost dynamics make it necessary to carefully monitor current and future changes in permafrost to provide reliable information on actual changes.

The most direct indicators of permafrost stability and changes in permafrost state are the temperature of permafrost and the depth of the active layer. The permafrost temperature regime (at depths of 10 to 200 meters) is a sensitive indicator of the decade-to-century climatic variability and long-term changes in the surface energy balance [*Romanovsky et al. 2002*]. This is because the range of interannual temperature variations ("noise") decreases significantly with depth, while decadal and longer time-scale variations (the "signal") penetrate to greater depths into permafrost with less attenuation. As a result, the "signal to noise" ratio increases rapidly with depth and the ground acts as a natural low-pass filter of the climatic signal, making temperature-depth profiles in permafrost useful for studying past temperature changes at the ground surface.

In this presentation we will discuss the results of long-term observations of permafrost temperature at multiple sites generally located along the Alaskan Permafrost/Ecological Transect that extends from Gulkana in the south to Prudhoe Bay in the north and spans all permafrost zones in Alaska. These sites are an important part of a global observational network that was established during the recently concluded International Polar Year.

Methods

The global borehole network measures permafrost temperature at 860 sites in both hemispheres [*Brown et al. 2010*]. A typical borehole includes multiple temperature sensors down to depths of several to hundreds of meters. Temperature measured by these sensors may be recorded continuously in time (with time interval from several hours to several days) and stored in a data logger at the field site or occasionally during visiting the sites. The most precise temperature data are obtained by lowering a very high-quality single temperature sensor on a cable into the borehole. The sensor stops at each measuring depth (typically every one or two meters) and the temperature is recorded after equilibration of the sensor and surrounding ground temperatures. Permafrost temperature is usually measured below the zero amplitude depth where seasonal variations in ground temperature are minimal. This depth varies from a few meters in warm, ice-rich permafrost to 20 m or more in cold permafrost and bedrock [*Romanovsky et al. 2010*].

Most of the sites along the Alaskan Permafrost/Ecological Transect were established in the early 1980s by professor-emeritus T.E. Osterkamp. The measurements of permafrost temperature at deeper (down to 50-80 m) and shallow (down to 1-3 m) boreholes at all these sites have been performed since then. The temperatures at deeper boreholes have been collected once every year. In the shallow boreholes temperatures have been measured continuously with one-hour time resolution.

Results

Most of the permafrost observatories in Alaska show a substantial warming during the 1980s and especially in the 1990s (Figure 1). The magnitude and nature of the warming varies between locations, but is typically from 0.5°C to 2°C at the depth of zero seasonal temperature variations (Osterkamp 2008). However, during the 2000s, permafrost temperature has been relatively stable on the North Slope of Alaska (Figure 1A), and there was even a slight decrease (from 0.1°C to 0.3°C) in the Alaskan interior during the last three to four years (Figure 1B). During the last ten years, only near-coastal sites in Alaska (including Barrow) still show continuous warming. The latest data may indicate though that the observed warming trend along the coast has begun to propagate south towards the northern foothills of the Brooks Range, where a noticeable warming in the upper 20 m of permafrost has become evident since 2008. In 2011, a new record high temperatures at 20 m depth were measured at all Permafrost Observatories on the North Slope of Alaska since the measurements started in the late 1970s.

Permafrost used as a calorimeter of high quality temperature data to a depth of 60 to 100 meters is available for some locations for some time period [*Osterkamp et al. 1994*]. The difference between the two temperature profiles, one at the beginning and one at the end of this period, and an estimate of the heat capacity of frozen material at this location may be used to estimate the amount of heat accumulated in or released from the permafrost during this period. Analysis of data collected from our Alaskan sites between the mid-1980s and 2010 show that the heat accumulation in permafrost persisted almost continuously from 1986 to the present at all our North Slope sites. The average long-term heat flux into permafrost was calculated based on these data. The largest heat fluxes on the order of 0.25 Wm^{-2} were estimated at the northernmost sites of West Dock and Deadhorse. In interior Alaska the accumulation of heat by permafrost was mostly pronounced during 1986-1996. Since the late 1990s, there was no further accumulation of heat by permafrost or even some heat loss. As a result, the average long-term heat flux into permafrost during 1986-2010 was estimated between 0.05 Wm^{-2} and 0 Wm^{-2}. For example, the data from the College Peat permafrost observatory indicate that all the amount of heat accumulated between 1984 and 1995 was completely lost during 1996-2010.

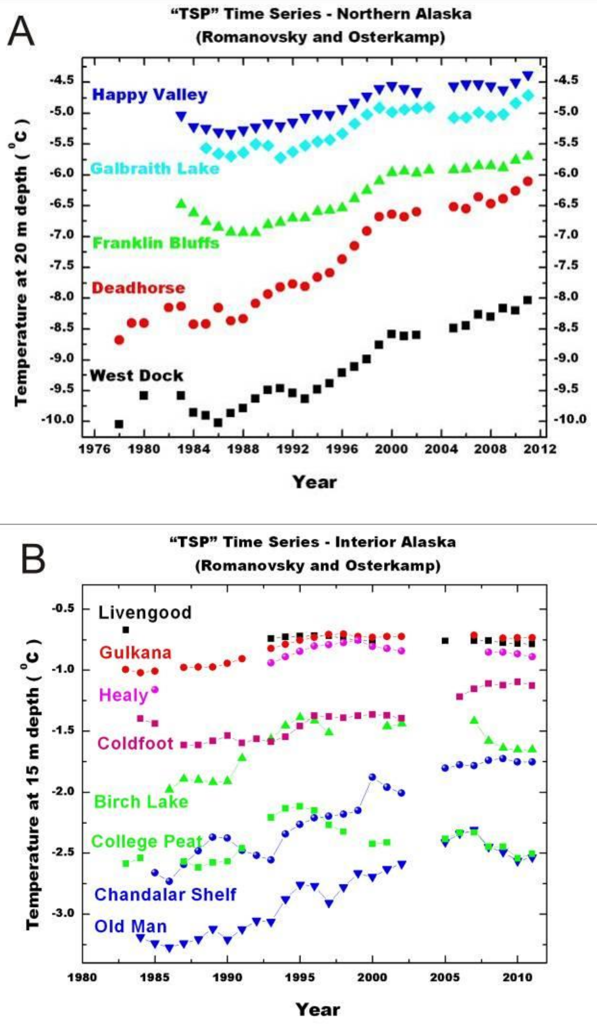

Figure 1. Time series of permafrost temperatures measured in Alaska in continuous (A) and discontinuous (B) permafrost zones.

Conclusions

The presented materials show that the permafrost temperatures in Alaska observed during the last 30 years were generally increasing at almost all the sites. However, the rate and, sometimes, even the direction of these changes were not the same for different time intervals and for different locations. This conclusion makes it clear that only specific information on permafrost dynamics collected at specific locations and for specific time intervals can be used for interpretation of changes in other environmental characteristics that are strongly related to changes in permafrost. The usage of global or even regional trends in permafrost evolution for this purposes may be misleading.

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Seasonal Dynamics of Water Drainage in a Lake Underlain by Through-going Talik

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Introduction

The disappearance of lakes across high latitude regions in recent decades has been cited as evidence for permafrost degradation [*Smith et al., 2005*]. In an area of warm discontinuous permafrost on the Seward Peninsula in Alaska, the complete loss of sub-lake permafrost in response to talik development has been argued to be the cause of observed lake/pond drainage [*Yoshikawa & Hinzman 2003*]. In this particular location the loss of permafrost has allowed water previously retained in lakes to drain to the subsurface. In a prior modeling study we investigated the timing for the complete loss of permafrost beneath a simulated lake and the influence of sub-permafrost groundwater flow on the stability and thaw rate of sub-lake permafrost [*Rowland et al., 2011*]. Here we expand on this prior study and examine the seasonal hydrological and thermal dynamics of a lake with a talik that fully penetrates the permafrost beneath the lake (through-going).

Model Description

In our prior study we used mean annual temperatures for the ground surface and lake to drive the model and held the depth of water in the lake constant. Under these conditions, a talik thawed through 16 m of frozen ground in less than two decades. In order to examine the effect of the through-going talik on lake dynamics, we used the final output from these simulations and modified our surface boundary conditions to account for seasonal dynamics in temperature. We also changed the conditions governing the water balance in the lake simulating the effect of evaporation and subsurface drainage on the volume of water in the lake. In this model, we do not account for surface water runoff or direct precipitation into the lake and therefore make a simplifying assumption that the lake is completely recharged every spring. This assumption is likely unrealistic but allows us to explore the dynamics of a still active lake in a region of discontinuous permafrost. The seasonal near surface temperature variations were based on data collected in the Council area of the Seward Peninsula by the Water and Environmental Research and the International Arctic Research Centers at the University of Alaska Fairbanks (http://ine.uaf.edu/werc/projects/seward/index.html).

In contrast to our prior simulations, rather than keeping the temperature of the lake waters constant the model allowed the temperature of the lake to varied seasonally. The seasonal variation in lake temperatures was tied to the near surface temperature at the upper model boundary by diffusion and convective thermal scaling arguments. When the lake is thawed, convective and wind-driven mixing will increase the effective thermal conductivity by one to two orders of magnitude, yielding a thermal time scale of about a day for a shallow lake. The lake temperature will be roughly the daily average air temperature.In the winter, a frozen lake will have the thermal diffusivity of ice, which is about an order of magnitude greater than that of water, yielding a thermal time scale of several days, so that the lake layer should correspond to the weekly average air temperature. These thermal conditions were applied to derive the lake boundary condition. The simulated lake refilled each spring to a depth of 2 m. As lake water infiltrated the subsurface, the water head in the lake decreased, slowing the rate of further infiltration. Additionally, evaporation from the lake surface was computed using the Shuttleworth-Penman [*1993*] formulation, as a function of temperature, relative humidity, wind speed, and solar irradiance.

The numerical model used in this simulation is the Arctic Hydrology (ARCHY) model. ARCHY solves time-dependent mass, solute and energy conservation equations in 1, 2, or 3-D geometries, includes diffusive and advective transport, change of phase with resulting volume change and latent heat balance, temperature dependent water and ice properties, non-uniform media properties, and saturated or unsaturated flow. It has other capabilities for solute transport and microbial activity but those are not exercised in this study. In this simulation, the 2-D geometry of Rowland et al. [*2011*] is used, with a shallow lake centered at the top of the domain, with a thin, high permeability channel supporting a horizontal groundwater flow at about 20 m depth. The model domain is 200 m wide and 30 m deep.

Results

In our simulations we see a seasonal cycle of freezing and thawing of the upper two to three meters of the talik beneath the lake (Figure 1). This freeze-thaw cycle arises because of the seasonal variation in temperature across the lake portion of the model domain. In the simulations that led to talik formation [*Rowland et al., 2011*] it was assumed that the lake maintained a mean annual depth greater than annual freezing depth resulting in a mean annual temperature at the base of the lake of 4°C. In our present simulations, the depth of the lake seasonally decreased due to both evaporation and infiltration of water into the unfrozen subsurface. Lake water level decreases by late summer to roughly 1 m depth (justifying the assumption of a frozen lake in winter). Due to the annual re-freezing of the lakebed, infiltration of water into the deeper subsurface through the sub-lake talik occurred only in the late summer to fall. In our present simulations, the annual re-freezing of material beneath the lake appears to lead to a slow re-establishment of permafrost beneath the lake. The current results only extend out 25 years but by the end of this time period only a fraction of the ice within the soil matrix thaws with the percentage of frozen pore space increasing over time (Figure 1).

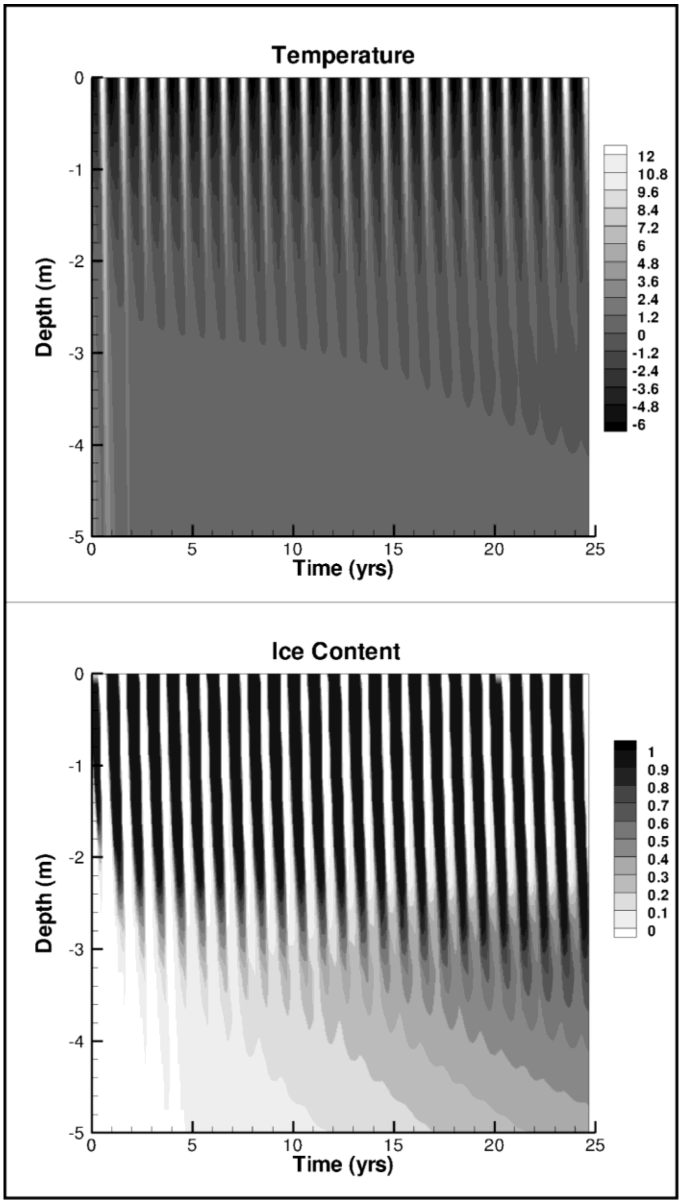

Figure 1. Temperature and ice content (fraction of pore space filled with ice) vs. time and depth along the midline of the 2-D simulation.

The model results are highly dependent on the assumptions concerning the depth of the lake entering the winter months and the rate of water infiltration through the lakebed into the subsurface. If enough water were retained in the lake to maintain a layer of unfrozen water throughout the winter, greater warming would occur in the subsurface preventing the re-freezing of the sub-lake talik. Conversely, if low runoff and precipitation prevented significant re-filling of the lake greater re-freezing of the upper portion of the sub-lake talik might occur leading to a re-establishment of a permafrost controlledaquiclude beneath the lake.

While simplistic, our results suggest that even in regions of warm permafrost the loss and re-establishment of permafrost associated with shallow lakes and ponds is highly dependent on annual to decadal influxes of water to lake basins. It is conceivable that re-freezing of drained lakebeds could lead to re-filling of these basins. The presence of increased standing water would likely thaw the newly frozen ground leading to a cycle of lake filling and draining. To assess the likelihood and timing of such a cycle, model simulations that include surface runoff contributions and an accurate measure of lake volumes will be needed to accurately capture the dynamics between local water balances and the thermal effects of lakes on the subsurface.

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Relict Pingos and Permafrost in the Netherlands and Northwest Germany

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Introduction

Pingos are periglacial landforms which currently are present in permafrost areas in Alaska, the Canadian Arctic, Greenland, Svalbard and Siberia. In permafrost areas with a continuous water supply, ice lenses can form and pingos can grow. Isolated circular and most often ramparted depressions are left behind when pingos degrade. In the Netherlands, especially the provinces Friesland, Groningen and Drenthe, hundreds of isolated circular, most often ramparted depressions are regarded as being remnants of these periglacial landforms. According to previous research, these pingos formed during the cold Weichselian Pleniglacial, when discontinuous permafrost conditions caused increasing hydraulic groundwater pressures in the partially frozen upper aquifers. During the warmer Late Glacial Interstadial, these landforms collapsed when the permafrost gradually started to thaw.

Methods & Study area

For this study 17 possible pingo remnants in the northern Netherlands and adjacent Germany were investigated. One of these depressions is Timmelteich in northern Germany, around 10 km south of the town Aurich (WGS 84; 53°22'01"N - 7°31'34"O).

Field analysis and coring has been used to create a lithological cross-section of the depression. Lab analysis, consisting of both Loss on Ignition (LOI, a method to determine the percentage of organic content in a soil sample) and pollen analysis is used to get an age estimation.

Besides individual depression investigations, all information is combined with previous research to create a pingo catalogue for the Netherlands. Geographical Information System (GIS) analyses are used to calculate density distribution and morphology. The spatial distribution and dimensions of these remnants show similarities with pingos in active permafrost regions.

Results

The Timmelteich depression in north-west Germany is one of the investigated depressions. Figure 1 shows the lithological cross-section of this depression. The substrate consists of impermeable glacial till sediments. A sample has been taken at the transition between the substrate and the first infill of the depression. In this sample, macro fossils were found from *Salix Polaris*. This dry terrestrial species occur in tundra environments and polar deserts. ^{14}C dating of this organic material is in progress. According to Hoek, W.Z., 1997, *Salix Polaris* was present in this area during the pleniglacial, when a periglacial climate was present. This layer in the depression originates presumably from The Early Late Glacial period. Because the sample is found at the lowest part of a peat filled depression, it is possible that this *Salix Polaris* was growing on top of the active pingo, as this species needs a dry and cold environment. The first infill of the depression consists of a very sandy gyttja, with less then 10 percent organic content (see LOI curve in figure 1). This has presumably been deposited during a cold period with high eaolean activity and only little organic sedimentation. The rest of the infill shows a shallowing sequence of the water depth in the depression, with an alternation between colder periods, with a lower organic content, and warmer periods with a higher organic content.

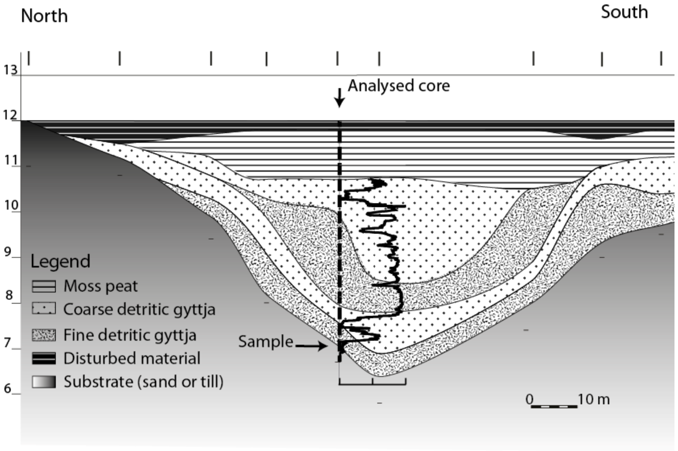

Figure 8: Cross-section of lihology and LOI of Timnmelteich depression, Germany. The LOI curve is shown for the analysed core, with left is 0% to reight 100% organic content.

The Timmelteich depression is one example of the 17 analyzed depressions. Pollen analyses are still in progress and will provide an age estimation of the first infill of the depressions. GIS analysis has been carried to calculate the spatial distribution of presumable pingo remnants in the Netherlands. The first results of a density analysis are shown in table 1, which is a shortened version of the analysis of Grosse, G. & Jones, B.M. 2011.

Discussion

The development and occurrence of the depressions in the Netherlands and Germany is still a point of uncertainty. Whether these depressions are pingo remnants or formed by other processes is important to know before using these depression infillings as pingos in reconstructions of past climate conditions. More insight in the occurrence of these depressions and the sensitivity for climate change can provide information about the response of the permafrost environment to climate change. This importance is not restricted to understanding of past climate conditions, as the permafrost is now degrading in the high Arctic as well and understanding pingo response may help detect the impact of global warming. More insight in paleoclimate reconstruction can help in understanding the process of degrading permafrost and the response of corresponding landforms (e.g. pingos), can help to get insight in the seriousness of the contemporary permafrost degradation.

If the depressions in the Netherlands satisfy the criteria of pingo remnants, the question remains which type of pingo could have generated these remnants. In a rule of thumb [*French 2007 and others*], close system pingos require continuous permafrost and a changing landscape with taliks. Open system pingos require a continuous water supply mostly in areas with sufficient relief. Both conditions where presumably not present in the Netherlands during the Late Glacial. However, the occurrence of an impermeable glacial till deposits in large parts of the Netherlands could have caused an increasing ground water pressure with degrading permafrost conditions. Permafrost causes the presence of an impermeable layer in the subsurface and a bifurcation of the groundwater flow. Water through flow is possible in the active layer above the permafrost and in the deep subsurface, below the permafrost. This differential ground flow has caused the development of small river valleys during the last glacial [*De Vries 1974*]. This shows that there was sufficient water supply. The combination between permafrost and glacial till both acting as an aquiclude might explain the occurrence of pingos in the Netherlands during the Latglacial. Pingos have therefore most probably been open system pingos, fed by a water supply from below the glacial deposits.

Table 1. Pingo density in different regions (shortened after Grosse and Jones, 2011).

Region	Reported density (km^2)	Source
Siberia		Grosse and Jones, 2011
Taymyr Lowland	0.12	
Khatanga-Anabar L.	0.13	
Central Yakutian L.	0.28	
Netherlands		This study
Drenthe	0.74	
Friesland	0.26	

The density analysis of the Netherlands is a method which shows that it is possible to have a spatial distribution as shown in table 1. However, the amount of pingo remnants is strongly dependent on the amount of research done in this area, which differs considerably.

Conclusion

Whether or not the features are pingo remnants and to what extent these pingos have degraded as a result of climate change is important for understanding the impact of climate change on the permafrost and periglacial environment in the past, present and future.

Pingos in the Netherlands were presumably open system pingos, grown by the water supply from below the glacial till sediments and presence of permafrost. The *Salix Polaris* found in the lowest part of the Timmelteich confirms the expectation of a pingo remnant.

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Separating Direct Temperature Responses from Phenological Control of Net Ecosystem Exchange during the Short Tundra Growing Season: Measurements and Process Modeling from the Lena River Delta, Russia

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Introduction

The photosynthetic response of tundra species with respect to incoming light can change rapidly through the short polar growing season. These changes are known to be caused by the comparatively rapid phenological vegetation development in this region. Concurrent to progression through phenological stages, however, photosynthetic performance of tundra species is modulated by direct temperature effects. Separating these influences on plant behavior is possible thanks to advances in measurement techniques (i.e., eddy-covariance systems) and analytical methodologies (i.e., time series analysis). This presentation evaluates the relative contribution of phenology and direct air temperature effects on photosynthetic performance during the 2006 growing season in a polygonal tundra ecosystem in the Lena River Delta in Northern Siberia (72˚22’ N, 126˚30’ E). We demonstrate that the timing of warm periods (characterized by warm, dry winds from the south during late June through the middle of August) is an important determinant of the magnitude of the ecosystem’s carbon sink function, as they drive temperature-induced changes in both assimilation and respiration.

In particular, these few, brief warm periods (with air temperatures exceeding 20 °C and approaching peaks near 30 °C for three to five days) have the potential to significantly alter the CO_2 balance of these ecosystems. High-temperature periods drive the ecosystem’s functioning away from optimal uptake, and may encourage both amplified respiration and deactivation of the photosynthetic apparatus. We suggest ways to model these temperature-based processes, and quantify the reduction of CO_2 uptake during hot spells occurring in different phenological periods. Hot spells during the early portion of the growing season are shown to be more influential in the region’s carbon balance than those occurring later in the season. The magnitude of the response to increased air temperatures depends on growth temperature, the integrated temperature of the antecedent 30-day period. However, this response shows hysteresis depending on its timing within the phenological calendar. Earlier periods have a stronger photosynthetic apparatus with respect to maximum uptake during high light conditions, but also show an amplified response to locally extreme high temperature conditions. Understanding and quantifying these processes is an essential precursor to describing the delays and lags linking assimilation and respiration at different time scales, as it allows a more confident partition of measured net exchange over a broader range of environmental conditions.

Study site

The study site is located on Samoylov Island (5km^2), 120 km south of the Arctic Ocean in the southern central Lena River Delta (72°22’N, 126°30’E), and is considered representative of the region’s modern delta areas that include a Late-Holocene river terrace and different active floodplain levels and cover about 65% of the total delta area. Over the past fourteen years, it has been the focus of a wide range of studies on surface-atmosphere gas and energy exchange, soil science, hydrobiology, microbiology, cryogenesis, and geomorphology [*Hubberten et al., 2006*]. The study site is located in the central part of the island’s 3 km^2 Late-Holocene river terrace and contains mostly flat macrorelief with elevations from 10 to 16 m asl. The surface of the terrace is characterized by wet polygonal tundra, whose development has created regular microrelief with typical elevation differences of around 0.5 m between depressed polygon centers and elevated polygon rims [*Kutzbach 2006*].

Methods

An eddy covariance system with a closed-path CO_2 and H_2O gas analyzer (LI-7000, LI-COR Biosciences, USA) measured the turbulent fluxes of momentum, heat, CO_2 and H_2O from June 9 to September 19, 2006. An ultrasonic anemometer (Solent R3, Gill Instruments Ltd, UK) measured wind velocity components in three dimensions and sonic temperature at 20 Hz frequency at a height of 4 m. These measurements are supported by an adjacent meteorological station. The flux measurements have a relatively flat and homogenous contributing area despite the microtopographic variation in the polygonal surface [*Kutzbach et al., 2007, Wille et al, 2008*]. The measurements are quality-controlled, including screens for turbulent characteristics, sensor performance, and high-frequency signal attenuation.

The CO_2 time series derived from this instrumentation set-up is analyzed in a simple partitioning model to separate the net exchange into gross photosynthesis (P_{gross}) and ecosystem respiration (R_{eco}), which includes respiration from soil microbes, roots, and above-ground biomass. This partition is performed in a 7-day moving window in order to separate longer-term phenological changes from shorter-term temperature responses. The simple partitioning model relies on a rectangular hyperbola function for P_{gross} as a function of incoming light, expressed as photosynthetically active radiation (PAR) and an exponential dependence of R_{eco} on temperature.

Air, surface, and soil temperatures are each used to generate the R_{eco} portion of the model, and the implications of this choice are demonstrated.

Results

A key finding within this measurement time series is the amplification of respiration during well-lit high-temperature conditions that should be nearly optimal for photosynthetic performance. One such period is demonstrated in Fig. 1, which presents the net ecosystem exchange (NEE) of CO_2, following the atmospheric convention where positive values indicate efflux from the land to the atmosphere (i.e., a dominant respiratory signal) and negative values indicate efflux from the atmosphere to the land surface (i.e., a signal dominated by photosynthetic uptake). This mid-day positive efflux of CO_2 occurs more frequently in early-season hot periods, and is largely absent in the second half of the growing season.

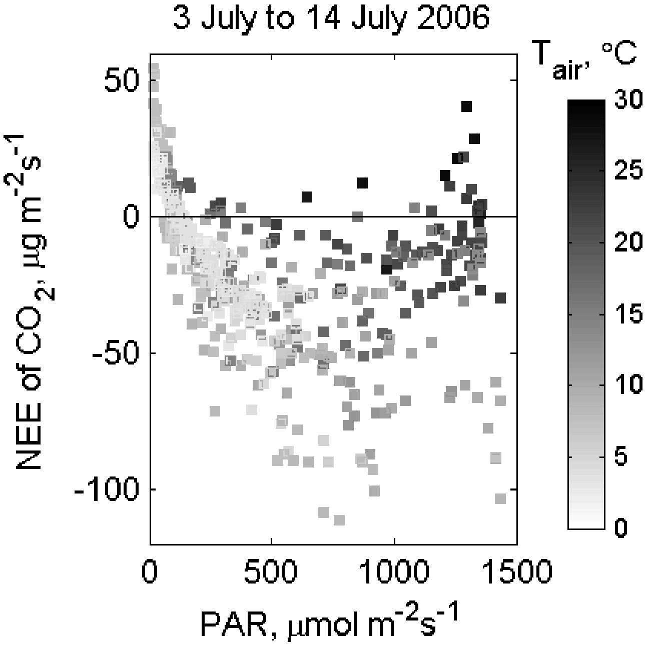

Figure 1. Net ecosystem exchange (NEE) during one heat spell, July 2006. Points are plotted against photosynthetically active radiation (PAR) and shaded according to air temperature (T_{air}), and represent half-hour measurement intervals (n = 464).

Conclusions

The effects of the mix of temperature-based and phenological processes on the annual carbon balance are demonstrated for the site for one growing season, and a sensitivity analysis of the timing, magnitude, and duration of these events is used to show the importance of synoptic meteorological conditions on the local carbon budget. This question is especially urgent given likely consequences of changes in Arctic sea ice coverage and the resultant modifications of the balance between continentally- and Arctic Ocean–derived weather systems.

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Cryogenic Processes in the Soils of Southern Tundra

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Keywords: automorphous dusty-clayey silt soils; Bolsheze-melskaya tundra; cryogenic processes; macro-, meso- and micromorphology.

Introduction

The specific cryogenic organization characteristic of soils is expressed in the unique components distribution: organization of particles, re-organization, substance transfer, destruction of organic residuals [*Fedorova 1974; Konishchev & Rogov 1977; Ershov et al. 1988; Cryosols 2004; Sokolov et al. 2006*].

Cycling is a peculiar feature of cryogenic processes in soils. Consequently, the soils gain the cryogenic structure and texture, accumulations and circles of the sand and aleurite material, and cryoturbation indicators.

Typical gley soils and cryometamorphic gley soils [*Classification and diagnostics of Russia's soils 2004*] or tundra peat-gley and tundra surface-gley soils (State soil map of Russia, Scale 1:1,000,000. Explanatory note to sheet Q-41 (Vorkuta) 2010) are the most widely developed soils in the southeast of the Bolshezemelskaya tundra that are formed on unconsolidated dusty-clayey silt deposits. The differences in the gleization degree depend on the permafrost bedding depth, the position of soils in the landscape and drainage conditions, the slope direction and the snow cover thickness. The purpose of research is to determine the dependence of cryogenic processes manifestation on the soil gleization degree.

Objects and methods

The research was conducted in the southeast of the Bolshezemelskaya tundra characterized by the gentle-ouval and the hill range terrain, the massive-island type of permafrost bedding, the spotty-mound microterrain and dwarf birch-suffruticous moss-lichenous vegetation associations.

Typical and cryometamorphic gley soils are research objects.

The detailed studies of the structural organization and differentiation of sand-dusty cutans (skeletons) were conducted on monoliths with undisturbed structure, with the use of macro-, meso- and micromorphological methods.

Results and discussion

Cryogenic process features are clearly traced in the typical gley soil (O, 0- 7(10) cm – G, 10-25 cm – G_1, 25-40 cm – CG, 40-65 cm) bedding on the flat poorly dissected windward slope of the ouval. With the permafrost present within the profile (90 cm) the soil, when dried, becomes conjoint, without any aggregation indicators, or very weak in the lower part (Horizon CG). Soil overhumidification causes the development of cryoturbations as a result of the thermal frozen material compression in case of fast cooling, and a significant mass transfer, which is indicated by arched dark-brown fragments at the 40-65 cm depth. Multiple vesicular pores in Horizon G_1 formed in the process of slow thawing and air preservation assist in the formation of the caseous porous construction characteristic of thixotropic horizons. The permafrost presence causes moisture migration along the thermal gradient, solid particles transfer in the form of suspensions and also the cryogenic sorting of the skeleton grains. The latter represent poorly expressed whitish pore filling in Horizons G and G1. The subhorizontal structure in Horizon G occurs as a result of freeze-thaw cycles and the formation of foliated belt aggregates from ice lenses. The indicated aggregates are very unstable during wet periods in the upper horizons. The granular aggregates between the peaty layer and the mineral stratum are formed as a result of the mechanical pressure and rotation in highly water-saturated environments.

The most clearly expressed cryogenic processes in this soil include: cryoturbations, components re-distribution, sorting and cryocautery aggregation of the organic substance.

The cryometamorphic gley soil (O, 0-13 cm – Bg(G), 13-38 cm – CRM1, 38-62 cm – CRM2, 62-100 cm) bedding on a flat hill peak is characterized by a higher aeration degree and the permafrost bedding depth ≈ 2 m. The aggregation at the boundary with the mineral stratum occurs as a result of particles glueing by cementing compounds in the process of their rotation, which assists in the formation of roundish aggregates, frequently with films. The following is typical of Horizon Bg(G): the subhorizontal structure with tabulate aggregates formed as a result of shlieren ice pressure, particle sorting indicators, skeleton grain accumulations in fractures and at aggregate surfaces, accumulations, and their orientations in the form of vertical and ellipsoid shapes. The isometric aggregates - ooids with the concentric internal structure in Horizon CRM represent clay and Fe oxides stratification on sand particles, concretions. The mechanism of formation is segregative-coagulative aggregation of particles with different particle size distribution.

The consequences of cryogenic processes in soils include: the destruction of organic residuals, the layered, reticulate cryogenic structure, the granular texture and the cryogenic material orientation (circles and accumulations).

Conclusions

Thus, the detailed macro-, meso- and micromorphological studies determined that automorphous clayey silt soils in the southeast of the Bolshezemelskaya tundra are developed in the conditions of the extreme continental climate and the shallow permafrost bedding and contain a set of cryogenic indicators and properties occurring at different organization levels. The manifestation degree and the occurrence depth of cryogenic indicators vary significantly, depending on the soil gleization degree: the maximum development of cryoturbations and of the physical material transfer occurs in the typical gley soil, while intensification of re-organization and of inter-profile re-distribution takes place in the cryometamorphic gley soil.

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Cryosphere as Microorganisms' Habitat and as Preservation Environment for Their Biodiversity

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Introduction

Permafrost is widely distributed on the Earth and is a source of the increase of microbial communities biodiversity in the modern soils of cold regions. In the process of permafrost exposure, relict microorganisms are released onto the surface and get included in modern ecosystems. The effect of the cryogenic conditions of existence as a factor of formation of procaryotes sustainability is poorly studied.

This paper aims to study the influence of regional particularities of permafrost and cryogenic conditions as a preservation and formation factor of procaryotes sustainability in Siberian permafrost.

The objects, materials, and methods of study

Microbial communities and characteristics of microorganisms identified in the samples of permafrost deposits and in the soils of the Holocene-Pleistocene age were examined.

The areas of research and sampling aimed at the selection of viable microbiota represent two different models of the cryosphere development and of the formation conditions of microbiota biodiversity in permafrost.

1) Site "Tarko-Sale" is located 15 km to the north-west of a similarly-named meteorological station in the north of Western Siberia in the area of discontinuous permafrost. The location on the plain determines the possibility of added microbiota carried by the Atlantic and Arctic cyclones from the territory of Europe and the Arctic. Permafrost here was exposed to marine transgressions and was degrading during interglacial periods and the Holocene Optimum. Now it is experiencing a significant influence of the modern global warming. The average annual temperature for the period of 1999-2008 made up -4.98°C, while the normal value is -6.4°C.

In December 2005 confluent permafrost grounds were exposed here by means of wells drilled by a core-drill method without flushing or adding chemical solutions. Geothermal studies have been conducted in these wells starting in April 2006.

Well No. 1 is located on the surface of the ridge covered with shrub-moss vegetation. In the section there is peat bedding down to 1 m. There is also silt with interbeds of sand, clayey silt and clay overlying clayey silt with interbeds of silt and clay down to the depth of 20 m. Organic content is 2.7-7.3%, moisture content is 28.8-46.26%, salinity is 0.00-0.05%, pH is 5.7-7.85.

Well No. 2 is located in light pine forest. There is peat down to 2.5 m from the surface, and sands with interbeds of clayey silt, silt, and clay. These sands overlie silt with interbeds of clayey silt down to 16 m. Organic content is 1.8-7.95%, moisture content is 19.05-42.45%, salinity is 0.00-0.02%, pH is 5-7.66. 13 permafrost samples from the core were used for microbiological studies.

2) Site "Chara" is located in northern Transbaikalia 6 km to the south-east of the Novaya Chara village. It represents Fragment I of the terrace of the Chara River with exposures of alluvial and biogenic deposits including vein ice. This area was influenced by glaciers and storage ponds. It is a part of the intermountain basin of Baikal-Stanovoy Region in the South Siberia's mountains with continuous permafrost supported by orographic inversions and "isolated" from transboundary transportation. According to the Chara meteorological station, the average annual temperature for the period 1999-2008 was -6.47°C.

The number of microorganisms was determined by inoculating onto Beet Extract Agar (BEA) and Potato Dextrose Agar (PDA). Dilutions of 10^{-3} and 10^{-4} ml were used. The bacteria were inoculated in triplicate. They were incubated at three temperature values: +5°C, +16°C, and +36°C. The bacteria were incubated from 2 to 10 days at temperatures of +16°C and +36°C, and from 50 to 60 days at the temperature of +5°C.

To study the activity of microorganisms at low temperatures colored nutrient medium was used that allows to estimate the activity of the cultures with low metabolic activity. The halotolerance study of isolated strains from the "Tarko-Sale" site was conducted on a dense nutrient medium with the addition of NaCl. We used salts with the concentration of 1-13%. The strains were incubated at a temperature of +10°C.

Results and discussion

Microorganisms were found in all samples studied. 63 strains of pure cultures of bacteria were found in the "Tarko-Sale" samples. According to the nucleotide sequence of 16S rRNA 44 strains were identified among them. The identification based on generic identity showed that well No. 1 was mainly dominated by the following bacteria: *Bacillus spp, Enterobacter spp, Stenotrophomonas spp,* in well No. 2*: Bacillus spp, Acinetobacter spp, Pseudomonas spp*.

Bacterial growth was observed only at the temperatures of +16°C and +36°C, and not at +5°C. The amount of the bacteria identified at the temperature of +36°C was by 10-30 times lower than at +16°C. For the bacteria of the same genesis similar in composition and age, the variability of average CFU along the section as a whole in wells No. 1 (temperature of permafrost -1.5÷ -1.7°C) and No. 2 (temperature of permafrost -0.4°C) was $8.5\times10^4 \div 3.8\times10^7$ and $1.12\times10^4 \div 1.72\times10^8$ respectively. The increase of the total number of bacteria was observed in the samples from the horizons characterized by the increase of organic content, salts, unfrozen water, and dispersion with the decrease of ice content in deposits.

There were 89 strains identified in the samples taken in the Verhnecharskaya Basin at various temperatures of cultivation on solid nutrient media (Table 1). Among them 25 strains were identified according to nucleotide sequence 16S rRNA. The predominat strains related to the following genera: *Pseudomonas spp, Bacillus spp, Bordetella spp*. High levels of similar strains in the samples is typical. The growth of bacteria at +5°C was detected in 15 strains.

Regional features of the distribution of bacteria are caused by the differences in temperature regime and permafrost temperature range, i.e. by the changes of the conditions of heat exchange on the surface. There is a redistribution of bacteria in the section of permafrost that is closely related to the variability in the range of temperatures and temperature regime due to seasonal and annual rhythms, interannual variability, and long-term climate variability. The differentiation of microorganisms in the section of permafrost that occurs in permafrost under the influence of cryogenic processes caused by climate variability is evidenced by the data of long-term regime geothermal research in the wells at the sampling sites.

The detected pattern allows the use of the microbiological testing of permafrost samples with the analysis of the distribution character of the number of microorganisms incubated at different temperatures as an express-method. This method can be used to determine the thickness of the layer of maximum thawing, the protective layer, and the layer of annual heat exchange even without long-term geothermal observations, which is of great practical importance.

14 antibiotics of 7 known classes were used to study strains in order to determine the sensitivity of bacteria to antibiotics,. The investigated strains showed multiple resistance to the tested antibiotics, apparently due to the fact that in natural conditions the bacteria coexisting with the producers of antibiotics (fungi) developed mechanisms of resistance to natural antibiotics. A comparative analysis of the bacterial strains that were used immediately after thawing in the experiments on resistance to antibiotics and the bacterial strains that were cultured in vitro during 1 year was accomplished. It was established that antibiotic resistance did not change significantly.

The study of the ability to grow under conditions of osmotic stress with the NaCl concentrations of 1-13% at the temperature of cultivation +10°C (this temperature is optimal for the growth of psychrophilic bacteria). During the experiment, 4 strains were identified that were capable of growing in the medium with 13% NaCl. These bacteria were classified as halotolerant bacteria.

The results of the sequence and the study of halotolerancy of the strains from "Tarko-Sale" indicate the presence of regional features in the formation of microbial communities.

For the considered region of Western Siberia, these features include: the possibility of long-term preservation of viable halophilic microorganisms after the end of marine transgression in cryogenic conditions; and possibility of the adaptation of the bacteria that are not originally halophilic to the conditions of saline deposits during the transgressions and cryogenic preservation; the possibility of participation in communities of microorganisms typical of the horizons with hydrocarbon deposits and those located on oil-contaminated lands.

At the same time, in Siberian permafrost the presence of microorganisms was established that were first identified in the samples of deposits in Western Europe (for Tarko-Sale – from forest soils near Braunschweig, Lower Saxony, Germany, for the Chara basin – from the mines in Frederiksberg, Copenhagen, Denmark), which is an indication of long-distance prokaryotes transboundary transportation in the form of nuclei of condensation and water crystals. This testifies to the role of the cryosphere in the preservation of microbiota biodiversity of the planet due to this mechanism.

Conclusions

At the sites of manifestation and activation of physical and geological cryogenic processes (thermokarst, thermodenudation, thermoabrasion, thermoerosion, cryogenic liquefaction slides, glides and slipouts) the biodiversity of microbiota increases due to the re-activation of relic viable microorganisms.

Induced by climate fluctuations, cryogenic processes in the section of the active layer and that of permafrost lead to the accumulation of microorganisms in the areas corresponding to the permafrost roof, the bottom of the layer of annual heat exchanges, and the layer of zero annual amplitudes.

There are regional and facies features of permafrost microbiota associated with their adaptation to environment conditions that are characterized by differences in temperature regime and the range of temperature variability of permafrost.

Contemporary and relict microorganisms that are the centers of condensation and crystallization in the phase transitions of water in the atmosphere can be transported over long distances by air, fall out with solid and liquid precipitation, and therefore, increase the biodiversity of microbiota in any natural zone of the planet.

Principles of Mapping of Bases of Oil and Gas Complex Facilities in Difficult Geocryological Conditions

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The global trend of the development of productive forces is distinctly and progressively getting focused on the northern territories. Arrangement and development of the oil and gas industry mineral deposits plays an important role in the life of our country. The geocryological situation in the deposit areas is often complicated, which, in its turn, complicates stability and reliability of the oil and gas complex facilities. In order to work out construction documentation and to choose management decisions ensuring stability and reliability of the oil and gas complex line structures during the operation period, basic engineering geocryological mapping is carried out in office.

The basic engineering geocryological mapping carried out in office includes design of a set of three schematic maps illustrating engineering, geocryological and temperature conditions, zoning according to the degree of hazard of geocryological processes. An analysis of a combination of the determining factors confined to the specific sections of the line structures enables the maximally thorough development of measures of engineering protection against hazardous geocryological processes and geotechnical monitoring as well as ensuring operational reliability during the whole operation period.

As an example, Figures 1-3 demonstrate fragments of the schematic maps which have been designed for the pipeline routes of the Vankor field.

The basic engineering geocryological mapping carried out in office includes predictive estimate of dynamics of adverse exogenous processes which are hazardous or potentially hazardous for the facilities operated or being under construction.

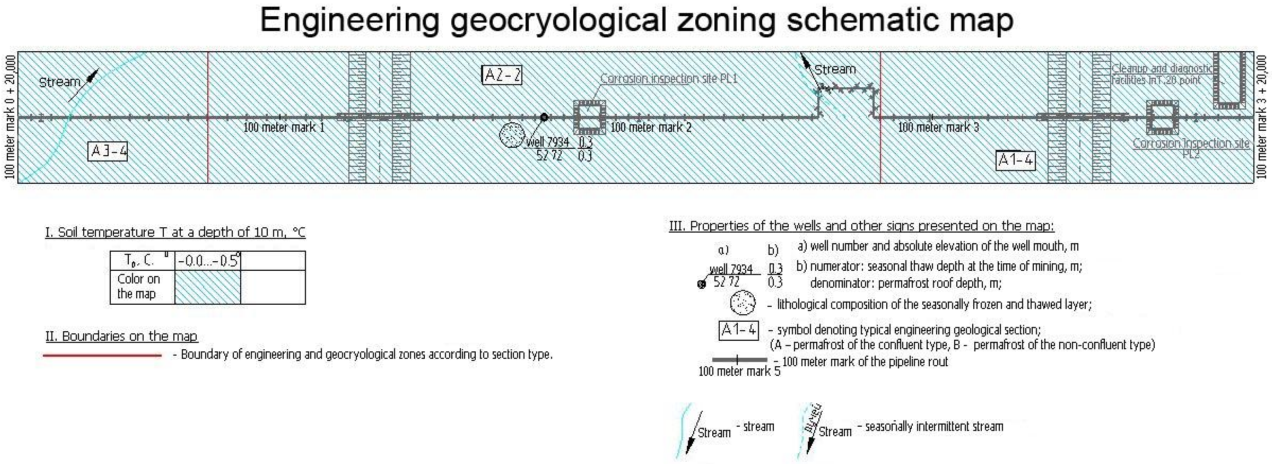


Figure 1. Engineering geocryological zoning schematic map

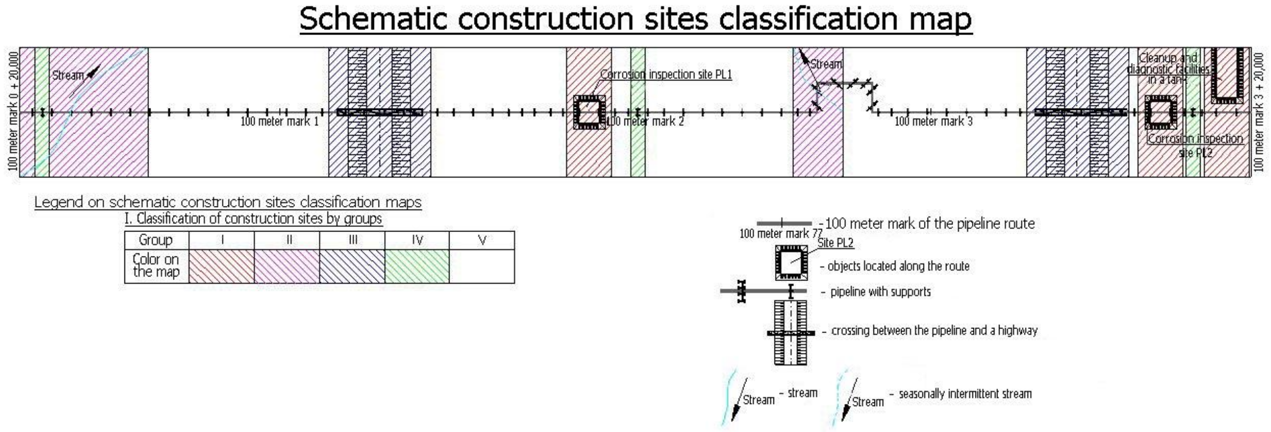
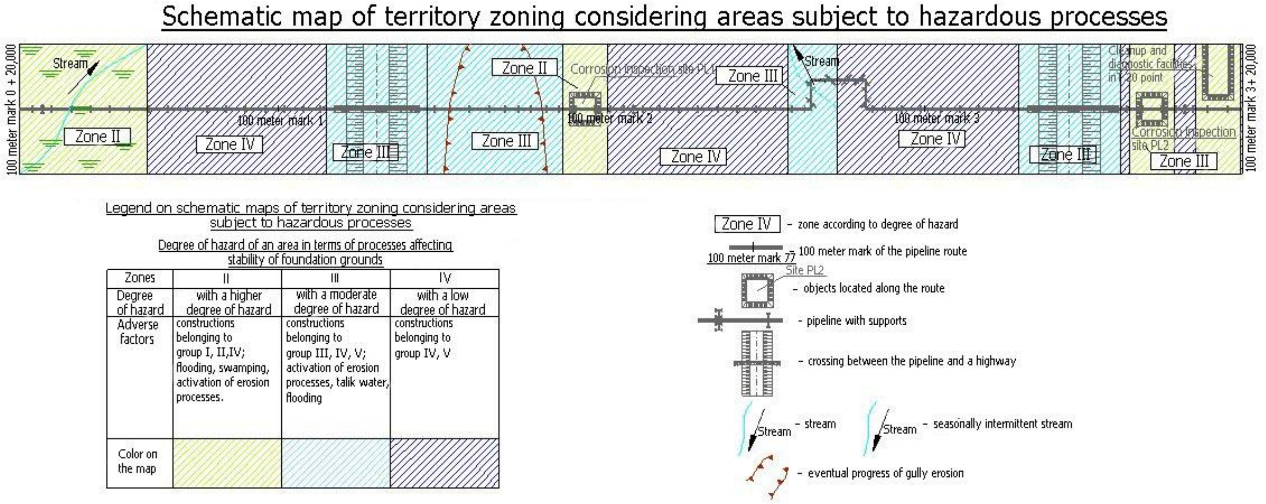


Figure 2. Schematic construction sites classification map

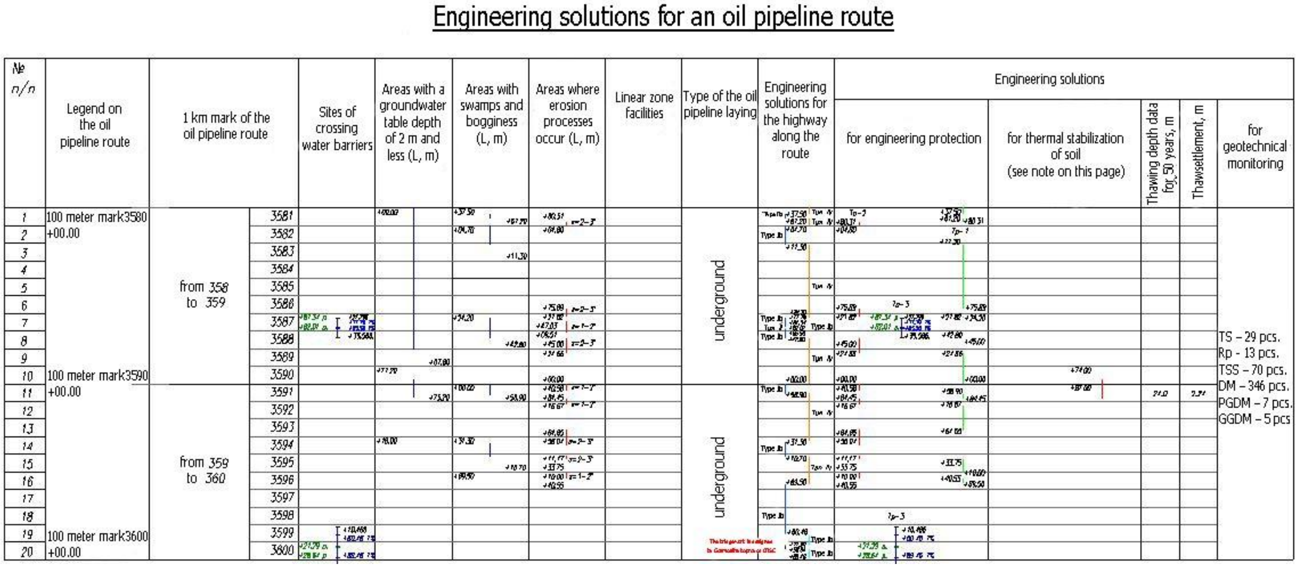


Legend on schematic maps of territory zoning considering areas subject to hazardous processes

Degree of hazard of an area in terms of processes affecting stability of foundation grounds

Zones	II	III	IV
Degree of hazard	with a higher degree of hazard	with a moderate degree of hazard	with a low degree of hazard
Adverse factors	constructions belonging to group I, II,IV; flooding, swamping, activation of erosion processes.	constructions belonging to group III, IV, V; activation of erosion processes, talik water, flooding	constructions belonging to group IV, V
Color on the map	▨	▨	▨

Figure 3. Schematic map of a site territory zoning considering areas subject to hazardous processes



Engineering solutions for an oil pipeline route

№ n/n	Legend on the oil pipeline route	1 km mark of the oil pipeline route		Sites of crossing water barriers	Areas with a groundwater table depth of 2 m and less (L, m)	Areas with swamps and bogginess (L, m)	Areas where erosion processes occur (L, m)	Linear zone facilities	Type of the oil pipeline laying	Engineering solutions for the highway along the route	Engineering solutions				
											for engineering protection	for thermal stabilization of soil (see note on this page)	Thawing depth data for 50 years, m	Thawsettlement, m	for geotechnical monitoring
1	100 meter mark3580 +00.00	from 358 to 359	3581						underground						TS – 29 pcs. Rp - 13 pcs. TSS – 70 pcs. DM – 346 pcs. PGDM – 7 pcs. GGDM – 5 pcs
2			3582												
3			3583												
4			3584												
5			3585												
6			3586												
7			3587												
8			3588												
9			3589												
10	100 meter mark3590 +00.00		3590												
11		from 359 to 360	3591						underground						
12			3592												
13			3593												
14			3594												
15			3595												
16			3596												
17			3597												
18			3598												
19	100 meter mark3600 +00.00		3599												
20			3600												

Figure 4. A fragment of a table of engineering solutions for an oil pipeline route

This, combined with a complex of schematic maps, helps one to describe a construction area in a more comprehensive way, determine the sites which are the most vulnerable during operational development and make a reasonable choice of the necessary measures for engineering protection (preparation) of the area and geotechnical monitoring.

As an example, Figure 5 presents a fragment of a table of engineering solutions for engineering protection and geotechnical monitoring that have been developed for pipeline routes.

Difficult geocryological conditions and effects of hazardous exogenous processes complicate the design of oil and gas complex facilities in the Far North. Fundamentproekt OJSC has many years' experience of design, as well as special-purpose calculation methods and software complexes. Thanks to the individual approach to facilities, detailed investigation and forecast of effects of geocryological conditions and hazardous cryogenic processes, the decisions taken ensure stability and long-term operational reliability in compliance with any engineering requirements.

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Permafrost Conditions in Kashin Island (Pechora Delta), from Seismic Profiling Data

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Abstract

The shallow-water part of the Korovinskaya Bay and the coast and beach areas of Kashin Island in the Pechora Delta have been explored by seismic profiling using the acquisition techniques and instruments designed at the Earth Cryosphere Institute SB RAS. The measured depths to the permafrost table are 4-6 m in the beach, increase slowly to 10 m in shallow water, and deepen abruptly to an unresolved depth at 180 m offshore, as a result of rapid coastal thermal erosion and aeolian processes. Permafrost occurs all over the island but the permafrost table is as deep as 2 to 5.5 m in kettles.

Keywords: Permafrost table; *P*- and *S*-wave velocities; seismic surveys; submarine conditions.

Introduction

Geocryological conditions in the permafrost zone of European Russia are quite well studied [*Ershov 1988, Oberman 2006, Malkova 2010, etc*.]. In the Pechora Delta, unfrozen ground is widespread beneath channels and floodplains while the elevated sides of the Korovinskaya Bay and islands are composed of frozen Quaternary sediments. The available data on the state and extent of permafrost at the sea-land boundary are still insufficient [*Melnikov & Spesivtsev 1995, Skvortsov et al. 2007*]. In 2011 seismic surveys were undertaken in the northwestern side of Kashin Island, located in the Pechora Delta within the shallow-water Korovinskaya Bay, to measure the depths to the table of coastal permafrost (Fig. 1, A). Seismic data were collected along three profiles (Fig. 1, B).

Results

Profile 1, 290 m long, was partly on the beach and partly in shallow water. Profile 2 (about 50 m) ran along the shoreline on the beach, and profile 3 (about 50 m) traversed a local depression of a sink kettle overgrown with willow and alder.

Velocities of compressional and shear waves excited by stacked repeated blows along the three profiles were measured by an ELLISS-2 digital station, with 10 Hz (resonance frequency) seismographs. Bottom measurements were performed using special instruments designed and manufactured at the Earth Cryosphere Institute SB RAS (Tyumen).

Shear-wave (horizontally polarized *SH* phase) refraction cross section along profile 1 is shown in Fig. 2. The refractor was identified as the permafrost table proceeding from high boundary velocities of both *P* and *S* waves. The permafrost table is uneven and lies at the depths 3-4 m on the coast within a sand bulge (point 0-90 m) and at 4-6m on the beach (point 90-110 m). The depth to the permafrost table increases seaward: it is 6-10 m in shallow water (point 110-250 m) and deepens abruptly at 150-160 m offshore (point 250-280 m) being undetectable by *SH* refractions. Offshore surveys were by *P*-wave reflection profiling which resolved the permafrost table as far as point 280-290 m.

Thus, submarine permafrost within the study area lies in the form of a cap as far as 180-190 offshore.

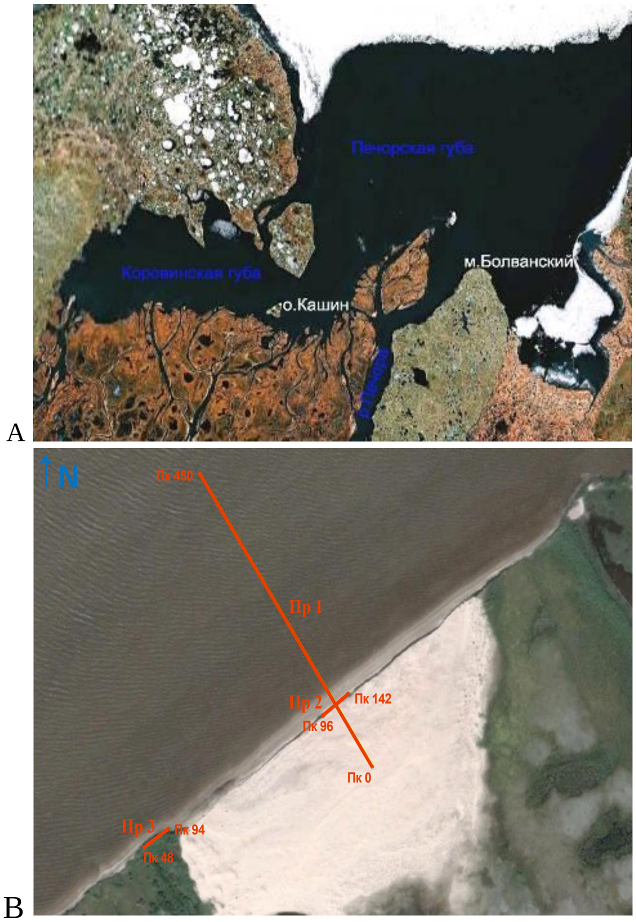

Fig. 1. Location map of Kashin Island (A) and position of seismic profiles (B)

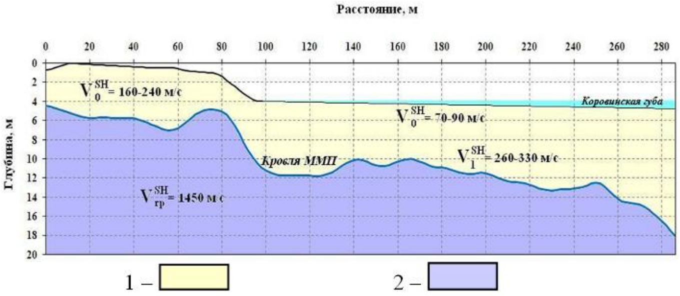

Fig. 2. *SH* refraction cross section of permafrost along profile 1. 1 – unfrozen ground, 2 – frozen ground

Figure 3 shows the seismic cross section of the beach along profile 2. The depths to the permafrost table are 4.5–5.5 m. These estimates appear to be reliable judging by a small difference between refraction and reflection data (no more than 0.5 m).

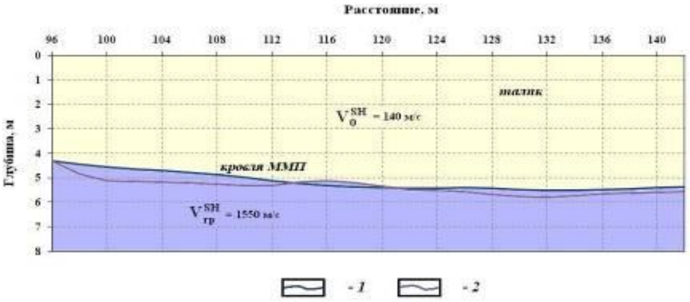

Fig. 3. *SH* refraction (1) and reflection (2) cross section.

Profile 3 was collected to measure the depths to the permafrost table in a sink kettle. The thaw thickness at points 1-13 of the engineering-geological profile (1-13 IGP) was estimated using a probe, but probing failed to reach the permafrost table at site 14-IGP. *P*-wave refraction profiling along profile 3 (from 48 to 94 m) revealed an above-permafrost unfrozen lens (talik), with its maximum thickness of 5.5 m at point 80 m.

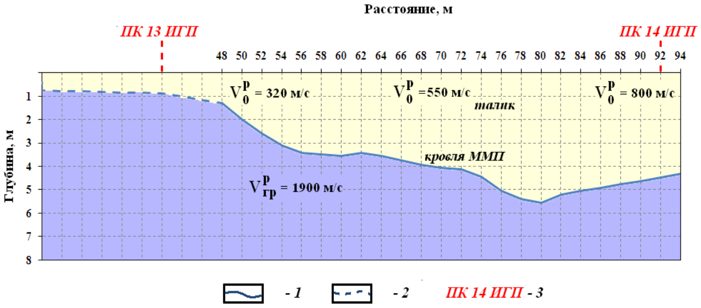

Fig. 4. Cross section obtained by seismic profiling and cryological probing. 1 – permafrost table defined by P-wave refraction profiling; 2 – probed permafrost table; 3 – points of engineering-geological profile

Thus, in the absence of drilling data, seismic surveys have resolved the permafrost table pattern in the northwestern side of Kashin island and in the adjacent shallow-water offshore area.

Acknowledgments

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Paleo-Permafrost Distribution Downscaled in South America and Northeastern Asia: Comparison of the GCM-based maps with the observations

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Introduction

Permafrost in late Quaternary

Changes in the distribution of frozen ground (permafrost and seasonally-frozen ground) are an important issue on a global context as it is widely recognized that the state and fate of the cryosphere is a key for a better projection of and mitigation against global change in this century. However, understanding the attribution and consequence of frozen ground changes needs a longer perspective, like the Quaternary, due to the inherent long time scale of the processes. There have been an accumulation of field materials providing the past periglacial processes in many areas. The temporal evolution of frozen ground under specific local conditions in the Quaternary has also been examined conceptually or numerically. The spatial extent of these works is, however, rather limited.

Improvement of the large-scale climate or earth system models (denoted as GCMs here) in the latest decade, has led to intensive use in global-scale investigations on the cryosphere or on the paleoclimate [*e.g., PMIP2, Braconnot et al. 2007*], but the models remain insufficient in terms of implemented physical processes or the horizontal resolution. The former limits the physical credibility of the model outputs, and the latter hinders direct comparison between the model results and the observationally-derived evidences.

Regional comparison by downscaling

In this paper, we show our attempt to compare the regional frozen ground distribution in South America and Northeastern Asia by a downscaling.

Due to relatively small portion of the terrestrial areas compared to that of the Northern Hemisphere (NH), the frozen ground distribution in the Southern Hemisphere (SH) has not been intensively surveyed and/or mapped. In Northeastern Asia, regional evaluations are limited, especially in paleoclimatic simulations, since the coverage of areas underlain by permafrost is small relative to the typical GCM grid scale. This scale gap is one of the reasons why the GCM results have not been widely used in investigations and applications in geography or geomorphology, although field surveys in these disciplines have intensively been conducted both in South America and in Northeastern Asia to evidence the periglacial processes and to determine their distribution in the Quaternary. Such research is necessary that bridges the gap between scales, and between the methodologies/disciplines.

Methods

Statistical approach and downscaling

Saito et al. [*2009*] presented a reconstruction of the NH frozen ground distribution on the large scale by a regression of the near-surface thermal conditions (i.e. freeze and thaw index, as the cumulative degree-day values below and above the freezing point, respectively). Validation with the current available map [*IPA map, Brown et al. 1997*] was reasonable despite simplifications of the factors that determine permafrost in the reality. We applied the regression to the global near-surface temperature outputs of PMIP2 for the pre-industrial (0ka), Holocene Optimum (6ka) and the last Glacial Maximum (LGM, 21ka) era to produce coarse-resolution distribution maps of global frozen ground under these late Quaternary conditions. Further, we used GTOPO30 (U.S. Geological Survey, 2004), a 30-minute resolution digital elevation model, account for the local topographic effect on surface air temperature in South America and Northeastern Asia. A common atmospheric lapse rate of 6°C/1000m and the sea-level fall by 120m at LGM were assumed. We did not consider other effects such as precipitation, snow depth, or aspect of the slope.

Results and Discussions

Southern Hemisphere

A slight cooling bias was found in the simulated pre-industrial surface air temperature in SH, as well as in NH. Mean annual surface air temperature (MAAT) for 6ka appeared even cooler. Still, the majority of the models produced no freezing in SH or, at most, seasonal frost in the Andes for 0ka. The lack of Holocene freezing resulted mostly from coarse topographic resolution (similar tendency was also found in the Himalaya for NH). For 21ka, Tierra del Fuego showed seasonally freezing, and only the Central Andes displayed permafrost.

Downscaling for South America and East Asia

The downscaled regional maps successfully showed the likely presence of frozen ground, such as permafrost in the Andes for 0ka, that the coarse-resolution global maps failed. However, it still showed insufficient and/or incorrect classifications, e.g., lowland in Patagonia and Tierra del Fuego that are not underlain by permafrost today but were in 21ka, failed to produce the LGM permafrost [*Trombotto 2008*]. The mid-latitude mountains with the Pleistocene permafrost evidence, such as Pampean Mountains and Ventania, also failed to be reproduced. This discrepancy is likely due to the regional warm bias in South America, in contrast to the cool bias on hemispheric scales.

As for Northeastern Asia, regional permafrost at LGM was reproduced well, like in the little Xing'anling and Changbai Mountains in the continent, and in the mountain ranges in the Northern (Hokkaido) and Main Island of Japan, which were not present at the GCM resolution (Figure 1). The height of the boundary between adjacent frozen ground types rose commonly by about 1000m at 36°N from the LGM condition to the present-day. This is well-compared to the observed evidences (Table 1). Presence of permafrost in the northeastern plains of Hokkaido is also consistent with the periglacial evidences found in the area. Overall, the downscaled reconstruction in Northeastern Asia was more in line with the geomorphological evidences than that in South America, partly owing that the regional climate in the NH mid-latitude is generally better simulated than that in the SH continents.

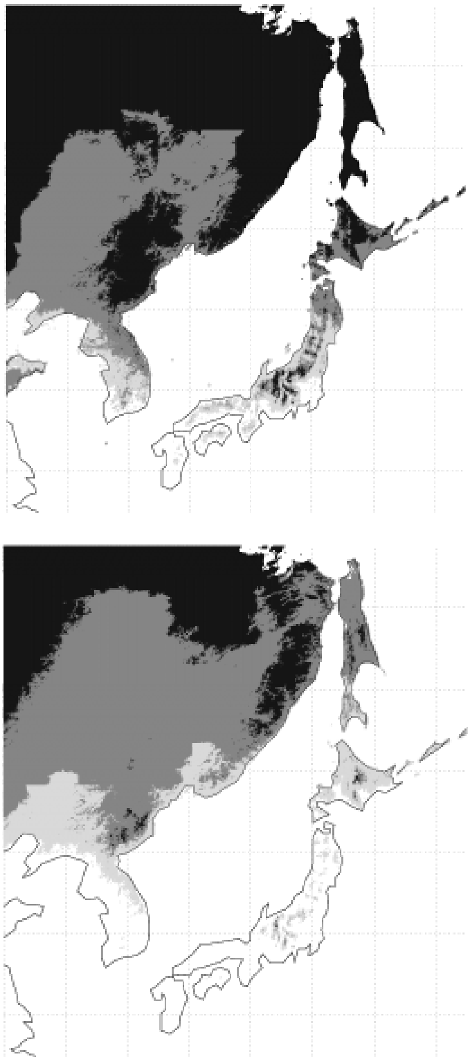

Figure 1. Distribution of frozen ground for the LGM (upper panel) and for the pre-industrial era (lower panel) in Northeastern Asia downscaled from the global reconstruction by the PMIP2 GCM outputs and the regression by Saito et al (2009). Black shades denote permafrost, dark grey seasonally-frozen (longer than two weeks) ground, and pale grey intermittently-frozen (less than two weeks) ground.

Table 1. Height of the boundary at 36°N (m) in NE Asia.

Era	Pre-industrial	LGM
Permafrost/ Seasonal	2304	1361
Seasonal/ Intermittent	1857	811
Intermittent/ No Freezing	870	-126*

* Extra-polated.

Implications and Future Steps

GTOPO30 covers only the current above-sea-level topography. Therefore, lowland or coastal areas at LGM, which are now under water, were not considered in this research. We will extend our investigation to include those areas. Evaluation of modeled surface air temperature in South American lowland (or, in general, in SH), both in terms of MAAT and the seasonality, will be worth paying attention for model improvement. Recent progresses in GCMs include coupling of permafrost dynamics with the biogeochemical processes, such as carbon and nitrogen dynamics, in some models. Some are also capable of simulating dynamical vegetation. Further examination of permafrost distribution and its variations through the physical perspective, as well as the biogeochemical, of the cryospheric environmental systems will enhance our understanding of the cold region environment, and readiness for better projection of and mitigation against global change to come.

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Experience in Construction and Operation of Buildings and Engineering Structures in Cryolithozone: Case of Mirny, Yakutia

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Abstract

The outer examination of the state of capital buildings and structures in Mirny (Yakutia) was conducted in Autumn 2011. It included the outer examination of building structures (foundations, walls, stair flights) and superstructure and substructure utilities. The data received can serve as the basic material for study of the buildings and utilities construction and operation experience in strict cryolithozone conditions.

Keywords: base; civil engineering; design; foundation; heat stabilizers; ventilated underground

The design of bases and foundations for buildings and structures construction on permafrost starts with the selection of the principle of their use.

Two main principles are used in the modern world:

1st principle - the grounds remain in a frozen state during construction and operation of the building or the utility.

2nd principle - the grounds are thawed before construction or during operation of the building or the utility, and construction and operation of the facility are conducted like on thawed grounds.

The adopted principle of use of the grounds assumes the use of corresponding measures and technologies.

The following technologies are applied when the 1st principle is used. They allow keeping the permafrost in a frozen state.

The use of ventilated undergrounds (low and high, with weep holes and of open type);

The use of ventilated channels or pipes (forced or natural ventilation);

Erection of ventilated shallow-buried foundations;

The use of heat stabilizers (by the time of work - seasonal and all-year-round; by the shape - vertical, horizontal and slightly inclined, by coolants - freon, carbon dioxide, ammoniac etc.);

The use of heat insulation;

Ground freezing with the use of refrigerating machines.

Heat stabilizers together with a ventilated underground or with heat insulation made of modern materials are most widely developed today.

Characteristic Features of the Mirny town:

- the climate is extreme continental;
- the annual mean air temperature is 7.1°C according to the long-term monitoring data;
- the annual amount of precipitation is 330 mm;
- the snow cover height does not exceed 50 cm;
- the lithological section of the town site is presented by Quaternary deposits, namely medium-ice clay silt and sand-crushed stone grounds, within the seasonal thawing layer depth 1.5-3.0 m. The grounds presented by limestone, dolomite, sandstone, marl and clay strata lie underneath.

The civil engineering is presented by buildings with up to 9-12 stories, with bearing walls made of lightweight concrete blocks. Ventilated undergrounds 0.5 to 2.0 m high are constructed under buildings.

Reinforced concrete or metal piles 10.0-14.0 m long are installed into preliminary drilled wells, filled with sand and clay pulp with a set composition. Pile caps and framing beams used in civil buildings are reinforced concrete, monolithic.

The so-called “cold” piles have become very popular recently.

General-duty production buildings are constructed on piles with a ventilated underground.

Preliminary construction of a crushed stone embankment 1.0-1.5 m high in the operational zone of all construction mechanisms is a process peculiarity of foundation construction in Mirny. The floor of the future ventilated underground is cemented inclined to the building contour by the end of pile works.

The authors of this work carried the outer examination of the state of capital buildings and structures in autumn 2011. It included the outer examination of building structures (foundations, walls, stair flights) and superstructure and substructure utilities. The list of main examined buildings included residential and public buildings, power transmission line towers, superstructure and substructure utilities. The main criteria used for evaluation of the state of examination targets were as follows:

1. Presence or absence of heat stabilization;
2. Presence and the state of a ventilated underground;
3. Presence or absence of fractures and failures in walls or foundations;
4. Presence or absence of structure enforcement (rails, frames);
5. Presence or absence of heat insulation of the utilities, its state.

A measuring tape and a ruler were used as metering means for examination of buildings. Photo and video registration of defects in buildings was conducted in the process of examinations.

The area of capital development of Mirny was assumed as a research one. It included stone and wooden buildings within the boundaries of the following streets: Ammosova, Industrialnaya, Shosse Kirova, Soldatova, and Shosse 50 Let Oktyabrya. This area was divided into 18 independent research sites corresponding to the main quarters of the town with capital development:

The following conclusions can be made on the basis of the completed research results:

1. We identified the following types of 385 buildings examined: wooden – 143 buildings, and stone – 240 (reinforced concrete structures), including living – 158, and public – 82.
2. All examined stone buildings were operated with the first principle of permafrost use: they were erected with the use of a ventilated underground.
3. The number of buildings with heat stabilizers is 94, which makes 39% of the total number of the examined stone buildings; these include 9 buildings where two different types of heat stabilizers and above are simultaneously used.
4. The number of stone buildings with these or other defects in structures (fractures in walls, destruction of the top part of piles) makes 16. This is 6.6% of the total number of stone buildings examined.
5. The number of stone buildings with these or other defects in structures (fractures in walls, destruction of the top part of piles) makes 13. This is 5.4% of the total number of stone buildings examined.
6. The number of the total stone buildings with enforced structures (walls, top parts of piles) in the form of metal frames makes 8. This is 3.3% number of stone buildings examined.
7. The number of stone buildings with registered utilities open leakage under them makes 4. This is 1.7% of the total number of stone buildings examined.
8. Multiple discontinuities or complete absence of heat insulation were identified in the process of examination of the outer utilities.

The received data can serve as the basic material for housing and municipal services not only in Mirny but also in other towns located in strict cryolithozone conditions. The results received can be valuable for construction of buildings and structures in severe climatic or ground conditions, and for reconstruction of the existing ones because they are presented by the abundance of technical and process solutions for provision of the frozen and thawed foundation grounds stability.

The Wash-Out of Organic Carbon from Degrading Shores and its Distribution at the Under-Water Coastal Slope (the Buor-Khaya Peninsula, the Laptev Sea)

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Introduction

The active supply of clastic organic carbon to the Arctic basin from degrading sea shores draws serious attention of many researchers because it serves as a greenhouse gas source. It was found out that the shores composed of the ice complex and alas deposits are the main sources of organic carbon in the East-Siberian Arctic Region [*Kholodov 2003; Grigoriev et al. 2004*].

The purpose of this research consisted in the evaluation of the quantity of organic carbon (C_{org}) supplied to the Buor-Khaya Gulf as a result of thermal abrasion and thermal denudation destruction of the Buor-Khaya Peninsula western shore and identification of the peculiarities of the C_{org} distribution in bottom sediments at the under-water coastal slope.

The theodolitic survey of shores and the analysis of remote survey materials made it possible to determine the average speed of the peninsular shore recession during the recent 36 years (1974-2010). The mass of the coastal material coming to the adjoining water area, including its organic component, was evaluated based on the calculation of the shore dynamics and morphology, and also on the analysis of the coastal deposits composition. The analysis of the C_{org} distribution at the under-water slope made it possible to determine rather clear regularities consisting in the significant growth of its concentrations with the sea depth increase.

Research area and object

The field works were conducted along the western shore of the Buor-Khaya Peninsula. The research area is referred to the Yano-Indigirskaya Lowland. The area represents an accumulative plain limited by the mountains of the Verkhoyanskoe Upland ridges from the south and the Laptev Sea from the north. The peninsula is mainly composed of the Holocene alas deposits filling thermokarst ditches (elevation is 10-15 m) and the Pleistocene deposits of the ice complex composing ouvals (elevation is 25-37 m) that separate alas depressions. The ice complex genesis is still discussed but most of researchers today are of the opinion that the ice complex can be composed of the sediments of polygenetic origin [*Alekseev 1970, Konishchev 1981 and others*].

The total length of the shores under study makes up 82 km, including 76% falling on the shores composed of alas deposits and 24% - on the ice complex.

Methods

In August 2010 deposit samples were taken on the peninsula and in the Buor Khaya Gulf from coastal benches, on the beach and in the estuaries of minor rivers, and also bottom sediment samples were taken along seven profiles up to 5.5 km long, adjoining the western shore of the peninsula.

Computer-aided laser tachometer ZEISS ELTA C30 with quartz deflectors was used for coastal line and cliff edge survey. Aerial images and satellite images of different survey periods were used for the calculation of the shore dynamic characteristics. Materials were processed with the help of the ArcGIS software.

The analysis of the C_{org} content in the samples from bottom sediments and coastal slopes in the Buor-Khaya Peninsula area was conducted in Limnology Institute of RAS. The C_{org} content in the samples was defined by the method of catalytic high-temperature oxidation of samples at 950°C with further determination of CO_2 with the help of the IR detector by using high-temperature carbon analyzer Vario TOC cube. The average values of three measurements for one sample were taken as a result. The value standard deviation does not exceed 0.01%.

Results

According to the completed calculations, about 4,400 tons of organic substance is washed out every year to the sea in the process of degradation of the western shore of the Buor-Khaya Peninsula.

The C_{org} content made up from 1.22 to 9.4 mass percent of the hosting strata mass in the ice complex deposits and in the alas depressions sediments exposed in coastal cliffs and sampled with a series of profiles. The organic carbon concentration is 2.66% on average for the shores composed of the ice complex, while for alas deposits it makes up 3.13%. These values agree well with the similar data received for the ice complex and alas deposits at the Bykovskiy Peninsula located in the southwestern part of the Buor-Khaya Gulf [*Schiermeister et al. 2002; Kholodov 2003*]. Very high C_{org} concentrations reaching 4-5 mass percent are found in the deposits of the estuary zone of the Orto-Stan River removing a large volume of silty material from the tundra.

In the meantime, the average C_{org} content in surface sediments is rather low - from 0.03 to 0.18 mass percent, and in individual cases - up to 0.99% in the coastal shallow waters (Fig. 1).

Clear and rather a fast increase in the C_{org} concentrations of bottom sediments is noted in all sea profiles with the increase of the sea depth down to 7-10 m at the distance of 3-5.5 km from the shore where the carbon content makes up 0.4-0.9 mass percent. Such distribution of C_{org} concentrations is explained by the active processing of bottom sediments in the relatively shallow-water part of the under-water coastal slope, and by organics transportation to the bold part of the water area. The C_{org} concentration anomalies at the under-water slope are evidently associated with the removal of large volumes of organics by minor rivers draining the catchment basins with a wide development of organic-bearing grounds - of the Pleistocene ice complex and of the Holocene alas deposits.

According to the data available, the highest C_{org} concentrations, up to 3 mass percent, are noted in the central sector of the Buor-Khaya Gulf, with the sea depth above 11 m.

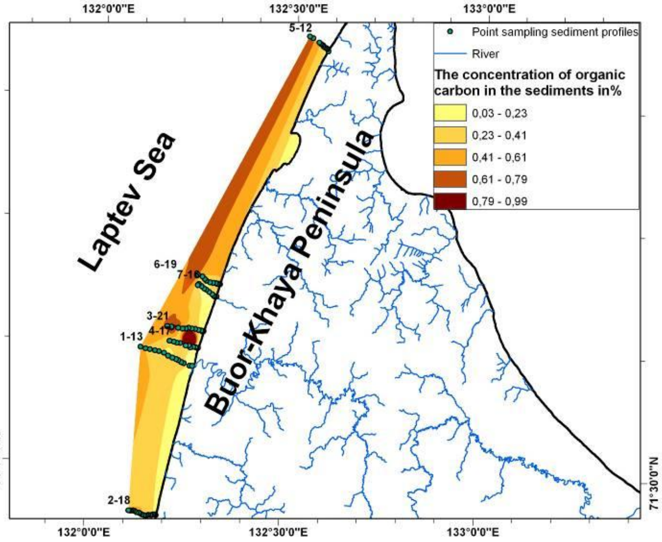

Figure 1. The distribution of organic carbon in bottom sediments.

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Modern Lake Dynamics in the Southern Fringe of the Siberian Permafrost Region in Mongolia Based on High Resolution CORONA and ALOS Data

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Introduction

There exist numerous lakes on the high latitude permafrost regions, Siberia, Canada, and Alaska [*Smith et al. 2005, Riordan et al. 2006 & Plug et al. 2008*]. Recently, the areal extent of these lakes has changed consistently with permafrost degradation. The thawing of permafrost was proposed as an explanation for both phenomena. It causes thermokarst and associated lake growth in continuous permafrost while enhancing infiltration to the subsurface in discontinuous, sporadic and isolated permafrost [*Yoshikawa & Hinzman 2003*]. Therefore, the long-term trend of the lake areas reflects the changes of the terrestrial hydro-geocryological regimes.

There are numerous lakes on the regions with permafrost over Mongolia [*Tumurbaatar 2001*], which have not been explored with regard to their spatiotemporal changes. The temperature and ice contents of permafrost vary significantly in their geographic settings in Mongolia, continuous and ice rich permafrost in the northern territory and discontinuous, sporadic and isolated permafrost with low and moderate ice content in the southern territory. Furthermore, large climatic gradients occur along latitudes, colder and wetter in the northern territory, and warmer and dry territories in the southern territory. These factors may have significant influence on the spatiotemporal dynamics of Mongolian lakes. The primary purpose of this study was to provide quantitative information of the decadal areal changes of lake size on the Mongolian permafrost region based on high-resolution satellite images in the past 46 years. We analyzed the factors that affect the changes of lake while focusing on the long-term trend of permafrost degradation and hydro-geocryological regimes.

Study Area

Mongolia is located in the eastern fringe of the Siberian permafrost region with the continuous, discontinuous and isolated permafrost zones. In this study, we selected eight representative sites as shown Fig. 1 with the continuous (sites 1, 2, 3, and 4) and isolated permafrost zones (sites 5, 6, 7, and 8). The permafrost of this country shows temperature close to 0°C, and is expect to thaw drastically due to climate-induced warming. Permafrost related landforms such as pingo, ice-wedge polygon, hummock, and thermokarst are distributed in Mongolia.Climate of Mongolia is characterized by cold and moist weather in the northern territory and warm and dry weather in the southern territory. Winter air temperature often reaches to -50°C in the northern territory whereas it reaches to 4°C in the southern territory. The warmest air temperatures occur in July, ranging between 10°C and 15°C in the northern territory. Summer season precipitation contributes to more than 60% of the annual precipitation over Mongolia. Annual total precipitation is 250-300 mm in the Hangai, Hentii and Hovsgol mountain regions, 150-250 m in Altai, and 50-100 mm in the south Mongolia.

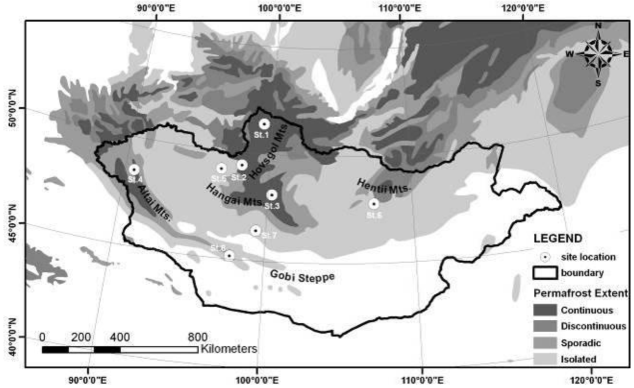

Figure 1. Map of the eastern fringe of the Siberian permafrost distribution and location of the study sites in Mongolia.

Data and Methods

In this study, we used high-resolution CORONA, and ALOS/AVNIR-2 satellite images from 1962 to 2008. High-resolution (1.8-7.6 m) CORONA KH-4, KH-4A, KH-4B stereo-pair images (16 scenes) of study sites were obtained from the USGS in digital format scanned at 3600 dpi (7 microns). Modern lake evolutions were determined by the AVNIR-2 images, which provide four bands from a visible to near-infrared radiometer with a spatial resolution of 10 m and ALOS images (8 scenes) taken from 2006 to 2008. These images were obtained from the RESTEC. The software package Leica Photogrammetric Suite (LPS 9.3 workstation) in ERDAS IMAGINE was used for ortho-rectification of Corona panoramic camera images. We surveyed the ground control points (GCPs) and lakes boundary with a mapping-grade GPS during fieldwork in 2009 and 2010. For ortho-rectification, more than 50 GCPs were extracted from topographic maps (1:100,000 scale) produced in 1970, Landsat ETM+ (band 8) images, and the ASTER GDEM. The overall root mean square error (RMSE) for rectifying the Corona images was 4.38 m.

Modern extent of lake areas was evaluated by AVNIR-2. We geo-referenced the AVNIR-2 images using the AutoSync workstation of ERDAS 9.1 and the Landsat ETM+ (band 8) images. For the geo-referencing, more than 20 GCPs were used per scene. The overall RMSE for geo-referencing the AVNIR-2 images was 1.00 m. To extract the lake area from the geo-referenced images we manually digitized all lake areas from each image, example of which is shown in the form of 46 years evolution in site 1 (Fig. 2). Lake areas were extracted as polygon data by manual digitizing. Then, we categorized lake area into nine distinct classes (i.e. 0.01-0.04 ha, 0.04-0.1 ha, 0.1-0.25 ha, 0.25-1 ha, 1-10 ha, 10-25 ha, 25-100 ha, 100-1000 ha, and 1000-10000 ha) to better understand the dynamics for individual lake categories.

We used reanalysis data (NCEP/NCAR: temperature and precipitation) to evaluate the relationship between the areal changes of lake and hydro-climatology parameters. To estimate summer potential evapotranspiration (PET: June-September

1960-2009), we computed Thornthwaite's Water-Balance Model. Then, we calculated the water budget at each study site as precipitation – PET for each year [*Saruulzaya & Ishikawa*].

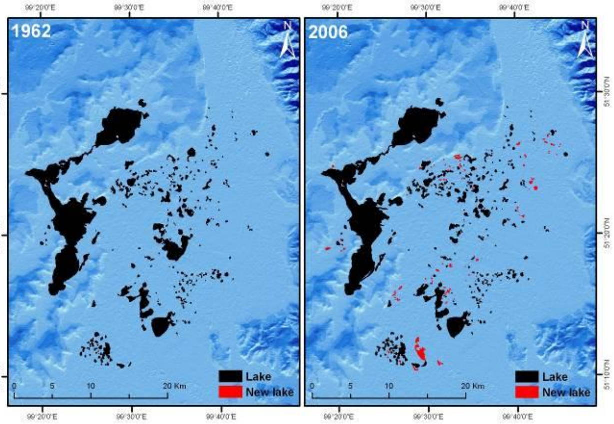

Figure 2. Lake changes at site 1 in the continuous permafrost.

Results and Discussion

We identified and delineated 1062 lakes in the continuous, and discontinuous and isolated permafrost. In the continuous permafrost, the total lake area was decreased from 10949 ha in (1960s) to 10639 ha (2000s). We found that the area and number of lakes ranged between 0.04 and 10 ha were increased while lakes larger than 1000 ha remained almost stable. Total 91 lakes, which occupied 486 ha, have appeared by 2000s and the area of 207 lakes has increased by 395 ha in some sites (1, 2, 3, and 4). While there was no significant areal change in 15 lakes, we found that some lakes were significantly degraded. The area of 109 lakes decreased by 566 ha and 19 lakes completely disappeared by 625 ha. These lake behaviors can be explained by the positive anomaly of MAAT that increased by 0.04ºC per year in the continuous permafrost. This atmospheric warming possibly thaw ice rich ground materials (i.e. ice-wedge) and produce undulating topography activating thermokarst processes [*e.g. Hinzman et al. 1998*]. This is the most probable mechanism for the appearance of the lakes smaller than 10 ha. In total, the lakes on the continuous permafrost decreased in area (4%) and increased in numbers (20%). Recent research found that there was ongoing permafrost degradation significantly in the continuous permafrost [*Sharkhuu et al. 2008*]. The number of lakes in the west and eastern Siberian continuous permafrost was also increasing [*Smith et al., 2005*]. We found similar trend in Mongolia, too. From 1960 to 2009, summer precipitation was decreased at all sites. MAAT was significantly increased for all sites, especially for sites in the continuous permafrost (see Fig. 1 for locations). The summer PET at all sites has increased significantly in the continuous permafrost whereas PET has remained stable in the isolated permafrost. The water budget showed negative trends at all sites [*Saruulzaya & Ishikawa*]. We found that lakes were degraded in the discontinuous and isolated permafrost (sites 5, 6, 7, and 8). Lake areas decreased from 534 ha in the 1960s to 509 ha in the 2000s in total and their numbers reduced by 51. The exception occurred in the isolated permafrost where 66 lakes increased by 70 ha in area and 48 lakes slightly decreased in area (56 ha). 53 lakes have completely disappeared by 37 ha. Previous studies have reported that lakes on the isolated permafrost are under degradation [*Smith et al. 2005 & Riordan et al. 2006*]. We found similar variation along permafrost zones over Mongolia. In total, the lakes in the isolated permafrost reduced by 5% in area and 30% in numbers. The high-resolution images from 1962 to 2008 revealed that the majority of the smaller lakes (0.01-10 ha) actively decreased in the isolated permafrost. These high resolution images revealed the majority of smaller lakes 0.01-10 ha are actively expanded in the continuous permafrost zone, whereas those lakes are decreased in the isolated permafrost zone. The behavior of smaller lakes is also controlled by degrading permafrost in continuous zone. Due to their behavior, thermokarst lakes have the potential to be a useful indicator of permafrost degradation that is occurring in the northern Mongolia. We concluded that the ongoing atmospheric warming over the continuous permafrost thaws ice-rich ground parts increasing the number of small lakes because the spatial differences of drying trend were significant. Deforming small lakes reflect their sensitively to the hydrological and geocryological regimes.

Acknowledgement

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The Basic Permafrost and Environmental Problems in the Process of Development of Gas Fields in the North of Western Siberia

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Introduction

Gas field development and operation lead to significant changes in geocryological conditions. The future stability of the permafrost and environmental conditions as well as the reliability of the geotechnical environment depend much on competent construction and operation of facilities of various applications (well clusters, pipelines, large heat-emitting industrial buildings etc.). The activation of hazardous cryogenic processes (ground subsidence as a result of thawing, frost heave etc.) can lead to gas pipeline blowout and facility destruction. Accurate research works for the development of gas fields and the correct choice of the methods for area engineering preparation and of foundation types are required for minimization of the adverse changes in permafrost bases. This ensures the fail-safety of facilities.

Research methodology

The on-site investigations were conducted in the north of Western Siberia, at the area of the Yubileynoe gas field (40 km to the west from Novy Urengoy) and the Yamburg gas condensate field (the Tazovskiy Peninsula). The flowcharts of gas production, preparation and transportation in the cryolithozone were studied. Field managers kindly explained and showed the methodology and the equipment used for gas filed development within the whole chain: gas well - well clusters - intrafield gas pipelines - gas pipeline coupling shop - booster compression station - gas treatment shops - absorbent regeneration facilities - compressors for pressure increase - main gas pipeline. Also, field routes were arranged along gas pipelines for evaluation of the degree of permafrost conditions change in their impact zone. It should be noted that gas field development and operation leads to the formation of specific natural-technogenic geocryological complexes [*Grebenets & Pavlunin 2007*] distinguished by specific heat exchange conditions through the surface in the "atmosphere - permafrost" system as well as by thermal and hydrogeological regimes.

Results and discussion

The Yubileynoe gas field is one of the oldest gas fields in the cryolithozone of Western Siberia and is operated since the beginning of the 1980s. The interformational pressure was initially 90-100 kg/sq.cm. Now, many years after the development (Cenomanian horizon) it fell down to 30-35 kg/sq.cm (but it makes about 65 kg/sq.cm in the main pipeline passing to the center of the country and further to Western Europe). Consequently, many devices increasing the pressure and reducing the temperature are required. These conditions make it possible to transport a greater volume of gas. The gas processing facility of the Yubileynoe gas field now receives gas from the newly developed Yamsovey structure located 40-60 km to the south from the Yubileynoe gas field. By now, only several clusters were constructed in the northern part (closer to the Yubileynoe field) of the Yamsovey field.

The gas from the formation goes together with water, soluble salts, condensate and ground particles. Thawing zones are naturally formed around gas wells. Sometimes accidents occur in case of thawing-out of large ice masses and ground subsidence. But in any case well operation leads to the occurrence of talik zones around wells. Annulus cementing is required in case of settlement of thawing grounds. The gas is produced directly from wells united into well clusters. Technogenic sand embankments are filled on cluster pads. Roads are built to them. Their construction and operation disturb the surface and the ground (within the active layer) water flows.

Gas contamination, gas hydrate formation and freezing of water in gas should be avoided. Two main methods of its treatment (from admixtures) and preparation are used for that: mechanical (water catchment), heat (water-vapour removal) and chemical (the use of absorbing compounds: tetraethylene glycol - TEG; and diethylene glycol - DEG or methanol). The gas from the nearest clusters goes to the intrafield gas pipeline passing to the valves shop located on the gas processing facility site. The whole area of the gas processing facility represents a specific technogenic zone within which a vegetative and a soil-moss covers are preliminarily removed with a mechanized method, and then thick technogenic sand fills are performed, large facilities are erected, roads are coated with asphalt, and pipelines, communication and energy cables are laid. Valves shops, booster compression stations, gas treatment and drying shops, a TEG and DEG regeneration shop and other facilities are located at the Yubileynoe gas field area. They have a great negative impact (heat, power, electromagnetic and mechanical) on the bases permafrost. A lot of heat stabilizers are installed on the site (several hundred). They maintain the permafrost state of grounds at facility bases. Rather a serious problem is frost heave of low-loaded towers of cable racks and the destruction of the road coating as a result of settlement of the seasonally thawed layer grounds (when thawed) and as a result of their heave (when frozen). After the gas processing facility, the gas in the gas pipeline goes to the measuring unit and only after that to the main gas pipeline.

The gas processing facility UKPG-1V located in Yamburg is already 20 years old. It treats and prepares for transportation the gas from 80 wells developing a deeper horizon - the Volonzhin one. The initial formation pressure in the process of gas production at this gas condensate field was 250 kg/sq.cm, and now it is 180 kg/sq.cm. The gas formation pressure falls with production increase. The field is exposed to technical inspection every year. It is carried out in summer due to the known reasons, and the work of the whole field is suspended then for 12 days.

38 mln. cub.m of gas is annually produced in the field. Then it is sent to Surgut and Novy Urengoy. Foreign countries

and the central regions of Russia are the main consumers of gas processing facility UKPG-1V. The gas for the needs of the field is transported to a special gas compressor unit consuming 300 th cub. m of gas per day (this is below 1% of the whole daily gas production volume in this field). This field is equipped with backup power supply sources in case of emergency outage, and also additionally with one diesel backup power station (the first category of facilities). There is diesel fuel production in the field for its own needs (vehicle charge etc.). Major industrial units of gas processing facility UKPG-1V are located at the large site where engineering preparation works were preliminarily conducted: the vegetation and the soil cover were removed, some minor watercourses were filled and a thick sand embankment was constructed. Two serious permafrost and environmental problems were registered: a) active development of thermal erosion and ravine formation near the territory of gas processing facility UKPG-1V; and b) intensive heave of metal pile piers for intrafield overhead pipelines.

The impact of the gas field outruns the enterprise itself. The reliability of gas-transport systems is improved in case of correct gas pipeline embankment. It is also improved when the trench ground-filling requirements are followed during underground pipeline laying, and when piles for the overhead gas pipeline laying are installed competently. The consequences of incorrect gas pipeline construction can be very serious (Fig. 1.)

Figure 1. Exposure of the underground gas pipeline at the Yubileynoe gas field area in the process of thermal erosion development, July 2009.

Incorrect embankment and filling of a trench with peat and peated clayey silt (local materials) led to the thermal erosion development, and, consequently, to the change of the gas pipeline position; side soil failure occurs very actively due to thermal erosion and threatens the normal operation of the inspection road constructed nearby. Accidents on gas pipelines sometimes occur in the zones of crossings across minor rivers or ravines; firstly, solifluction develops on slopes, and, secondly, temperature differences in the grounds of coastal junctions and at the valley bottom are significant. The reliability of these sites is improved by means of construction of pipe-in-pipe systems and pile piers with regard to the differences in geocryological conditions on the banks and in floodplains of minor watercourses.

Conclusions

New natural-technogenic geocryological complexes are formed in the process of gas field developed in the north of Western Siberia. Their type and state depend, firstly, on natural geocryological conditions and, secondly, on the type and the intensity of technogenic loads.

The probability of formation of blowouts at the gas pipeline is the main problem occurring in the process of gas field development in the north. It is associated with the change (as compared to the research period) of strength characteristics of foundation grounds: in case of underground laying - formation of irregular thawing halos, and in case of overhead laying - frost heave of pipeline towers. Thermal erosion activation in easily-washed strong silty sand and sandy silt grounds is the second problem of this region. Severe worsening of geocryological conditions is observed along multiple roads constructed for gas field maintenance: flooding and underflooding zones are formed and thermokarst is activated along the roads. High snowiness in the region also reduces the geotechnical safety of bases: superstructure (condenser) parts of heat stabilizers are covered with snow, which significantly reduces the efficiency of operation of these seasonally cooling devices. This problem can be intensified due to winter warming and an increase in snowiness in the north of Western Siberia predicted for the next decades. Inexpediency of extreme economy during the gas pipeline construction period should be noted. Permafrost is very variable. Consequently, it is necessary to increase (as compared with the calculations received on the basis of standard methodologies) the depth of burial of pipelines and other facilities towers in permafrost. This will improve their further operational reliability.

Acknowledgments

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Research Coordination Network on the Vulnerability of Permafrost Carbon

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Approximately 1700 Pg of soil carbon are stored in the northern circumpolar permafrost zone, more than twice as much carbon than currently contained in the atmosphere [*Tarnocai, Canadell et al. 2009*]. Permafrost thaw, and the microbial decomposition of previously frozen organic carbon, is considered one of the most likely positive feedbacks from terrestrial ecosystems to the atmosphere in a warmer world [*Schuur, Bockheim et al. 2008*]. Yet, the rate and form of permafrost C release is highly uncertain but crucial for predicting the strength and timing of this carbon cycle feedback this century and beyond. Here we report on the first products of a new research coordination network (RCN) whose objective is to link biological C cycle research with well-developed networks in the physical sciences focused on the thermal state of permafrost. We found that published literature in the Science Citation Index identified with the search terms 'permafrost' and 'carbon' have increased dramatically in the last decade. Of total publications including those keywords, 86% were published since 2000, 65% since 2005, and 36% since 2008. Increasing publications with the search terms 'permafrost' and 'carbon' show the potential for synthesizing existing research. The network is structured into five working groups that prioritize on 1) the quantity of permafrost C pools, 2) the quality of permafrost C, 3) thermokarst and thermal erosion of permafrost C, 4) anaerobic and aerobic C mineralization and 5) upscaling and modeling of permafrost C to answer specific questions for quantifying permafrost C climate feedbacks. Working groups are open to new participants interested in making substantial contributions to the creation of databases and other proposed synthesis products http://www.biology.ufl.edu/permafrostcarbon/.

The first RCN activity consisted of an expert elicitation that revealed the total effect of carbon release from permafrost zone soils in climate is expected to be 9-26 Pg C (median values under lowest to strongest warming scenario presented to the group) over the next three decades, reaching 67-245 Pg C by 2100 and potentially up to 178-619 Pg C (Fig. 1) over the next several centuries [*Schuur, Abbott et al. submitted; Schuur & Abbott 2011*]. These values, expressed in billions of tons of C in CO_2 equivalents, combine the effect of C released both as CO_2 and as CH_4 by accounting for the greater heat-trapping capacity of CH_4. However, the higher global warming potential of CH_4 means that almost half of the effect of future permafrost zone carbon emissions on climate forcing was expected by this group to be a result of CH_4 emissions from wetlands, lakes, and other oxygen-limited environments where organic matter will be decomposing. These results demonstrate the vulnerability of organic C stored in near surface permafrost to increasing temperatures. Future activities of this network include synthesizing information in formats that can be assimilated by biospheric and climate models, and that will contribute to future assessments of the IPCC.

Figure 1: Cumulative carbon emissions predicted by experts as a result of warming climate for three different time horizons on high (1a, 2.5°C at 2040, 7.5°C at 2100) and low (1b, 1.5°C at 2040, 2°C at 2100) warming trajectories. Colors represent median values per permafrost zone and are expressed in CO_2 equivalents.

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Controls on through-talik development after ice sheet retreat under lakes in West Greenland

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Introduction

In the Kangerlussuaq area, West Greenland, the proglacial area stretching from the margin of the Greenland Ice Sheet (GrIS) to the coast was covered by the GrIS during the last glacial maximum (LGM). Comparison of radiocarbon dates of shallow lake sediments and moraines suggest lake development to coincide with the retreat of the ice-sheet margin [*Willemse 2002*]. At present day, boreholes show that permafrost is approximately 300 m deep near the ice-sheet. Taliks penetrating the thickness of the permafrost are believed to occur underneath lakes large enough to provide sufficient thermal insulation. Nevertheless, observations have shown that a small lake (radius of 30 m, maximum depth 3.5 m) after partial lake drainage, refilled itself within a few months. Considering heat conduction only, a thermal through talik is unlikely; however, we hypothesize that advective heat flow by groundwater discharge could have resulted in conditions that have locally hampered permafrost development after retreat of the GrIS.

Regions in front of an ice sheet are subject to high hydraulic head gradients if the ice-base is under pressure melting, and groundwater flow paths can extent into the proglacial area where upwelling to the surface can potentially occur via localized high permeable zones. Lakes forming immediately after ice retreat may be connected to a deep aquifer system, hydraulically linking the sub-glaical and proglacial domains while permafrost is forming around these lakes. Whether the connection to the subpermafrost aquifer gets cut off, is subject to the size of the lake, the lake bottom temperature, the mean annual air temperature and the rate of groundwater discharge into the lake.

In this study, we aim to improve understanding of the occurrence of groundwater flow in permafrost covered areas by numerical modeling of coupled heat and fluid flow including phase changes and their impact on hydrogeology. (1) The relation between lake radius, depth and temperatures at the lake bed by numerical modeling over seasonal cycles is studied. (2) Results from (1) are incorporated for a 2D regional- scale hydrogeological model of an ice sheet covered area from which the ice retreats starting from the end of the LGM to its present position. In the forefield of the ice-sheet we mimic lake formation. In this way, we study the possibility of the development of through taliks due to advective heat flow through groundwater discharge.

Numerical Modeling

We calculate coupled heat and fluid flow with finite elements, using FlexPDE, a scripted Finite Element Solution Environment for Partial Differential Equations (www.pdesolutions.com). The governing equations describe a transient hydraulic head and heat flow. The transient hydraulic head (h [m]) is calculated assuming:

$$\nabla \cdot [K\nabla h] = S_S \frac{\partial h}{\partial t} \tag{1}$$

where K [m s^{-1}] is the hydraulic conductivity, and S_s [m $^{-1}$] is the specific storage of the aquifer.

Temperature distributions (T [°C]) are calculated using the advection-diffusion equation and taking into account the effects of latent heat of freezing/thawing groundwater.

$$\nabla \cdot [\kappa_a \nabla T] - C_W \vec{q} \cdot \nabla T = C_a \frac{\partial T}{\partial t} + L_i \frac{\partial \theta_w}{\partial t} \tag{2}$$

Where C_w [J m^{-3} K^{-1}] is the heat capacity of water, L_i [J m^{-3}] the volumetric latent heat of fusion, and $\vec{q}$ [m s^{-1}] the Darcy flow rate. The effective thermal conductivity (κ_a [W m^{-1} K^{-1}]) is calculated as a geometric mean from the components of rock, water and ice and the volumetric heat capacity (C_a [J m $^{-3}$ K $^{-1}$] is calculated using a weighted average. Phase change of water is described using a smooth stepping function between 0°C and -0.25°C. Permeability reduction over the freezing interval is modeled as a function of water saturation state, based upon experimental data from Kleinberg and Griffin [*2005*].

The boundary conditions for both heat and fluid flow are a dirichlet boundary on top, driving the model. The sides and the base are closed, but for heat flow, a flux boundary at the base represents the geothermal gradient.

Lake bed temperatures over a seasonal cycle

Here, the top boundary conditions are set to air temperatures and thermal properties in the lake are adjusted. Steady state modeling of a lake with a mean annual air temperature (MAAT) below 0°C results in a completely frozen lake, using heat flow only, and hence this approach is not suitable. As long as the lake is unfrozen, the temperature profile of a shallow, unstratified lake is strongly influenced by wind driven convection. This process is not included by equation 2. Therefore, to model the lake bottom temperatures, convection is included by the means of an artificially high conductivity for water (κ_a) at temperatures > 0°C. When surface temperatures reach 0°C, κ_a is set to its natural value.

Results show that temperatures along the lake shore follow the seasonal cycle of air temperature; however their amplitude is slightly reduced. In deeper water, the lake bottom temperatures follow air temperatures in summer, however in winter they remain at temperature of 0-4°C. This temperature depends on the lake size for a lake radius of less than a critical radius. Above this critical radius, mean annual temperatures at the lake bed stabilize at 4°C. The lake bottom temperature in the middle of the lake does not change once a critical radius is reached, but the temperature at the margin continues to alter with increasing lake size / depth.

Lakes forming in front of retreating ice sheet

To model a 2D regional scale system of a retreating ice sheet starting at the last glacial maximum and retreating to its present boundaries with lakes forming in the glacier forefield, the following alterations to the top boundary conditions are made. 1) The hydraulic head follows the surface elevation and under the ice sheet, the 90 % of the ice thickness is added. This assumes a hydrostatic pressure with a connection of surface with the glacier bed through channels and crevasses. 2) Temperatures under the ice sheet are at pressure melting temperature, and in the proglacial area subject to mean annual air temperatures. At the ice margin, there is a smooth transition zone between the two temperature regimes. 3) Lake bed temperatures follow the temperatures calculated in the previous section for different lake sizes.

Results show that due to high hydraulic head gradients, the proglacial area is subject to groundwater discharge. During the freezing process, groundwater discharges preferentially through taliks underneath lakes. Some of them remain open over the period since the LGM, whereas a conduction only model with the same settings does not show a through talik.

The comparison of a model of a single lake with a high hydraulic head, as it can be found in front of an ice sheet with a model without fluid flow, reveals that the through talik freezes down within a few hundred years, whereas in the same setting but with consideration of advective heat flow due to subsurface flow, the through talik does not freeze down (Figure 1).

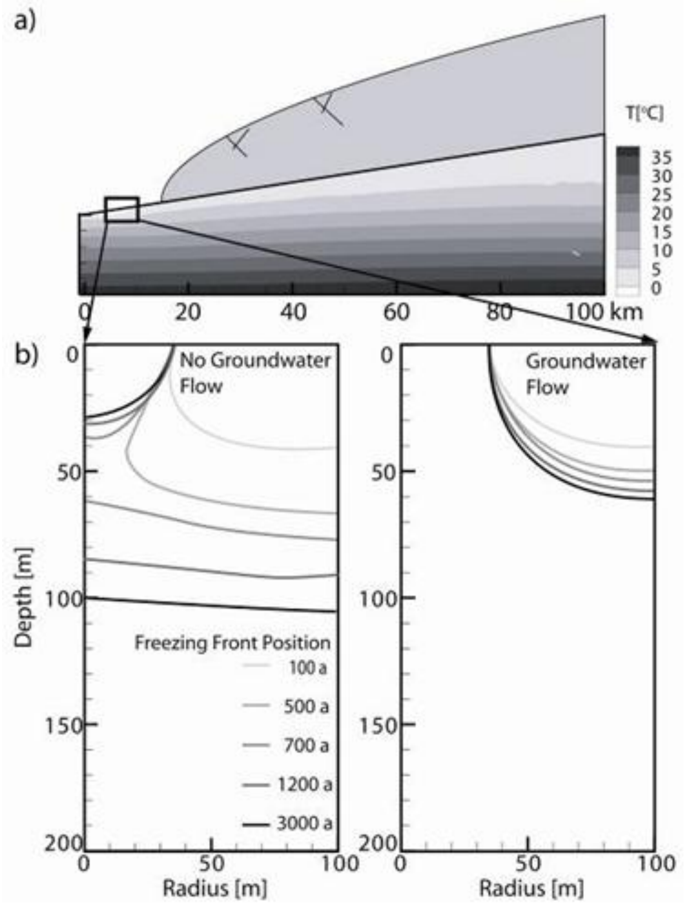

Figure 1. a) Retreating ice with permafrost forming in the glacier forefield. b) Two scenarios of freezing front migration under a small lake (r = 35 m) after exposure to air temperatures. Left, without the influence of advective heat transfer, the through talik freezes down after 600 years. Right, with influence of a steady groundwater flow as experienced in front of an ice sheet, advective heat transfer hinders the freeze down of the through talk.

Concluding Remarks

Numerical modeling of coupled heat and fluid flow, including phase change and associated permeability reduction, provides a useful tool for estimating e.g. talik development, temperature distributions, and hydrological changes in 1D, 2D or 3D. Our results demonstrate that taliks that are subject to advective heat flow remain open for longer than without advective heat flow. Hence, some of these lakes can have a through talik, which would not be existing in a talik from heat conduction only.

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Organic Matter Properties in Late Quaternary Permafrost of NE Siberia

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The major objective of this presentation to summarize new regional datasets on the quality and quantity of fossil organic matter (OM) in permafrost sequences of NE Siberia (Figure 1), in order to show the permafrost carbon pool heterogeneity related to paleoenvironmental dynamics, and the improved estimation of permafrost organic carbon stocks. OM stored in Quaternary permafrost grew, accumulated, froze, partly decomposed, and refroze under different environmental condition, reflected in specific biogeochemical and cryolithological features. OM in permafrost is mainly represented by twigs, leaves, peat, grass roots, and plant detritus.

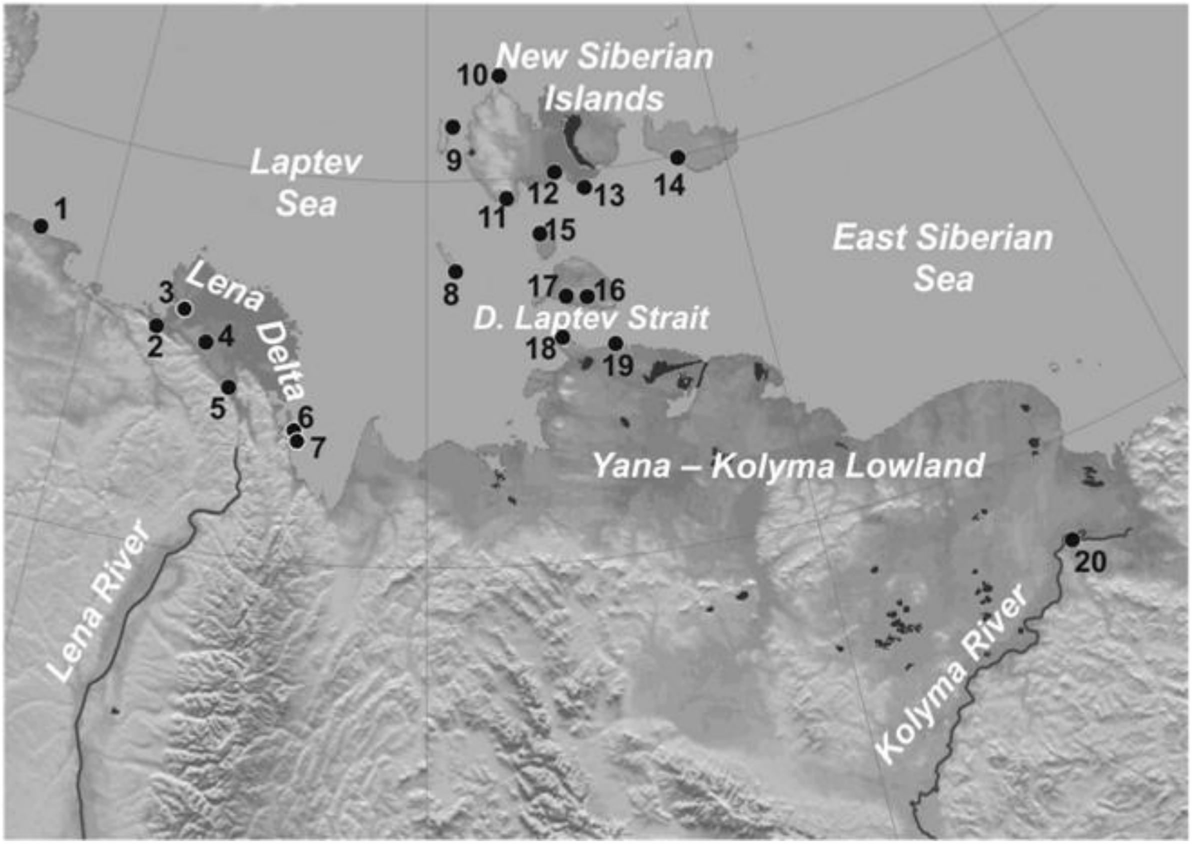

Figure 1. Study sites in the NE Siberia. *Western Laptev Sea*: (1) Cape Mamontov Klyk; *Lena Delta*: (2) Turakh Sise Island, (3) Ebe Sise Island (Nagym), (4) Khardang Island, (5) Kurungnakh Sise Island; *Central Laptev Sea* (6) Bykovsky Peninsula, (7) Muostakh Island; *New Siberian Archipelago* (8) Stolbovoy Island, (9) Bel'kovsky Island, (10) Kotel'ny Island (Cape Anisii), (11) Kotel'ny Island (Khomurganakh River), (12) Bunge Land (low terrace), (13) Bunge Land (high terrace), (14) Novaya Sibir Island, (15) Maly Lyakhovsky Island; *Dmitry Laptev Strait* (16) Bol'shoy Lyakhovsky Island (Vankina river mouth), (17) Bol'shoy Lyakhovsky Island (Zimov'e river mouth), (18) Cape Svyatoy Nos, (19) Oyogos Yar coast; *Kolyma lowland*: (20) Duvanny Yar.

Since 1998, northeast Siberian permafrost sequences have been analyzed as frozen archives for paleoenvironmental reconstruction of the last about 200,000 years in the context of the joint Russian-German science cooperation SYSTEM LAPTEV SEA (Figure 1). Fossil OM data have been obtained and interpreted as biogeochemical paleoproxies. Variations in OM parameters are related to changes in vegetation, bioproductivity, pedogenic processes, decomposition, and sedimentation rates during past climate variations. High total organic carbon (TOC) contents, high C/N, and low $\delta^{13}C$ reflect less-decomposed OM accumulated under wet, anaerobic soil conditions characteristic of interglacial and interstadial periods. Glacial and stadial periods are characterized by less variable, low TOC, low C/N, and high $\delta^{13}C$ values indicating stable environments with reduced bioproductivity and stronger OM decomposition under dryer, aerobic soil conditions (Table 1).

Table 1. Carbon inventory estimates for different stratigraphical units according the average and range data across all sites in Figure 1. IC - Ice content [wt %], BD - Estimated bulk density [g cm^{-3}], TOC – total organic carbon [wt%], CI – Carbon inventory [kg C m^{-3}], SD - Standard deviation (propagated error),

StratigraphicalUnits	IC	BD	TOC	CI	SD
Holocene thermo-erosional valley	44.2 ± 9.0	0.781	5.3 ± 4.9	41.42	40.87
Holocene thermokarst	44.4 ± 16.0	0.775	6.9 ± 9.0	53.51	77.22
Holocene cover	47.4 ± 14.5	0.686	10.9 ± 12.9	74.73	96.26
Taberites	28.8 ± 4.8	1.242	2.7 ± 1.4	33.55	17.82
Late Weichselian Ice Complex	38.3 ± 12.5	0.958	2.2 ± 0.9	21.08	11.92
Middle Weichselian Ice Complex	40.5 ± 12.8	0.892	3.7 ± 4.1	33.23	40.07
Early to Middle Weichselian fluvial deposits	22.4 ± 11.3	1.434	0.5 ± 1.4	7.17	18.72
Eemian lake deposits	29 ± 8.3	1.236	3.2 ± 4.2	39.57	50.10
Pre Eemian floodplain	32.6 ± 8.3	1.129	1.0 ± 0.8	11.29	8.28
Saalian Ice Complex	58.7 ± 20.1	0.347	5.3 ± 4.3	18.41	34.93

The absolute ice contents of frozen ground reflect among other factors water availability, soil drainage, temperature, freezing regimes and their dynamics during permafrost formation. On a global scale, processes of permafrost formation and deformation are strongly controlled by climate variation and the direct and indirect impact on the thermal regime of frozen ground. This is reflected in the variable composition and cryolithological characteristics of permafrost deposits formed and transformed during different late Quaternary climate periods. The relation of ice and OM features in permafrost to climate and lithostratigraphical classifications are essential indicators for understanding past, current and future processes of OM accumulation, preservation, and degradation in permafrost soils.

The vertical distribution of TOC in exposures varies from 0.1 wt% of the dry sediment in fluvial deposits to 45 wt% in Holocene peats. Total inorganic carbon (TIC) contents range from 0 to 7.2 wt%, C/N ratios from 0.03 to 38.4, and $\delta^{13}C$ values from -31.0 to -23.4 ‰ vs VPDB. For individual strata, OM accumulation, preservation, and distribution are strongly linked to a broad variety of paleoenvironmental factors and specific surface and subsurface conditions before inclusion of OM into the permafrost.

Based on TOC data and updated information on bulk densities, we estimate average organic carbon inventories for different stratigraphic units in Northeast Siberia, ranging from 7.2 kg C m^{-3} for Early Weichselian fluvial deposits, to 33.2 kg C m^{-3} for Middle Weichselian Yedoma Ice Complex deposits (Table 1), to 74.7 kg C m^{-3} for Holocene peat layers (Schirrmeister et al., 2011). The resulting landscape average is likely about 25% lower than previously published permafrost carbon inventories.

The OM distribution for the upper permafrost zone (down to 100 m depth) of the NE Siberian Arctic indicates considerable variability between different stratigraphical units, between the same stratigraphical unit at different study sites, and even within stratigraphic units at the same site. Thus, the complexity of OM must be taken into account in future inventories of the carbon pool stored in permafrost.

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Characteristics of an Last Interglacial Thermokarst Landscape based on fossil Bioindicators from Permafrost Deposits at the Dmitrii Laptev Strait, North-East Siberia

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Background

Fossil bioindicators such as plant macrofossils and ostracod valves from two selected permafrost profiles of last interglacial age at Dmitrii Laptev Strait were studied within the frame of a Bachelor Thesis at the Institute of Geography (Humboldt University, Berlin). The aim was to identify fossil species compositions and to infer habitat information. Thermokarst landscape features from the last interglacial in north-east Siberia are deduced.

Studied Deposits and Sample Processing

Last interglacial lake deposits with numerous large ice wedge casts are well-exposed along the Dmitrii Laptev Strait. Such a 2.5 m deep ice wedge cast at the southern coast of Bol´shoy Lyakhovsky Island was selected for detailed palaeoecological studies. Its filling consists of alternating plant detritus layers and laminated silty sand. The surrounding material is composed of fine-laminated deposits with a massive cryostructure and several ice veins interpreted to be taberits.

A second interglacial sequence from the opposing Oyogos Yar mainland coast is considered to be a fossil thermokarst lake margin. The material consists of silt layers alternating with detritus layers containing mollusk shells. The 110 m long and 2 m thick outcrop is superimposed by late Pleistocene Yedoma deposits. Sampling intervals in both profiles were approximately 50 cm. The gravimetric ice content varies between 23 to 43 wt%. About 20 to 50g of dry sediment from 25 samples was sieved wet using a mesh size > 250 µm and dried for later bioindicator analyses.

Fossil Records and Indications for Habitats

In total 315 ostracod shells of 14 taxa and 568 plant macrofossils of 38 species and six genera were identified. Mollusk shells of *Pisidium*, insect remains, wood fragments, moss remains, and ephippia of *Cladocera* were also found.

The occurrence of *in-situ* preserved fresh water ostracods, mollusks and aquatic plants demonstrates the former existence of lake habitats. They were ice free during the summer season with a sufficient oxygen supply down to the thermokarst lake bottom. Cold stenotherm and halotolerant ostracod species point to cool waters with varying salinity probably due to lake level changes.

In contrast, plant macrofossils indicate diverse terrestrial habitats. Meadow, steppe, dwarf-shrub and forest tundra communities are predominant. Additionally peat bog, riparian plant associations and hydrophytes occupied thermokarst depressions, lake shores and shallow waters. Shoreline fluctuations were inferred from pioneer species and plants that tolerate changing soil moisture and salinity conditions. Small-scale variations in microrelief e.g. on well drained and drier habitats such as slopes alternate with wet and moist habitats inducing a mosaic-like plant community distribution.

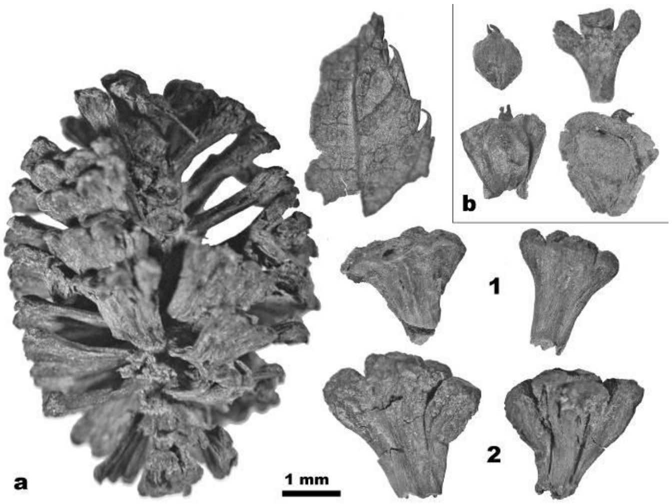

Figure 1. Plant macrofossils from last interglacial deposits. (a) Alder catkins (complete catkin and 1 – *Alnus fruticosa*, 2 – *A.* cf. *incana*) and leaf fragment and (b) Birch (*Betula*) catkin scales.

Conclusions

Despite a sea-level globally 6 m higher than today [*Dumas et al. 2006*], the fossiliferous deposits, found directly at the coasts of the Dmitrii Laptev Strait only 3.5 m above the modern sea-level indicate, that the last interglacial marine transgression did not advanced beyond the current coast line. Instead, terrestrial and lacustrine settings shaped the environment in the coastal lowlands. Stronger continentality caused a considerably higher mean temperature of the warmest month (MTWA) slightly above 13°C which is about 10°C warmer than today [*Kienast et al. 2011*]. As a consequence of increased mean annual temperature and precipitation, extensive thermokarst processes spread in ice-rich permafrost deposits. Thermokarst depressions, thaw lakes and ice wedge casts were common features of the north-east Siberian interglacial landscape and are well preserved in terrestrial permafrost deposits.

Ostracodes inhabited such waters, whose lake levels fluctuated throughout the summer season. Both *Tonnacypris glacialis* and *Candona muelleri jakutica* are found for the first time in last interglacial permafrost deposits in arctic Siberia. The terrestrial biocenoses mainly consisted of wetland, meadow, steppe and forest tundra communities which formed a vegetation mosaic depending on local habitat conditions. Thus, both, generally warmer summer temperatures and changes in surface topography altered local moisture and microclimate settings. While exposed, snow free sites provided cool and dry habitats for steppe communities, depressions filled with snow in winter remained wet for a longer period during the summer season and were preferred habitats of snow bed vegetation. In contrast, south facing slopes were warmer and protected sites that provided growth conditions favorable for dwarf-shrubs.

Our macrofossil findings are supported by earlier vegetation reconstructions from the same study area [*e.g. Lozhkin & Anderson 1995, Andreev et al. 2004, Wetterich et al. 2009*]. The macrofossil evidence of boreal woodland species such as *Alnus incana* and *Larix dahurica* on Oyogos Yar are so far the northernmost last interglacial macrofossil evidence of tree species on Yakutian mainland [*Kienast et al. 2011*]. The presence of Birch and Alder (Figure 1) indicates shrub tundra vegetation on Bol´shoy Lyakhovsky Island during the last interglacial thermal optimum and deviates well from modern tundra vegetation. Thus, the northward shift of shrub-tundra biomes expanded over today´s mainland and reached at least the southern coasts of the New Siberian Islands.

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The Borehole 2Alpes-3065: a Pilot Installation for Fiber Optic DTS Measurements in Permafrost

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A 100 m deep borehole was drilled in September 2010 through permafrost ground in the upper part of the ski resort Les Deux Alpes, in the French Alps (Massif des Ecrins, 45°00’00’’ N / 6°11’30’’ E, 3065 m asl). The borehole is equipped for ground temperature measurement and is a key site of the French PermaFRANCE, of the Alpine PermaNET, and of the global GTN-P permafrost monitoring networks.In addition to a standard thermistor chain instrumentation, the borehole is equipped with an optic fiber, to simultaneously measure using the innovative distributed temperature sensing (DTS) technique.The paper will present the DTS technique, the equipement of the borehole and the first results..

Methods

Distributed temperature sensing

Distributed temperature sensing (DTS) is an innovative temperature measurement technique, that uses an optic fiber as sensor. The technique is based on the scatter of light in the fiber. A laser pulse is sent into the fiber, and the instrument measures the returned light. The travel time of the light is used to determine the distance to the instrument. The frequency of the light is modified by the travel in the fiber, and shows peaks shifted to higher and lower frequency respectively. The method uses the peaks known as “Raman scattering” [*fig. 1, Selker et al. 2006*]. The amplitude assimetry of the peaks is dependent on the temperature of the fiber. The analysis of the spectrum allows a calculation of the temperature. The technique permits a spatial resolution of up to 1 m and a relative temperature resolution of less than 0.1 °C, depending on the instrument used, on distances of up to several kilometers. The absolute temperature shows an offset depending on the fiber used, thus the fiber needs to be calibrated at least once in an ice bath. Once calibrated, it is supposed to remain stable. The technique uses quartz multimode fibers of 50/125 µm, with E2000 connectors. The first 50 to 100 m of the fiber are not usable for measurement, as well as the last tens of meters.

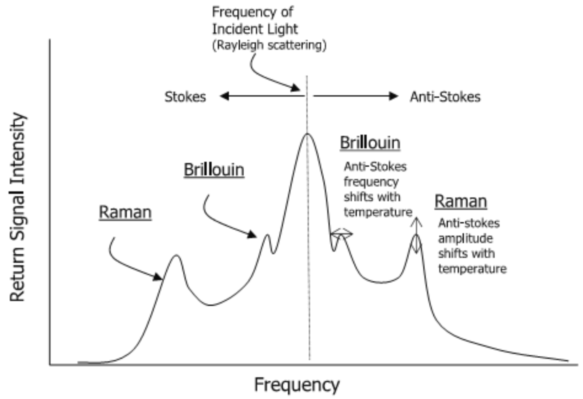

Figure 1. Diagram of Rayleigh, Raman, and Brillouin return scattering intensity below (Stokes) and above (anti-Stokes) the frequency of the injected light (from Selker et al. 2006).

The borehole

The 100 m deep borehole is situated on a flat top, at 3065 m altitude. It is entirely in homogenous paragneiss bedrock, covered by ca 2 m of in situ frost shattered rock. It was drilled in September 2010 by dry percussion drilling, with compressed air. The borehole is cased with a PVC tube down to 98 m.

Borehole equipement

In addition to a standard thermistor chain instrumentation (30 PT100 at standard GTN-P depths), the borehole is equipped with an optic fiber, to simultaneously measure using the innovative distributed temperature sensing (DTS) technique. A 700 m long fiber optic cable has been placed in two loops (fig. 2). One first loop has been installed on the outside of the plastic tube and pushed down the borehole with the tube. A second loop has been placed inside the plastic tube, together with the thermistor chain. This setting permits to measure both the temperatures in direct contact with the ground and those inside the open tube, to detect possible influence of air convection in the tube.

A 50/125 µm quartz graded index multimode fiber optic cable with a 2.8 mm plastic coating, was used. It is set with a E2000 connector with angle cut at each end, in order to allow double ended measurement to enhance precision. The 700 m long fiber optic cable was set as follows (fig. 2): the first 100 m are left outside for calibration, 200 m are used for the outer loop, the intermediate 100 m are left for calibration, 200 m are used for the inner loop, the last 100 m are left for calibration.

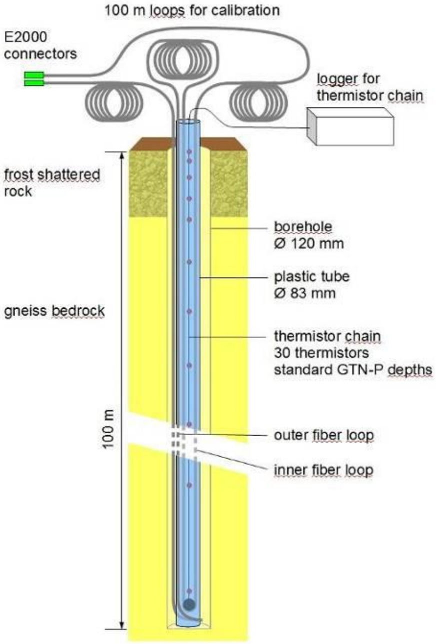

Figure 2. Instrumentation scheme of the borehole.

Mesurements

First measurements were made with an Agilent N4386A instrument, belonging to EFLUM-EPFL. This instrument has a spatial resolution of 1 m and a temperature resolution of 0.1 °C. The first measurements were made in February 2011 in very cold winter conditions. The first and last calibration sections were put in an ice bath. Due to icing conditions, the intermediate calibration section could not be used, and only a one ended measurement could be performed because of a defect connector. Measurement time was limited because the ice-bath was freezing. The fiber was measured for 30 minutes.

First results

The first results are shown in figure 3. The temperature profile shows very low surface temperatures in the order of -13°C, corresponding to air temperature at the day of measurement. The borehole profile shows a classical shape for permafrost borholes, with minimal temperatures around -30 m, and a moderate warming trend downwards. The DTS provides 4 parallel temperature profiles: each of the outer and inner fiber optic loops is mesured downwards and upwards. The two parallel profiles of the outer loop are consitent and show a mean difference of 0.03 °C. The profile is in good agreement with the thermistor loggers. The two profiles of the inner loop show a mean difference of 0.05 °C, but with an offset of -0.2 °C compared to the outer loop, due to a slight defect in the fiber that could not be corrected without calibration of the intermediate calibration section. The outer fiber optic loop is therefore considered to be the most reliable, and it is shown in figure 3.

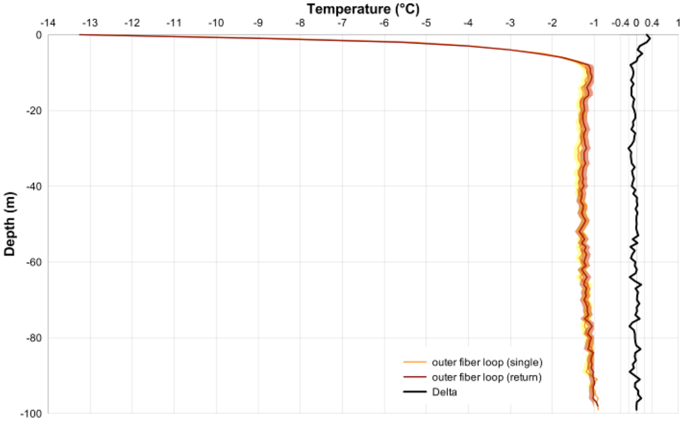

Figure 3. DTS temperature profile of the outer fiber optic loop. The curve to the right shows the difference between the downhole and the uphole fiber sections.

Discussion

The DTS technique is used only for a few years in environmental science. It has been applied in hydrologic studies [*Selker et al. 2006*], for ground surface temperature measurements under snow cover [*Tyler et al. 2008*], or for temperature profiles on glaciers [*Huwald et al. unpubl.*]. The present study is the first application of the DTS for permafrost borehole monitoring.First experiences made on the borehole 2Alpes-3065 show that the technique can provide temperature profiles with an accuracy similar to that of thermistors, but with a much higher spatial resolution. Due to the high cost of the DTS instrument, it can not be used however for continuous monitoring, but is best suited for periodic measurements. In order to monitor seasonal variations, the fiber optic is best combined with a classical thermistor chain down to the ZAA depth.Due to harsh field conditions in high mountain environment, some limitations have to be considered. Repair works on the fiber, especially, need specialized technical skills and special equipements, due to high altitude and cold temperatures.

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Quartz Weathering in Freeze-Thaw Cycles: Experiment and Application to the El'gygytgyn Crater Lake Record for Tracing Siberian Permafrost History

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Summary

The object of this study is to test the assumption that cryogenic weathering preferentially breaks up quartz grains. Quartz enrichment over feldspar in the coarse silt fraction when compared with the fine sand fraction has been observed in various studies earlier on [*e.g. Konishchev & Rogov 1993*]. We apply the results of an own laboratory test where sandy grains are cracked in the course of freeze-thaw cycling to a Quaternary sediment record.

Quartz enrichment in the fines evolves from seasonal freeze-thaw weathering as demonstrated in laboratory testing where >100 freeze and thaw (F/T) cycles crack quartz grains preferentially over feldspar. Microscopic grain features demonstrate that F/T cycling probably disrupts quartz grains along mineral impurities such as bubble trails, gas-liquid inclusions, or mineralogical sub-grain boundaries. Single-grain micromorphology (e.g. angular outlines, sharp edges, microcracks, brittle surfaces) illustrates how quartz becomes fragmented due to cryogenic cracking of the grains. The single-grain features stemming from the weathering dynamics are preserved even after a grain is transported off site (i.e. in mobile slope material, in seasonal river run-off, into a lake basin) and may serve as first-order proxy data for permafrost conditions in Quaternary records [*Schwamborn et al. 2008*] (Figure 1).

We use the cryogenic weathering index (CWI) [*Konishchev 1998*] as a proxy to trace permafrost conditions in a lake sediment archive. CWI values greater than 1 are indicative for cryogenic weathering in the soil. The CWI has been used in a few studies to identify permafrost episodes in a terrestrial Quaternary record [*Konishchev 1999; Demitroff et al. 2007; French et al. 2009*] or to support thermal modelling of permafrost environments [*Romanovskii & Hubberten 2001*].

Hypothetically, lake sediments approximately resemble surface soil in terms of the imported minerogenic detritus. The combination of silt production, relative quartz enrichment in the silt fraction, and quartz grain micromorphology is traced in a multi-Ma lake sediment archive as indicator data for frost weathering. Intensification of cryogenic weathering dynamics is inferred after about 2.3 Ma BP from a lake sediment core of El'gygytgyn Crater, Far Eastern Russian Arctic. This is the longest continuous terrestrial archive currently known for the continental Arctic.

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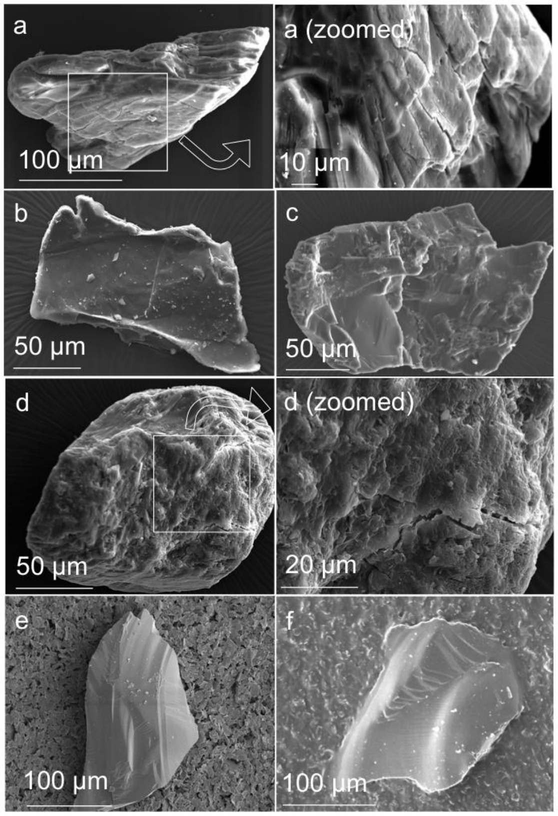

Figure 1 a to f. quartz grains from El'gygytgyn Late Pleistocene aged-lake sediments (core Lz1024) with presumably inherited cracked surfaces that have survived transport. Grains with (sub-) angular outlines, and fresh fracture surfaces and sharp edges are associated with complete grain fracture of quartz in permafrost and short transport.

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The Temperature Field and Permafrost of the Vilyui Basin

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The Vilyui Basin is one of richest and rapidly developed gas province in the Siberian craton. The basin is located in the eastern part of the craton and has outcrops of Paleozoic rocks along its northern and southern boundaries. It grades into the Verkhoyansk foredeep eastward and borders the Nepa-Botuobia arch uplift in the west.

The climate of the area is sharply continental, with extremely harsh poorly snow winters, the basin being an anticyclone zone where cold air accumulates. The snow cover is 20-40 cm thick and the snow-free season lasts about 220 days. Summers are warm and dry or relatively dry. The mean annual air temperature is from -7.8 °C (Suntar weather station) to -11.2 °C (Khatyryk-Khomo weather station), and annual precipitation ranges from 257 mm/yr (Khatyryk-Khomo weather station) to 354 mm/yr (Sobo-Khaya weather station) [*USSR Climate 1989*].

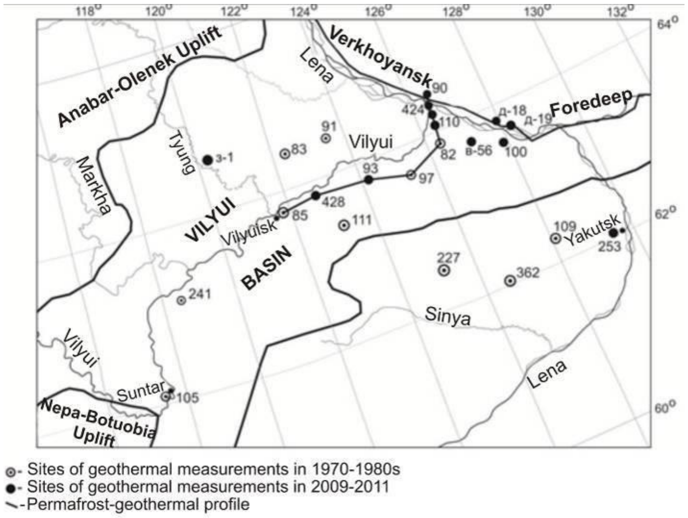
Geomorphically, most of the Vilyui Basin belongs to the Central Yakutsk plain which consists of two hypsometric levels: an older and more highly elevated Late Neogene surface and a more depressed younger terraces of the Lena and the Vilyui and their tributaries. The hypsometrically lower surface ranges in elevation from 60 to 200 m above sealevel and the higher one lies in the range 300 to 500 m asl. The area abounds in thermokarst features: ice-wedge polygons, frost heaves, pingoes, thermokarst lakes, and alases. Erosion is not very active and lags behind deposition [*Korzhuev 1965*].

The earliest evidence of permafrost and first estimates of its thickness and temperatures were obtained in the course of geological surveys in the early 1970s by different prospecting groups (VNIGRI, YaTGU, SYaNRE, YaNGR). In 1976-1980, a team from the Melnikov Institute of Permafrost, Yakutsk (V.N. Devyatkin, A.I. Levchenko, B.V. Volodko, V.G. Rusakov) performed geothermal measurements at some geological prospecting sites. Since 2009, we have continued geothermal studies in the area as part of the program “The Temperature and Permafrost Patterns in the Siberian Craton“ and have covered eleven prospecting sites over the period of observations (Fig. 1).

The studies have revealed unsteady temperature patterns in the permafrost of the basin. The ground temperatures at the depth of zero annual amplitudes (20 m) varies from 1.6 °C (Middle Vilyui site) to -0.4 °C (Sobo-Khaya site).

Deeper subsurface is from minus 1.4 °C (Middle Tyung site) to +13.7 °C (Sobo-Khaya site) at 500 m and from + 11.6 (Middle Vilyui site) to + 17.6 °C (Mastakh site) at 1000 m.

The collected temperature logs include four domains: (1) a zone of negative thermal gradients, from 30 m (Ust'-Vilyui site) to 210 m (Middle Vilyui site) thick (Fig. 3), where the gradients (g) are in the range -0.58 (Middle Tyung site) to -3.2 (Middle Vilyui site) °C/100 m; (2) a zone of zero or low gradients (g = 0 to 0.3 °C/100 m), with its thickness from 20 m (Ust'-Vilyui and Middle Vilyui sites) to 160 m (Middle Tyung); (3) a zone of positive thermal gradients in permafrost, from 80 m (Ust'-Vilyui site) to 480 m (Middle Vilyui site) thick, with the gradients from 0.4 (Middle Vilyui site) to 2.04 (Ust'-Vilyui site) °C/100 m; (4) a sub-permafrost zone of positive thermal gradients ranging from 1.18 (Kitchan) to 3.6 (Middle Tyung) °C/100 m.



Arabic numerals stand for site names: B-56 –Bergeinskaya; D-19 – Eksenyakh; 241 – Nyurba; 85 – Vilyui; 93 – Mastakh; 91 – Linde; 83 – Balagachi; 97 – Nidzhili; 82 – Badaran; 111 – Khailakh; 109 – Uordakh; 90- Kitchan; 94 – Sobo-Khaya; 110 – Ust'-Vilyui; 100 – Oloi; 428 – Middle Vilyui; 105 – Suntar; 362 – Berdigestyakh; 227 – Orto-Surt; 3-1 – Middle Tyung; 253 – Vilyui Roadway, 23 km; unnumbered site – Lower Vilyui

Fig. 1. Location map of geological prospecting sites in Vilyui Basin.

The permafrost thickness varies from 50 m at the Sobo-Khaya site to 680 m at the Middle Tyung site (Fig. 2) and increases northward and westward. Furthermore, considerable variations in permafrost thickness have been revealed within some sites: e.g., it is from 500 to 630 m at the Middle Vilyui site.

In the central and northwestern parts of the Vilyui Basin, where the permafrost thickness reaches or exceeds 600 m, there is a zero-gradient zone of phase transition with temperatures from -0.2 to -0.4°C and thicknesses from 20 m (Middle Vilyui site) to 40 m (Middle Tyung site). However, there is no such zone in the eastern part where the permafrost is thinner (within 200 m).

The collected data, along with prospecting field reports, were used to compile a permafrost-geothermal cross section of the Vilyui Basin along a W—E profile (Fig. 3).

Heat flows derived from the temperature data for the basin and for separate sites within its limits [*Zheleznyak et al. 2011*] are 30-34 mW/m^2 higher in the unfrozen sub-permafrost zone than in the permafrost. This is evidence for the existence of an unsteady-state frozen layer thawing from below, at a rate depending on heat flows and moisture capacity of rocks [*Balobaev 1991*]. The permafrost base is being degraded and the phase transition front moves at 1.7 to 2.3 cm/yr at different sites. The amount of degradation in the area has been 140 m on average for the Holocene, as it was inferred from the estimates of geothermal parameters and physical properties of rocks [*Zheleznyak et al. 2011*].

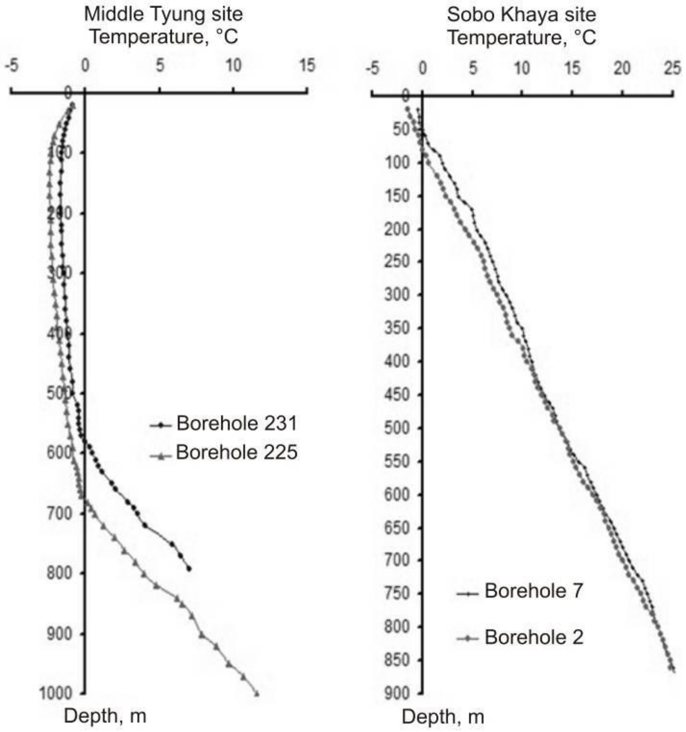


Fig. 2. Temperature logs.

Thus, the reported studies provided characteristics of geothermal and permafrost conditions in a nonsteady-state area of the Siberian craton and allowed estimating the permafrost dynamics over the Holocene.

Currently the available data on geothermal patterns and permafrost parameters in the Vilyui Basin are being systematized and put into an electronic database.

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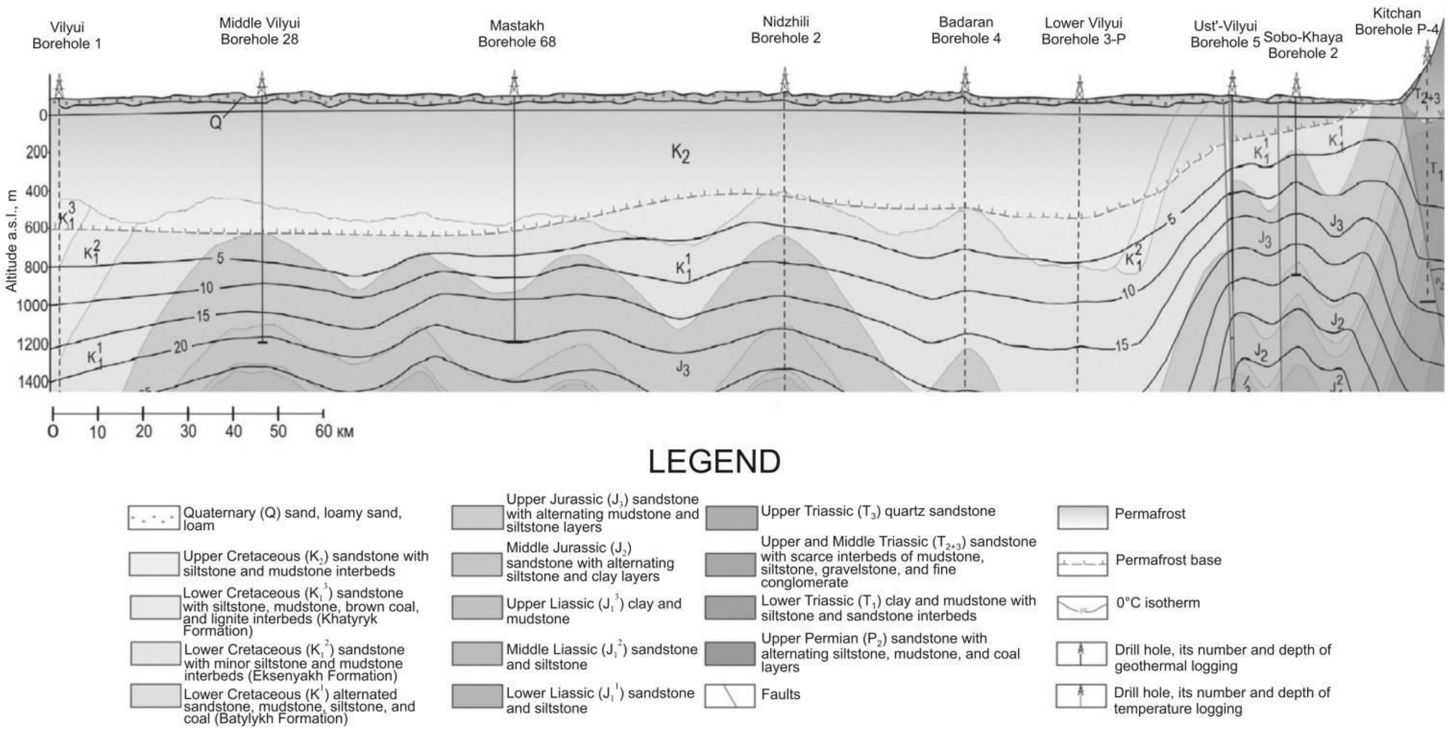

Fig. 3. Permafrost-geothermal cross section of Vilyui Basin

Intrapermafrost Taliks in Central Yakutia and Thermal State of Overlying Permafrost

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Intrapermafrost taliks are widespread in Central Yakutia in the right side of the Lena River, in its terrace IV (Bestyakh) above the floodplain. Water from the taliks discharges onto the ground surface in large springs which are active all year round and produce icing (Ulakhan-Taryn, Eryuyu, Sular, Muostakh springs, etc.). The natural resources of intrapermafrost water exceed 50,000 m^3/day [*Boitsov 2009*]. The aquifers are 25 – 40 m thick and rather shallow (16-35 m below the surface); they consist of Quaternary fine- and medium-grained sand with pebble at the base.

One perennial spring occurs on the left bank of the Tamma River (a right tributary of the Lena), 12 km upstream of the estuary, and is known in the literature as Eryuyu Spring. Groundwater vents through the bottom of a 15 to 35 m deep U-shaped gully incised in the sandy Bestyakh terrace [*Shepelev & Lomovtseva 1981*]. The long-term mean flow rate of the spring is 40-43 l/s. It has a sodium bicarbonate chemistry, stable over a long-term cycle, and the salinity ranges from 0.2 to 0.5 g/l; the water temperature holds at 0.2˚C all year round.

The first evidence that the Eryuyu spring recharges from an intrapermafrost aquifer appeared in 1976, when a survey group of the Melnikov Institute of Permafrost (Yakutsk) drilled a 68 m deep test hole (No. 1e) 200 m northwest of the main discharge site. The drill hole stripped the aquifer top and bottom at the depths 24.5 m and 55.4 m, respectively (Table 1). According to temperature logging in 1976, the permafrost temperature grew from -0.8 ˚C to -0.2 ˚C above the aquifer, in the interval between 3.0 m and 8.0 m, but remained almost invariable (-0.2…-0.1˚C) from 8 m below the surface to the top of the aquifer.

The same survey group identified the recharge zone of the intrapermafrost aquifer proceeding from water chemistry sampling of the venting water, groundwater, and lake water, and estimated preliminarily the area of the surface runoff at 26.5 km^2. The aquifer receives meteoric water percolating through taliks located beneath a group of lakes (Elgen, Abaga-Kyuel, and Bosogor) [*Shepelev & Lomovtseva 1981*].

Later drilling of hydrogeological boreholes in the area confirmed that the permafrost thickness above the aquifer was 23-24 m (hole 77, 1e, 1-07). The depth to the aquifer surface increases to 53 m (Table 1) at the venting site, at the account of lateral freezing.

In 2010, a team from the Institute of Permafrost further studied the extent and thickness of the intrapermafrost aquifer by means of vertical electric soundings. The geophysical data indicated that the aquifer was discontinuous in area and varied in thickness from 7 to 27 m. The depths to its top and bottom were detected in the ranges 12 to 29 m and 19 до 50 m, respectively. Geothermal measurements in 1976 and 2009-2010 recorded no change at the hole 1e site.

According to temperature logging in a borehole located in the gully head part near the Eryuyu spring, 2m away from the terrace edge, the thickness of the active layer (seasonal thaw depth) is 4.5 m, and the depth of zero annual amplitude is 9.0 m. The permafrost temperature between 4.5 and 9 m below the surface increases from -2.5 to -0.5 ˚C, and is -0.4˚C below (measured in the interval 9.0-13.0 m).

Geologists of the Yakutsk Surveys reported -0.1…-0.2˚C temperatures of permafrost above the aquifer (53 m) and 0.2˚C within the latter, from hole No. 7 drilled in 2007, 8 m away from the terrace edge, at the vent site. They are apparently the warmer ground temperatures in the southern slope that are responsible for the perennial discharge of groundwater at the slope foot.

An automatic ground temperature logger installed in 2007 in hole 1-07 within the aquifer basin between lakes Elgen and Abaga-Kyuel showed a temperature of 0.02˚C invariable all year round at the base of the active (seasonally thawed) layer which coincides at the site with the depth of zero annual amplitude. The ground temperature held about zero (-0.02…-0.08 ˚C) below the active layer and till the 15 m depth. The drill hole stripped the aquifer surface at 23.9 m but was not deep enough to reach its bottom.

Geothermal data from another drill hole (4-07) located 350 m to the northeast of 1-07 indicate an active layer thickness of 3 m and a zero annual amplitude depth of 7 m. The permafrost temperature in the 3.0-7.0 m interval varies seasonally from -0. 2 ˚C to -1.1˚C and remains constant (-0.3…-0.4 ˚C) below 7 m till the hole bottom (10 m). Geophysical survey has revealed no intrapermafrost water at the site.

Signature of an intrapermafrost aquifer was recognized only at two control geophysical sites between lakes Yueliir 1 and Chemogulakh, among a group of lakes located 2 km west of the outlined recharge area of the Eryuyu spring. The aquifer top and bottom were resolved at the depths 13 and 23 m, respectively, at one site and at 18 and 38 m at the other site.

Proceeding from the geophysical evidence, a 15 m hole (3-10) was drilled in 2010 for ground temperature monitoring above the aquifer near Yueliir lakes. Year-long monitoring showed the active layer thickness to be 4.2 m and the depth of zero annual amplitude to be at 12.0 m. The permafrost temperature in the interval between 4.0 and 12.0 m grew from -0.5 to -0.2˚C.

Thus, the available temperature monitoring data show that the permafrost above taliks in areas of intrapermafrost aquifers approaches 0˚C being warmer than that in areas where intra-permafrost waters are absent or deeply buried.

This hypothesis has to be checked with additional drilling and geothermal studies.

Table 1. Parameters measured at geothermal boreholes.

Hole number and depth	Active layer thickness (m)	Depth of zero annual amplitude (m)	Temperature at active layer base (annual mean), °C	Permafrost temperature, °C	Aquifer depth interval, m
1e 68	3	8	-0.2	-0.1	24.5-55.4
1-07 32	5	5	0.02	-0.02	23.9-…
7 100	5-6	10	-0.1	-0.02	53-76
4-07 13	3	7	-1.1	-0.4	not stripped
Eryuyu 13	4.5	9	-1.1	-0.3	not stripped
3-10 16	4.2	12	-0.5	-0.3	not stripped

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Monitoring of the Depth of Seasonal Thawing in the Lower Reaches of the Yenisey River at Site CALM R-40 of Igarka Town

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Introduction

The problem of "global warming" is very acute today. 'The consequences of this process are observed in various spheres of the Earth. In particular, permafrost responds sensitively to any temperature fluctuations – both local and global ones. About 2/3 of the area of our country is occupied by permafrost the degradation of which can directly influence the life of people in the areas with permafrost [*Anisimov et al. 2010*].

A seasonally thawed layer is the most dynamic permafrost layer undergoing short-term changes. Monitoring of this parameter indirectly allows us to judge on the impact of climate fluctuations on the permafrost dynamics.

The area of research

The Igarka site (R40) is located at the right bank of the Yenisey River, 5 km to the northwest from Igarka Town, at the high river terrace with discontinuous permafrost. The climate of the region is moderately continental with a long snowy winter and a short chilly summer [*Tishinskiy & Davydova 1976*]. The period with negative daily temperatures lasts up to 250 days on average. The annual mean temperature is -8.3 °C. The mean temperature of the coldest month (January) is -27.6 °C and the mean temperature of the warmest month (July) is +15.4 °C. Permafrost with the thickness reaching 40 m has the annual mean temperature from -0.4 to -2.5 °C.

The vegetation of the site characterizes the vegetation of the region in general. The minor part of the site is represented by birch light forest, and 2/3 of the site is occupied by tundra landscapes. Tundra landscapes are represented by moss-lichen tundra with the Arctic birch low shrubs on uplifted surfaces. Depressed zones are bogged and represented by lacustrine-thermokarst depressions. A detailed description of the site is given on the website of the CALM program (www.udel.edu/Geography/calm).

Methods

Monitoring of the seasonally thawed layer depth at the site is conducted under the guidance of the Circumpolar Active Layer Monitoring (CALM) international program. Monitoring was conducted within the framework of this program at almost 170 monitoring points since the beginning of the 1990s [*Shiklomanov et al. 2008*].

The monitoring of the seasonally thawed layer dynamics at the site in Igarka Town (Index R40) is conducted since 2008. Measurements are made every year at the end of the warm season by means of a metal permafrost probe within a grid with an interval of 10 m at the site of 100 x 100 m. The averaged values of the seasonally thawed layer depth are received at 121 points as a result. Two measurements are executed at each point for control. Then they are averaged (additional measurements are conducted if the deviation between the values exceeds 10 cm). Additional measurements were performed in the middle of summer in 2010 and 2011 for assessment of the seasonal thawing dynamics.

The landscape conditions (mainly vegetation) directly influence the depth of the seasonally thawed layer. The presence of various natural-territorial complexes (NTC) characteristic of the research area is taken into account, when choosing a site. Three natural-territorial complexes are identified within the chosen site: tundra – moss-lichen (NTC1), forest – birch light forest (NTC2), and lacustrine-thermokarst depressions (NTC3).

Results and discussion

An insignificant reduction in the seasonally thawed layer depth is observed during the monitoring period at the site (between 2008 and 2011). In 2008 the seasonally thawed layer depth was maximum for the monitoring period. This is associated with the early beginning of the period of stable positive temperatures and a comparatively large sum of positive degree-hours. At the same time, the summer of 2008 was very humid and this also had a warming impact. The minimal depth of the seasonally thawed layer falls on 2010. This was a year with a comparatively cold summer. The sum of positive degree-days is significantly lower, as compared with the other years of the monitoring period. The averaged monitoring results for the natural-territorial complexes are given in Table 1.

Table 1. Average thawing depth in different natural-territorial complexes and over site CALM R40 in general

Year	Degree-days (^{o}C)	NTC1 (cm)	NTC2 (cm)	NTC3 (cm)	Average (cm)
2008	1571	66.4	86.7	>150	74.1
2009	1565	66.0	74.4	>150	71.5
2010 (July)	434	29.7	31.3	26	29.8
2010	1020	62.2	67.1	>150	66.7
2011 (July)	802	39.0	47.2	>150	44.2
2011	1730	67.5	73.3	>150	72.5

At the research site, vegetation is the main factor influencing the spatial variability of the seasonally thawed layer depth: in the forest NTC the seasonally thawed layer values are higher than those in tundra. This is clearly traced on the maps of the seasonally thawed layer spatial variability (Fig. 1). The thawed ground till 150 cm depth is observed under lacustrine-thermokarst depressions. This makes it impossible to register the roof of the permafrost with our method.

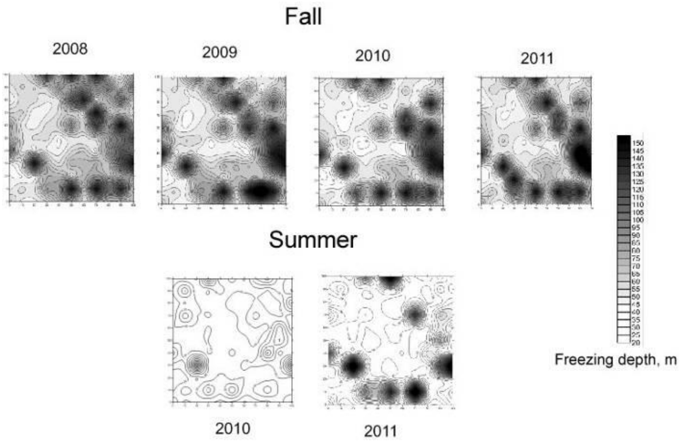

Figure 1. Spatial variability of the seasonally thawed layer thickness at the Igarka (R-40) CALM site

The results of measurements in the middle of summer showed that in the summer of 2011 the seasonally thawed layer had the values almost twice as high as in the summer of 2010. This can be directly associated with the sum of positive degree-hours by the middle of July. The summer of 2011 was warm and quite dry, while the first half of the summer of 2010 was very cold and rainy. The dependence of the seasonally thawed layer depth on the natural-territorial complex type remains the same: freezing is less under tundra landscapes than under forest ones. The thickness of the seasonally thawed layer in thermokarst depressions is evidently quite high, because even in the middle of summer it exceeds 150 cm. This can testify to the presence of taliks.

The analysis of the seasonally thawed layer data for the whole monitoring period and the comparison with meteorological parameters allow us to state that the connection of the seasonally thawed layer depth with the sum of positive degree-hours is rather strong both for forest natural-territorial complex (r^2=0.86) and for tundra natural-territorial complex (r^2=0.85). The curve inclination is higher for the tundra landscape. This testifies to its stronger response to the thermal conditions of the summer period, as compared with the forest one.

Conclusions

Site CALM R-40 located in the forest-tundra zone is represented by three main landscape types characteristic of this region. The analysis of the spatial differentiation of the seasonally thawed layer showed strong dependence of the seasonally thawed layer on the vegetation: tundra landscapes are characterized by a thinner seasonally thawed layer, as compared with the forest landscapes. This is associated with the presence of moss and peat horizons. Slight reduction of the seasonally thawed layer is observed during the monitoring period between 2008 and 2011. Nonetheless, this assessment is not very reliable due to a short monitoring series. The strongly expressed dependence of the seasonally thawed layer on the thawing degree-days is observed in both landscapes. In this case, the curve inclination testifies to a more expressed response of the tundra landscape to climatic changes of the summer period.

Acknowledgements

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Tushinskiy & Davydova 1976

Monitoring of the Dynamics of Rocks' Thermal Regime in Eastern Siberia

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At present when the climate warming is registered everywhere, much attention in the system of the Earth sciences is paid to the study into the climate influence on the response of ecosystems, including the cryolithozone as one of the ecosystem components.

Reliable reference data are necessary to develop, adapt and reanalyze the contemporary forecast models. The data can be obtained only by creating a monitoring geocryological network.

For the period of 10 years already, the international permafrost community working within the framework of the TSP (THERMAL STATE PERMAFROST) program develops an international network that monitors the temperature field dynamics of the upper lithosphere horizons.

In 2007 the Melnikov Permafrost Institute developed a program with the support of the TSP international project. The program is aimed at the creation of a monitoring geocryological network in Eastern Siberia. The actual (mainly financial) conditions of the academic science do not make it possible to fully implement this program. Nevertheless, more than 20 monitoring sites were put into operation in 8 regions of Eastern Siberia during the last 5 years (Fig. 1). Some of these sites were equipped at boreholes where geothermal observations (one-time observations or monitoring) were carried out since 1980s and then were suspended. In 2007 the observations were resumed.

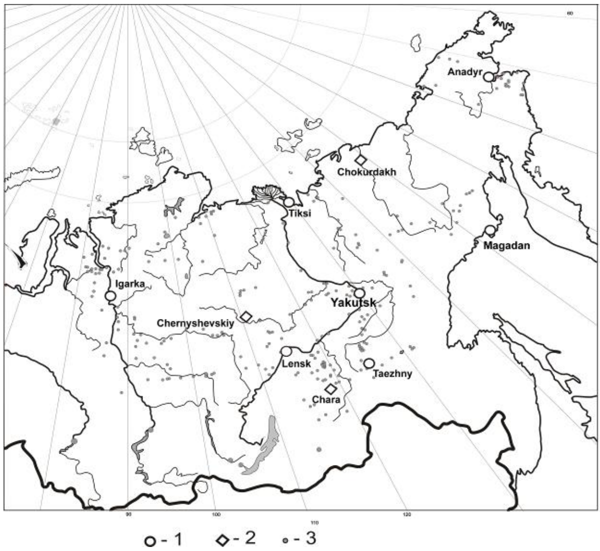

Figure 1. The location scheme of the geothermic monitoring observation sites.
1 – the sites equipped by the Melnikov Permafrost Institute of SB RAS;
2 – the sites equipped by other organizations;
3 – geothermic sites

The use of automated systems (loggers) for controlling grounds' thermal state allows us to adopt a more differentiated and reasoned approach to evaluation of the reaction and to the identification of causes and factors that influence the dynamics of grounds' thermal regime. Here we should note a significant role of the International Permafrost Association (particularly, the University of Alaska) in the implementation of these systems for organization of monitoring research in Russia.

The nature and the dynamics of rocks' reaction to the climate change are different in various regions and depend on the peculiarities of circulation processes, on the conditions of heat exchange at the surface and on rocks' composition.

The 30 years long cycle of observation of rocks' thermal state in central Yakutia showed that the seasonal thawing depth remains rather stable under the condition of a considerable increase in the mean annual air temperature. The rocks' temperature at the depth of annual heat exchange has considerable inter-annual fluctuations due to cold (summer) or warmer (winter) separate periods (2-3 years). However, a notable trend towards the temperature increase was not observed during this period (Fig. 2). The formation time of the stable snow cover is of particularly considerable importance. Higher temperatures are formed during snow-rich years with abnormally early formation of the stable snow cover [*Varlamov et al. 2011*].

During the period from 1966 to 2009 the air temperature was increasing with the trend of 0.30 - 0.50°C/10 years in the mountain regions of South Yakutia. Within the area permafrost exhibits a discontinuous and island distribution. Here, in various geomorphological conditions 10 monitoring sites are equipped and operate. The data of the studies in South Yakutia show that in most cases the increase in rocks' temperature is registered at the depth of the annual heat exchange disappearance. It is determined that for the period from 1980 up to now the temperature of rocks (20-30 m) in various landscape conditions rose by 0.4 - 1.9°C. The temperature increase maximums were registered in bald areas, while the minimums were registered at the slopes and in the valleys. Like in central Yakutia, one of the main factors regulating rocks' thermal state is the snow accumulation regime.

In the area of Lensk of south-western Yakutia, the air temperature trend made up 0.31°C/10 years in 1966-2009. In 2006 observation wells were drilled and equipped at the first fluvial terrace above flood-plain and at the bedrock bank of the Lena River. Borehole (brh. L-1) located at the first fluvial terrace above flood-plain revealed permafrost in the depth interval of 3-12 m. The grounds at the bedrock bank are in the thawed state (brh. L-2).

According to the observation data, rocks' temperature at the depth of 10 m in borehole L-1 remains stable (-0.1°C), while at the depth of 15 m in borehole L-2 it varied within the range of 0.4 °C during these years without having a clear trend to an increase.

In Magadan region (the weather station of Nagaevo) we observed a gradual increase in the mean annual air temperature increase (1960-2008) with the trend of 0.031°C/year. In the vicinity of Magadan, on top of the Marchekanskaya bald mountain, 2 observation wells were restored (down to the depth of 200 m) and equipped with loggers in 2007. These observation wells were used by A.V. Zuev for geothermic research in 1988. During the period from 1990 to 2011, rocks' temperature at the depth of 20 m increased by 0.40°C at the flat watershed and by 0.24°C in the bald zone. The analysis of the change in the mean annual temperature of rocks at the depth of 10 and 15 m showed that it increased for the last 4 years of observations respectively by 0.37 and 0.08°C at the flat watershed and by 0.19 and 0.13°C in the bald zone.

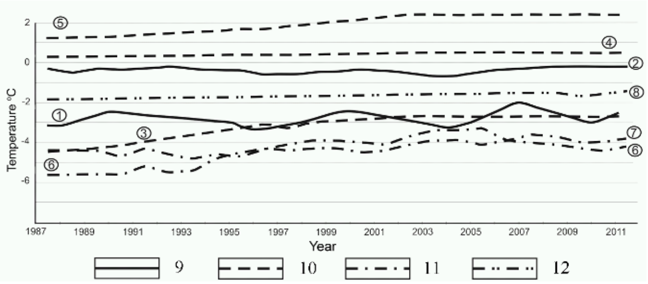

Figure 2. Rocks' temperature changes at the depth of annual heat exchange.
9 – Central Yakutia (1 – small valley terrain type; 2 – slope terrain type); 10 – South Yakutia (3 – bald area; 4 – river valley; 5- slope of southern aspect); 10 – Chukotka (6 – watershed; 7 – lake basin terrace); 11 – Magadan (8 –watershed, bald area)

In the Anadyr Lowland of Chukotka, the mean annual temperature for the period from 1975 to 2009 increased by 1.8°C with the trend of 0.047°C/year. In 1988 the Anadyr expedition of the geological company "Sevvostgeologiya" established the "Dionisia" research site at 15 km to the south from Anadyr. The dynamics of cryogenic processes, of seasonally thawed layer and of rocks' temperature was monitored there. This research is partly active nowadays. In 2007 we equipped 3 boreholes (located in different landscape conditions) with logger systems.

Permafrost within the territory has a continuous distribution with grounds' temperature of -5.5 - 2.0°C. Climate warming in the region led to the increase in the seasonally-thawed layer thickness and to the increase in rocks' temperature with the trend from 0.022 to 0.060°C/year during the period from 1989 to 2010. [*Ruzanov 2011*]. Within this period, the inter-annual variations of the change in rocks' temperature were observed (see Fig. 2).

In the north of Krasnoyarsk Krai, the air temperature increase with the trend of 0.46°C/10 years is also observed during the period from 1966 to 2009. 2 boreholes located in the forest tundra and tundra landscapes were drilled and equipped with logger stations at the Graviyka River's mouth within the first fluvial terrace above flood-plain of the Enisey River at 6 km from Igarka in 2007. Rocks' temperature at the depth of 10 m in the boreholes equals –0.2°C. The analysis of the change in the rocks' temperature at the depth of 1 m indicates that it slightly increased during the 4 years, while at the depth of annual heat exchange (10 m) it indicates the stable state of the temperature.

Apart from the monitoring sites enumerated above, the sites in South Verkhoyansk (Lazurny), the Chara basin and in the Kodar Ridge foothills were equipped and operate in East Siberia for the last 2 years. In 2012 the preparation and equipment of monitoring sites are planned in the lower reaches of the Hatanga and Nizhnaya Tunguska Rivers.

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Geomorphological Mapping in Antarctic Periglacial Environment. The Geomorphological Map of Fildes Península (King George Island, South Shetlands Archipelago)

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Abstract

We present a new geomorphological map of Fildes Peninsula. Field studies, aerial photograph and satellite imagery interpretation were implemented to produce a detailed map of Fildes Peninsula. The map contains 48 types of landforms, being 15 of them periglacial.Surface and altitudinal distribution of periglacial landforms have been analysed, establishing relationships between different mophodynamic systems -coastal, glacial, periglacial and structural landforms- and the periglacial one. Landforms are grouped in four main landform systems -cryoturbation, geliflution, gravitational and nival- and their spatial distribution and altitudinal organization have been studied. The periglacial processes are intense above 20 m a.s.l., and an increase of periglacial landforms with altitude has been pointed out. Patterned ground and stone fields are the most common periglacial landforms, being located mainly above 40 m a.s.l. Other significant landforms as protalus lobes, rock glaciers or debris lobes indicate the presence of extensive permafrost.

Keywords: Geomorphological mapping, Periglacial environment, Periglacial landforms, South Shetland Islands, Antarctica

Introduction

Fildes Peninsula is located in the south-western end of King George Island (aprox. 62º 11´S-58º 58´W), in the South Shetland Islands (Fig. 1). The peninsula occupies 30 km^2, being one of the biggest ice free areas in the archipelago. Four scientific stations and one airport are located in the peninsula, that to the north is limited by the Collins Glacier. The relief is characterised by two small massifs of 142 and 139 m a.s.l. respectively, and a central depression of E-W direction in which the airport and the Chilean and Russian stations are located. The ice free area is mainly occupied by Early Tertiary to Quaternary volcanic rocks outcropping basaltic, andesite and dacite lavas, agglomerates, lapillistones and tuffs. The Fildes Peninsula was shaped by glaciers and the deglaciation has been dated between 8 and 5 ka BP [*Mauschbacher et al. 1989*]. The climate of Fildes Peninsula is cold maritime (Table 1), defined by annual mean surface air temperature at the coast line between -2 and -2.7ºC, and daily summer temperatures that can be higher than 0º C. During summer the total snow cover melts and there are around 122 freezes and thawing cycles per year. The summer precipitations, the relative air wet (80-90%) and the snow melting imply high summer water availability to soils.

Table 1. Climatic data of King George Island (After Blümel and Eitel 1989, Simonov 1977, Bello et al. 1996)

Location	AAMT ºC	AMP mm	SMP mm	Altitude m a.s.l.
Collins	-2.5	476	173	17.2
Bellinhausen	-2	773	193	6
Marsh	-2.7	460	---	6

AAMT, Annual Air Mean Temperature. AMP, Annual Mean Precipitation. SMP, Summer Mean Precipitation

Previous geomorphological studies in Fildes Peninsula have mainly focused on deglaciation processes, marine features and periglacial landforms. Most of the periglacial environment studies have been dedicated to patterned ground, gelifluction, cryoclastic and cryoturbation processes, as well as to permafrost and the active layer [*John & Sudgen 1973, Simonov 1977, Barsch et al. 1985, Vtyurina & Moskalevskiya 1985, Xie 1988, Cui et al. 1989, Qingsong 1989, Blümel & Eitel 1989, Zhu et al. 1996, Jeong 2006, Serrano & López-Martínez 2000, Serrano et al. 2008, López-Martínez et al. 2012*].

The aim of this work is to show the distribution of the existing periglacial landforms and to present the first detailed geomorphological map of Fildes Peninsula (1/15,000 scale). This is a contribution to the study of the periglacial landforms in the ice free areas of the archipelago. Previously, our group has published geomorphological maps of Byers Peninsula, Livingston Island (1/25,000 scale), Deception Island (1/25,000 scale) and Barton Peninsula (1/10,000 scale) (López-Martínez et al. 1996, 2000, 2002), covering the most extensive ice free areas of the South Shetland Islands.

Methodology

Geomorphological mapping is an effective method to study the location, distribution and morphostratigraphy of landforms, and it has been very useful to study the periglacial landforms of the South Shetland Islands [*López-Martínez et al. 2012*]. The geomorphological map of Fildes Peninsula has been compiled by means of field work, aerial photographs and, in some cases, satellite imagery interpretation.

The legend includes forty eight symbols divided in seven groups: topographic, structural, glacial, periglacial fluvial, marine and human. Used colors, symbols and frames have been adopted from the most common geomorphological cartographic systems used by French, German, Dutch and Swiss researchers. To analyze periglacial landforms and processes fifteen individual forms have been inventoried and grouped in three main morphogenetic subsystems (i. gravity, ii. gelifluction and frost creep, and iii. Cryoturbation, patterned ground and stone fields).

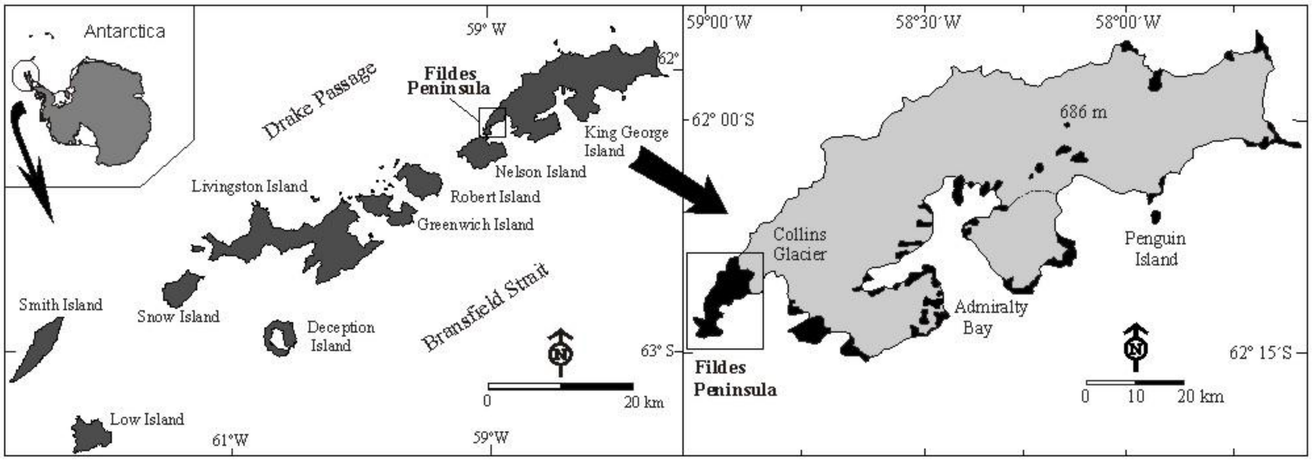

Figure 1. Location map of Fildes Peninsula

Furthermore, the altitudinal distribution of each type of phenomena was analyzed. We have used three topographical bases, from Germany (1/25,000 scale), Brazil (1/15,000 scale) and Chile (1/10,000 scale). Using the detailed geomorphological map we have completed a synthetic periglacial map, a simplified map containing only periglacial information [*López-Martínez et al. 2012*]. We have quantified the extension and altitudinal distribution of each morphogenetic system looking for a better knowledge of the representativeness of the different landforms systems distribution (Fig. 2).

Periglacial landforms distribution

The periglacial environment in Fildes Peninsula is characterised by active processes linked to surface activity and permafrost presence. The periglacial landforms occupy a moderate extent, around the 30% of the total surface of the peninsula. The extended raised platforms of marine origin are favourable to the development of periglacial processes at Fildes Peninsula However, in some places Holocene raised beaches and low and medium platforms, are mainly occupied by glacial landforms and deposits with present day nival processes and a moderate periglacial activity.

The most common periglacial landform in Fildes Peninsula is patterned ground (Table 2) including polygons, stone stripes and circles. Patterned ground is common above 60 m a.s.l. and is dominant above 90 m a.s.l., where circles and stone stripes are the most common periglacial feature. Patterned ground and stone fields are the more spread out periglacial landforms, the last one being very common above 40 m a.s.l. (Table 2). The dominance of raised platforms with flat topography at 20 to 100 m a.s.l., the poor drainage in the platforms and the snow cover melting during summer produce an optimal environment for patterned ground and stone fields development.

Gelifluction processes are linked to the slopes, with protalus lobes, a rock glacier and debris lobes occupying mainly altitudes above 50 m a.s.l. Gelifluction lobes and debris lobes are very common on slopes of the two mentioned massifs, where solifluction displacements between 15-55cm.y^{-1} have been measured [*Simonov 1977*]. The poor drainage of platforms linked to patterned ground development and the existence of frozen bodies in protalus lobes and the rock glacier support the interpretation of an enlarged extension of permafrost on platforms and mountains of Fildes Peninsula.

Table 2. Altitudinal distribution of periglacial landforms systems in Fildes Peninsula.

Altitude m a.s.l.	Surface	Cryoturbation		Gravitational processes	Gelifluction
		Patterned ground	Stone fields		
0-20	km^2	0.003	--	0.031	--
	%	8.82	--	91.17	--
20-50	km^2	0.211	0.212	0.009	0.003
	%	48.50	48.73	2.06	0.68
50-100	km^2	0.117	--	0.04	0.01
	%	70	--	23.95	5.98
>100	km^2	0.017	0.003	0.005	0.003
	%	60.71	10.71	17.85	10.72

The debris talus and cones are dominant at low altitudes (0-20 m a.s.l.) linked to palaeocliffs and structural scarps, but they are developed at any altitude. Nival landforms as snow pavements, sandur, asymmetrical valleys and flat floored valleys are common on flat and slope areas.

Conclusions

Fifteen different periglacial landforms have been inventoried in Fildes Peninsula, linked to two landforms systems: platforms and slopes. An altitudinal organization of landforms and processes can be recognised from the geomorphological map. Only a few periglacial features exist at low altitude (0-20 m a.s.l.), but they are dominant above 50 m a.s.l. On high altitudes patterned ground is the most common feature, but on low areas the nival and gravitational landforms and processes are dominant. Above 40 m a.s.l. it is probable the presence of a permafrost environment, with common active layer-related processes and frozen bodies, but sporadic permafrost could also be present at lower altitudes. Fildes Peninsula is one of the best places to study the distribution and conditions of permafrost and periglacial environment in maritime Antarctica and it seems interesting the continuation of projects and works dedicated to these matters.

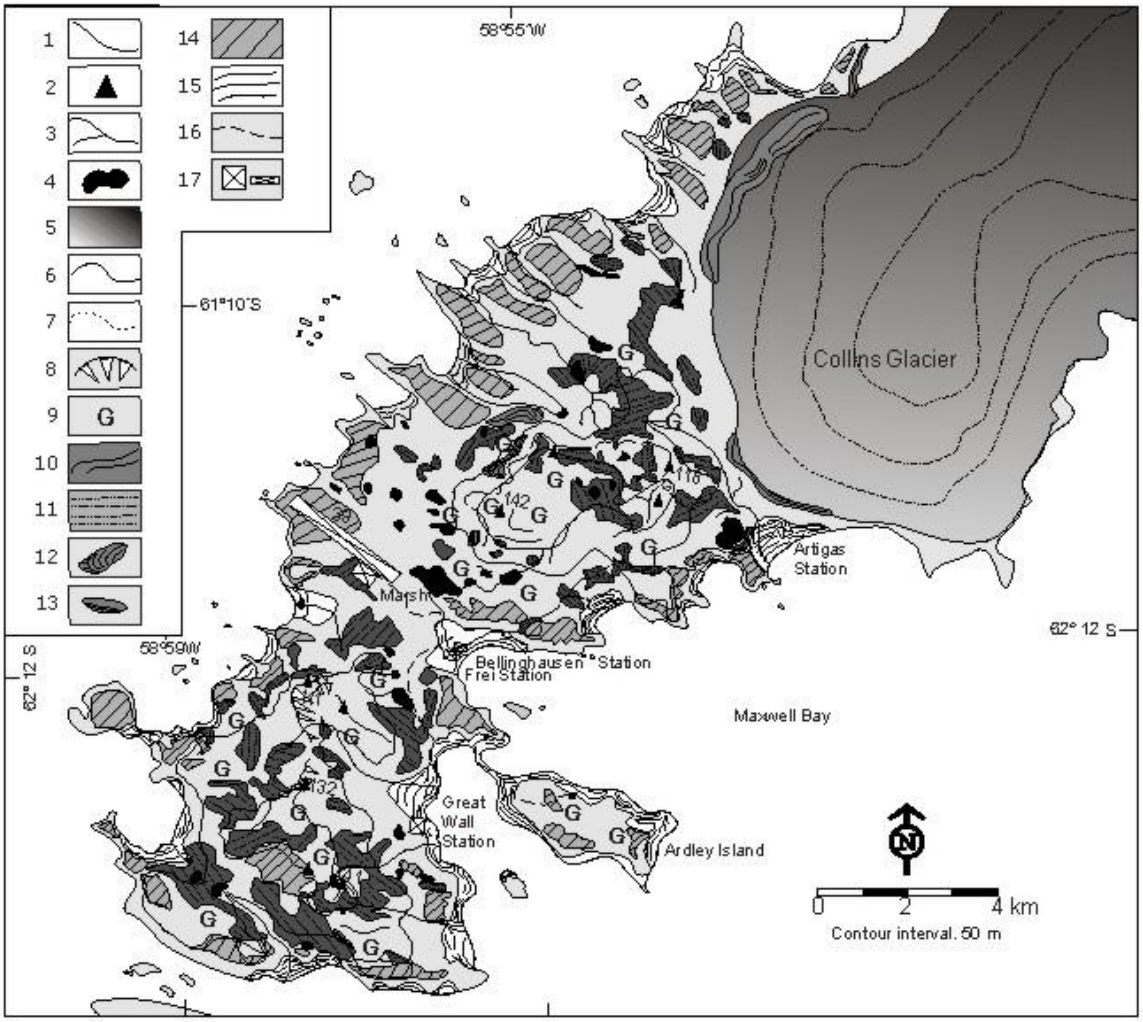

Figure 2. Geomorfphological sketch map of Fildes Peninsula. Modified from the geomorphological map at 1/15,000 scale. 1, crest, ridge. 2, peak, height. 3, river. 4, lake. 5, glacier. 6, contour level on rock. 7, contour level on ice. 8, structural slope. 9, erosive glacial landforms (overdeepened basin, abraded rocks, rock bars). 10, moraines. 11, cryoturbation and gelifluction landforms (patterned ground, debris lobes, gelifluction lobes, stone stripes). 12, rock glacier. 13, protalus lobe. 14, marine platforms. 15, Holocene raised beaches. 16, car track. 17, station or airport.

Acknowledgements

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The Response of Permafrost in the Northern Tien Shan to Climate Change

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The state of permafrost and its possible future trends under the effect of climate change have been a top priority issue in geocryology and other sciences for the past two decades.

The Kazakhstan Mountain Geocryological Laboratory has been running geothermal monitoring in the Zaili Alatau (Jusalykezen Pass, Northern Tien Shan, 3000-3340 m above sealevel) since 1974. The measurements are taken continuously, all year round, at a network of stations located in different landscape conditions depending on the slope direction, rock lithology, and vegetation, in the subzone of discontinuous and sporadic permafrost. This is the only available source of knowledge of the permafrost temperatures and dynamics, both in the study area and generally in the mountains of Central Asia.

The monitoring boreholes have been drilled in Late Pleistocene and Holocene coarse-clastic moraine material that has ice contents from 5 to 40 vol.% and porous-massive cryostructures with large ice lenses. The local climate is characterized by the following long-term annual means: minus 3.9°C, minus 14.2°C, and +6.4°C annual, January, and August air temperatures, respectively; the warm season lasts about 125 days. There are no frost-free periods: frosts of 5-6°C below zero may occur even in June. The stable snow cover forms in October and holds till early June. The snow cover varies largely in thickness and density as a function of slope direction and surface ruggedness because of high wind activity.

The climate of the Northern Tien Shan highlands has warmed up markedly for the past 70 years. For instance, the mean annual air temperature measured at the Tuyuksu-1 weather station in the middle of the northern slope of the Zaili Alatau Range, at 3450 m asl, increased for 0.8°C over the period from 1970 through 2006, or 0.02°C per year. The respective warming recorded at the Mynjilki weather station (3017 m asl) was 1.4°C for 75 years (from 1937 to 2005), i.e., likewise 0.02°C per year.

According to data from the same weather stations in the glacial-nival belt, the annual amount of precipitation has been almost the same for the past 35 years. It has even slightly increased: 115 mm of annual totals at Tuyuksu-1 since 1970.

Temperature logging of permafrost showed variations from -0.6 to -0.8°C in the beginning of observations in 1974 but the permafrost became 0.2-0.5°C warmer in the subsequent 21 years. From 1995 to 2009, the ground temperature in the Jusalykezen Pass held at -0.2 – 0.25°C (Fig. 1).

Through the last three years, another warming trend has appeared in permafrost: a 0.13-0.15°C temperature increase from -0.28°C in 2008 to -0.13°C in 2011. Generally, the permafrost temperatures show slow progressive growing of 0.01°C/yr over the 37-year period. If this trend holds on, one can expect an almost gradient-free temperature regime, about zero, in the nearest 25-30 years.

Synchronous minor fluctuations of permafrost temperatures (within 0.1°C) have been recorded for the past 16 years at different depths, with 10-11 cycles, e.g., from 1998 to 2008.

The geocryological conditions change rapidly within short distances (from a few meters to hundreds of meters) at the same elevation in the highlands, where the terrain is highly rugged. For instance, permafrost in the Jusalykezen Pass thins down from 100 m in the southern margin at the foot of the northern slope to 35 m beneath the flat saddle surface 200 m away, and on to 13 m another 280 m far; finally, it pinches out completely within a distance of 500 m in the northern end of the Pass at the foot of the southern slope.

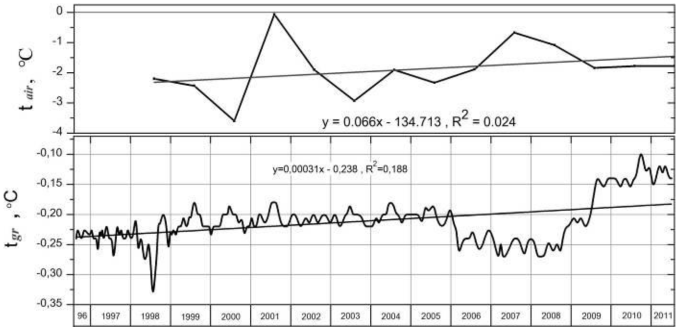

Fig. 1. Air temperatures (decadal and yearly means) and ground temperatures at 20 m below the surface. Borehole Jusaly 1.

The thaw season becomes ever shorter with altitude and changes notably from year to year. The mean seasonal (June-September) air temperature grew 0.9°C warmer between 1970 and 2006 at the Tuyuksu 1 station (3450 m asl) and 0.8 °C warmer at Mynjilki (3017 m asl).

The seasonal thaw depth increased from 3.2-3.5 m in 1974-1975 to 5.0 m in 1991, 1999, and 2000, and reached the maximum of 6.0 m in 2001. In the following 8 years, the active layer thickness remained relatively stable, with minor seasonal fluctuations within 4.6-4.9 m. However, the thaw depth increased again in 2010-2011, to 5.5-5.8 m, which is on average 1 m more than in the previous years. Note that the active layer thickness in different landscape conditions of the Northern Tien Shan shows no explicit response to the contemporaneous warming.

Thus, the permafrost of the Northern Tien Shan has little responded to warming for the past 37 years, this being evidence of its quite a high thermal stability.

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Changes in Permafrost Parameters at the Turn of the 21^{st} Century

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Introduction

Climate change has been observed everywhere lately. Warming and its effects on the state of permafrost are the strongest in Arctic and Subarctic regions. The permafrost changes may, in turn, influence the climate system through feedback mechanisms. Furthermore, the northward retreat of the permafrost line and the increase of seasonal thaw duration and depth pose failure risks to engineering structures and affect the ways of economy and everyday life of northern peoples.

Goals and objectives of study

The main goal of the study is to reveal and analyze the trends of permafrost changes in the Northern Hemisphere using all available sources of knowledge. The key parameters that characterize the state of permafrost are its extent (position of the southern boundary), thickness, seasonal thaw depth, and ground temperature at the depth of zero annual amplitudes.

The objectives of the study include compiling a reference digital map of permafrost for the time 1970-1980, inventorying the available measured data, with longest possible time series of the principal parameters to cover the period of most intense changes (past 20 years), and predicting the future trends.

Work progress and first results

In the course of the study, an ArcGIS digital map has been compiled which records the state of permafrost according to the selected parameters. The map covers the territory of Russia, Mongolia, Canada, and Alaska and presents permafrost as it was in 1970 through 1980. For this various previously mapped data were digitized for the time before 1983, the year chosen as a conventional boundary between the historic (unperturbed) and present (highly perturbed) states of permafrost. The Permafrost Map of the USSR [*Baranov 1977*], which contains all permafrost parameters, was used as a basic one while the other maps of Mongolia [*Gravis et al. 1974*], China [*Shi & Mi 1988*], Alaska [*Ferrians 1965*], and Canada [*Brown 1973*] were spliced to it. The obtained data can be used for reference to measure further change.

A database is being created that contains data of temperature and thaw depth monitoring in the permafrost zone of the Northern Hemisphere, with ground temperatures measured at different depths near that of zero annual amplitudes. The collected data are brought to a standard format. Point data are put on the reference digital map and can be presented as curves or spreadsheets (Fig. 1).

The data collection and processing work is coming to the end. The next step is to estimate the trends of the parameters and, possibly, also the permafrost retreat for the past decades provided that necessary data are available. The permafrost thickness, the fourth parameter we chose, apparently has not changed much for the past 50 years over a greater part of the permafrost zone, except for areas of discontinuous (sporadic and patch) permafrost.

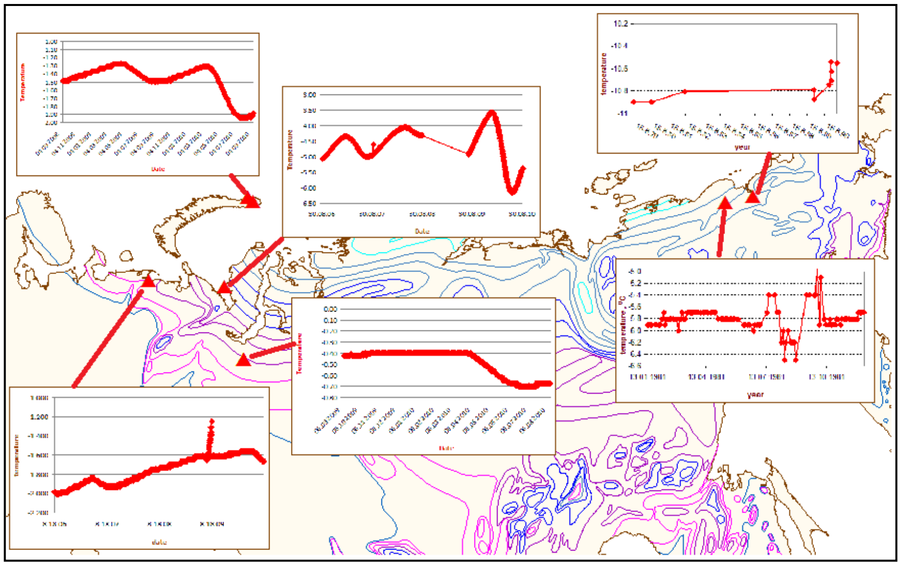

Fig. 1. Reference map of permafrost parameters and ground temperature curves.

Expected results

The presentation at the Conference will include the digital permafrost map of the Northern Hemisphere for 1970-1980, with estimated trends in seasonal thaw depths, ground temperatures at the depth of zero annual amplitudes, and northward permafrost retreat (if possible). We also shall describe the difficulties we faced when processing data from different sources that differ in accuracy, quality, and resolution.

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The Anthropogenic Changes in the Geocryological Conditions of the Obskaya-Bovanenkovo Railway Line (the Yamal Peninsula) Based on the Results of the Engineering and Geocryological Monitoring

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Abstract

Engineering and geocryological monitoring of the Obskaya-Bovanenkovo railway line was performed in 2007-2010 at 240 cross-section profiles to determine the trends of anthropogenic changes in geocryological conditions in the embankment body and within the railway track. A ubiquitous increase by 0.63 m on average was observed in thawing depth of grounds at the slopes, at the foot of embankment slopes and at the roadbed. A frozen core is formed in the embankment base. Its thickness ranges from 0.2 to 9.8 m., depending on the embankment height, laying depth and thickness of thermal insulation layer. An increase in average annual temperature of grounds by the embankment base and in its proximity, at the distance of 10-30 m, was registered. Grounds thawing depth increase causes the development of such processes as thermokarst, thermal erosion, creep of ground and cryogenic heaving. This leads to subgrade destabilization and to environmental degradation. Thermokarst is the most widespread of these processes. The scale of hazardous engineering and geological processes manifestation and their development dynamics are reflected on the map of anthropogenic disturbances of the area. A set of measures dealing with engineering protection of the embankment and of the territory against hazardous engineering and geological processes manifestation was developed.

Keywords: anthropogenic disturbance; engineering protection; geocryological monitoring; hazardous cryogenic processes; railway; Yamal.

The Obskaya-Bovanenkovo railway line is located in the hardest natural climatic and engineering-geocryological conditions. Its biggest part is located in the zone of continuous distribution of ice-rich permafrost with monomineralic deposits of ground ice and extensive development of hazardous cryogenic processes. To secure the embankment stability and the accident-free railway operation, "Industrial and Scientific Research Institute for Engineering Survey" JSC carried out geotechnical monitoring of the subgrade and culverts (in the area from 268 to 525 km) in 2007-2010.

The main characteristics of ground properties were monitored. They included particle size distribution, moisture content, ice content, density, heaving, compressibility during thawing, erodibility, filtration properties, thermal conductivity, heat capacity, freezing temperature and unfrozen water content. Seasonal thawing depth, grounds temperature in the embankment body and at its base, development of hazardous cryogenic processes and subgrade state during the construction and operation of the railway were also monitored.

The evaluation of the dynamics of these parameters was carried out in 240 cross-section profiles crossing the subgrade and the adjacent territory in the area of railway influence. During the profiles placement, engineering and geocryological conditions of this section of the railway line, design features and embankment erection technology as well as culverts system were considered. A geodesic survey with wells location was carried out in the areas of observation profiles. Deformation markers were installed. Physical-mathematical modeling of grounds thermal state in the embankment body and at its base was performed. Its results were used to develop a set of protective measures against hazardous engineering and geological processes.

One of the main goals of engineering and geocryological monitoring of the Obskaya-Bovanenkovo railway line was to determine the trends of anthropogenic changes in the geocryological conditions of the embankment body and within the railway track. Monitoring of permafrost upper surface dynamics during a three-year period (2007-2009) allowed us to determine an almost ubiquitous increase in the thawing depth of grounds at the slopes, by the foot of embankment slopes and on the roadbed. According to average statistical data, the increase in the thawing depth of grounds by the foot of the embankment was 0.63 m. The thawing depth on the roadbed varied within the range from 1.0 to 2.5 m, depending on the lithological composition of ground, its moisture content and the position of thermal insulation layer in the embankment body. Thawing depth was 2.1-3.5 m. in the proximity of the culvert.

It was determined that a frozen core is formed in the embankment base. Its thickness (0.2-9.8 m) is determined by the embankment height, laying depth and the thickness of thermal insulation layer (Fig. 1).

Over the two-year monitoring period at the operational stage, a location stabilization of permafrost table on the roadbed was registered at almost all observed objects. The results of grounds temperature observations show that over the two-year cycle of railway line construction and operation, a trend to the increase in average annual temperature of grounds by the embankment foot and in its proximity, at a 10-30 m distance away from it, is observed. The extent of the embankment influence on the grounds thermal regime mainly depends on the embankment height and the snow accumulation conditions.

Since icy permafrost that often contains monomineralic deposits of ice (wedge ice and massive ice) displays extensive surface distribution in this area, the registered increase in grounds thawing depth causes the development of hazardous cryogenic processes. These processes include thermokarst, thermal erosion, creeps of ground and frost heaving during freezing. The development of these processes leads to subgrade destabilization and to environmental degradation.

The scale of hazardous engineering and geological processes manifestation and their development dynamics are reflected on the map of the territory's anthropogenic disturbances. The map was drawn based on the results of the comparison of anthropogenic disturbances inventory performed in 2008 and 2009. It was determined that along the right-of-way, throughout the entire examined area, thermokarst is the most widespread anthropogenic cryogenic process. It is connected with bogging and waterlogging of the territory directly adjacent to the embankment. The development of these processes that induce thermokarst activation within the areas composed of icy grounds is preconditioned by the disturbance of surface water and ground water runoffs, by the removal of soil and vegetation cover as well as by the change in the snow accumulation nature (in its thickness, density and structural features) during the embankment construction.

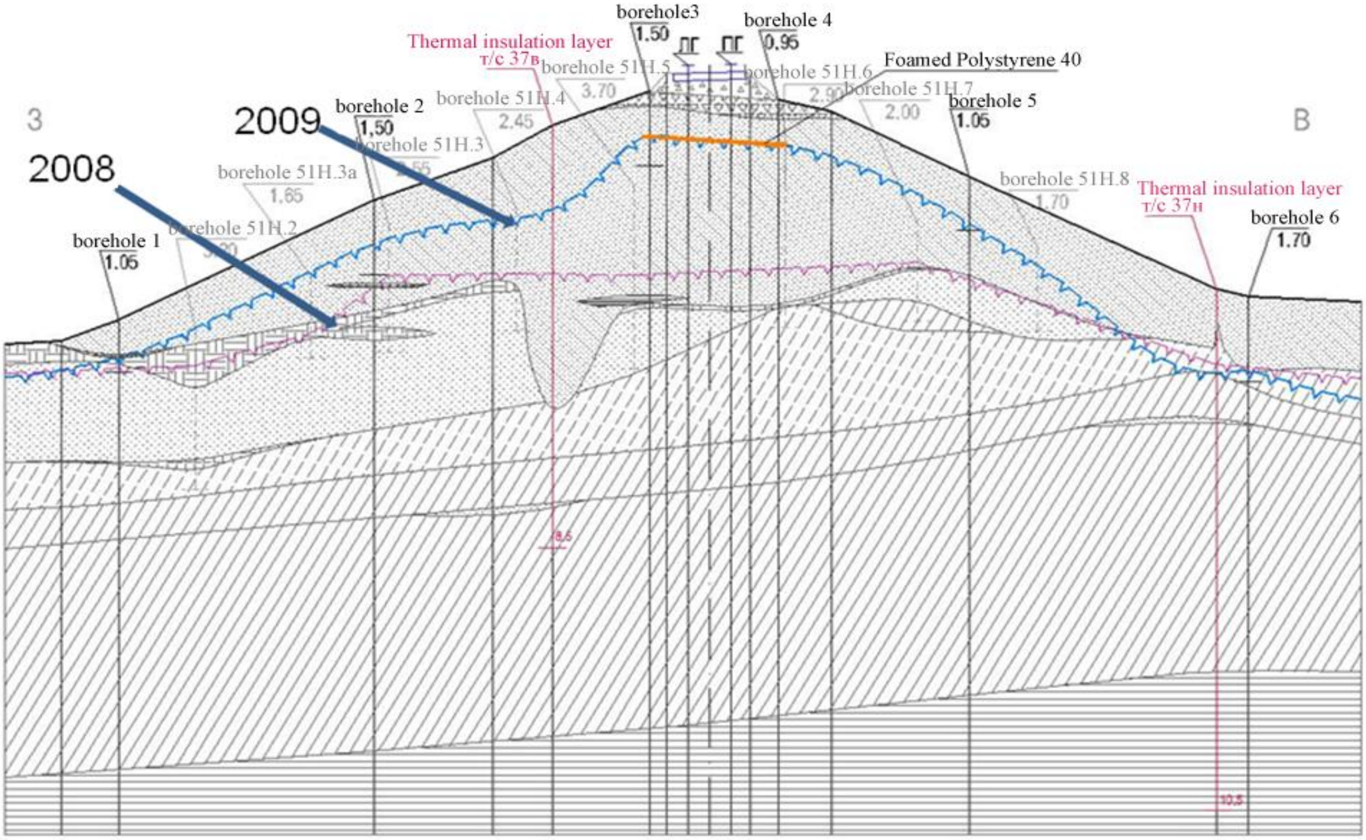

Figure 1. Permafrost core formation in the embankment body.

When the railway was switched into the operational regime, localization of waterlogging and bogging zones was registered. They were confined to depressed, sub-horizontal surfaces with hydromorphous landscape conditions or to linear oriented zones with the highest concentration of tracks. The extension of blowout lands where thermal erosion actively develops was also observed. Stabilization or attenuation of engineering and geological processes is observed in separate areas of the line. As an efficient protective measure that neutralizes the development of hazardous engineering and geological processes, filling of bogged and water-logged areas with rock and sand ground is successfully exercised.

Monitoring results made it possible to evaluate the potential possibility of development of hazardous engineering and geological processes, depending on the ice content of the foundation grounds, the position of thermal insulation layers in the embankment body and under pipe-culverts, steepness of the slopes as well as on the presence or absence of protective rubble-sand layer or peat layer on the embankment slopes. A set of measures dealing with engineering protection of the embankment and of the territory against hazardous engineering and geological processes manifestation was developed.

Mapping of Dynamics of Permafrost Landscapes and Assessment of their Resistance (the Case of the Prilenskoe Plateau)

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Introduction

This work is devoted to application of vegetation succession stages in engineering-geocryological mapping. Successions are processes of a logical alteration of vegetation in the same location or landscape. Secondary (anthropogenic) successions arising after fires and clear-cuttings are studied in the Lena-Aldan interfluve area.

The work is aimed at the improvement of methodology of engineering-geocryological mapping by applying vegetation succession stages for demonstrating a dynamic state of engineering-geocryological conditions in the process of mapping.

This work is based on the materials collected by the author during permafrost-landscape studies in Yakutia in 2005-2011. The work was performed as a part of competition scientific programs of the Siberian Department of the Russian Academy of Sciences (projects 25.1.5, 7.10.2.5 and VII.63.2.5 during 2004–2011). The results of studies were used when performing a number of contractual works with manufacturing and design organizations and when making a digital engineering-geological map of the Russian Federation with the scale of 1:2500000 (2008-2010).

Study methods

The methodology of making landscape maps of a studied area includes: conducting landscape cryoindication, classifications of landscapes with due consideration of vegetation successions, making layers of a digital landscape map – types of terrain and types of plant associations, as well as making an integral landscape map – types of stows by overlaying the aforementioned layers. Geobotanical elements were mapped with the help of aerophotographs and space images of the GOOGLE EARTH program and LANDSAT-7 ETM+ satellite scenes, by singling out terrains with the same interpretation signs. For this purpose, the photographs with scales of 1:25000 and 1:50000 in 1978 и 1989 correspondingly and space images in 2002 – 2009 were used.

Results

The landscape structure of the region is composed of flat interfluve, slope and small valley types of terrain (Shestakova 2008). Fires and clear-cuttings play rather an important role in modern landscapes. For example, the fires of 2001-2002 in Central Yakutia damaged 30% of the territory, which significantly affected the engineering-geocryological conditions of this region.

Vegetation succession stages were divided into 2 complexes: up to 20 years and 20-50 years. Successions with duration of up to 20 years are composed of birch and larch sproutings that are often hard to go through and represent the first stage of recovery. Successions lasting for 20-50 years are characterized by stabilization of landscapes and permafrost conditions. In this time the grass-low shrub cover begins to grow, while forest stand is thinned out.

The results of field research and studying of stock and publications materials [*Bosikov et al. 1985*] made it possible to identify the change in ground temperature and in thickness of a seasonally thawed layer in different succession stages. For example, in flat interfluve and slope types of terrain in successions with the age of up to 20 years the temperature of grounds increases by 0.5-1 °C and the thickness of the seasonally thawed layer increases by 1 m. On relatively old burnt areas (20-50 years old) the temperature of grounds and the seasonally thawed layer thickness stabilize and almost reach invariant values for non-disturbed landscapes.

Comprehensive permafrost-landscape studies in the Lena-Aldan interfluve area served as a basis for studying the use of vegetation successional series in case of large- (1:25000), medium- (1:200000) and small-scale (1:2500000) mapping.

Let us consider the preparation of landscape maps using large-scale mapping.

In the process of large-scale mapping 10 plant communities were distinguished. Indigenous fir-larch blueberry-moss forests (46%) dominate among them. The overlay of the maps of terrain and vegetation types resulted in obtaining of 25 classification units at the level of stow types. 12 such units represent successions in various terrain types (Fig. 1, b). In this case successions occupy about 16% of the total area. The content of the map of stow types was then correlated with the materials of the field permafrost-landscape studies on this territory and stock materials of the Melnikov Permafrost Institute of SB RAS that were collected from the 80s to the present day.

Using the GIS attributive tables attached to a landscape map, there were prepared digital thematic permafrost maps of temperature of grounds, thickness of a seasonally thawed layer and permafrost-geological processes that reflect the principles of spatial distribution over various elements of landscapes. The maps are made in two variants: Variant 1 – maps made by traditional method, without considering the disturbances of landscapes (successions); variant 2 – maps made by the proposed method with due consideration of disturbances of landscapes (successions).

The ground temperature map made on the landscape basis without consideration of vegetation successions – on the basis of the map of terrain types, includes 3 temperature units.

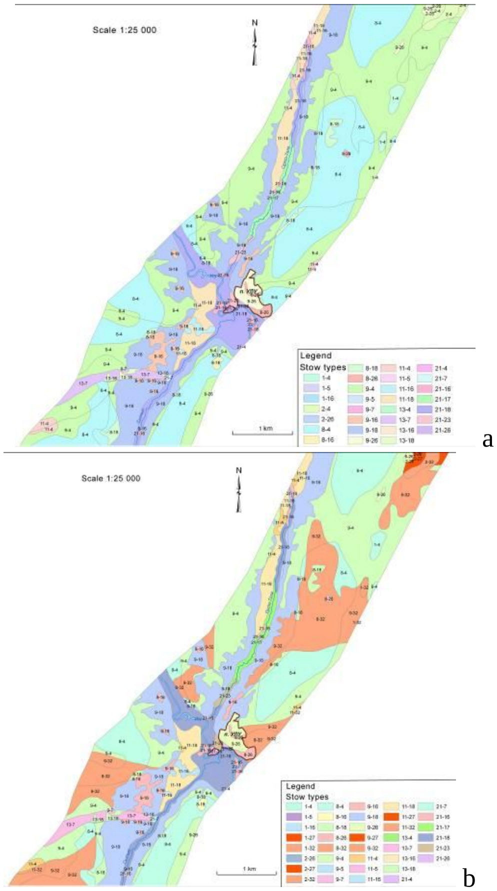

Figure 1. Maps of stow types without consideration of successions (a) and with consideration of successions (b). Scale 1:25000.

The map of grounds temperature with consideration of vegetation successions includes 7 units. The first 5 units of temperature of grounds are typical of flat interfluve and slope terrains where successions of up to 20 and 20-50 years were identified. Here the use of vegetation successions allows us to differentiate the grounds temperature range from 0 to –1.5 ºC.

If the thickness of a seasonally thawed layer on the map without regard to vegetation successions is divided into 3 units, then 5 units are distinguished on the map with regard to such succession. The major territories are occupied by stows with the seasonally thawed layer thicknesses of 0.5 – 1.0 and 1.0 – 1.5 m (37 and 58% of the total area, accordingly). Maximum seasonally thawed layer thicknesses of 2.0 – 2.5 and 2.5 – 3.0 m are associated with serial facies – successions.

At the initial succession stages permafrost-geological processes are activated by changing engineering-geocryological conditions. The most widely spread combinations of processes are as follows: frost cracking, solifluction, erosion and frost cracking, heaving as well as thermokarst. Karst and local karst sinkholes are observed in the landscapes where successions are identified.

The permafrost-landscape maps with different scales became the basis for making the maps of resistance of natural territorial complexes (NTC) to anthropogenic impacts, depending on ice content, the course of permafrost-geological processes, temperature of grounds and thickness of a seasonally thawed (frozen) layer [*Shpolyanskaya 1994*]. The analysis of the NTCs resistance map showed that prevailing areas (88, 43, 57%) are occupied by relatively unstable NTCs on slopes in large-, medium an small-scale mapping accordingly. The relatively stable NTCs on flat interfluve terrains occupy comparatively large areas in medium (34%) and small-scale (39%) mapping. The lower parts of the bottoms of slopes, ravine- and small valley NTCs are rated as unstable and occupy 20% of the total area in medium-scale mapping. Stable NTCs are spread inconsiderably and occupy up to 3%.

Conclusions

1. The methodology of mapping the engineering-geocryological conditions of permafrost landscapes with the use of vegetation successional series and GIS-technologies was improved. Application of modern GIS-technologies simplifies classification mapping with overlaying individual layers and facilitates the process of landscape classification.
2. The work provides a comparative analysis of natural and disturbed permafrost landscapes on the basis of main geocryological characteristics. The temperature of grounds in successions increases by 1º C and the thickness of a seasonally thawed layer grows by 0.5-1.0 m, as compared with natural permafrost landscapes. Such types of permafrost-geological processes as thermokarst, solifluction and erosion processes were activated.
3. The use of succession models as indicators in classification landscape-dynamic mapping made it possible to assess the modern state and development trends of permafrost landscapes in the Lena-Aldan interfluve area, with demonstration of recovery of both landscape and permafrost conditions.
4. Large-, medium- and small-scale digital thematic maps that are made on the basis of attributive tables with due consideration of vegetation successions reflect the modern state of permafrost landscapes and enable a more detailed assessment of space-time principles of their development.

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Cryolithozone, Climate and Emergency Risks

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Abstract

In this article we examine the impact of climate and technogenic load on the distribution, thickness and temperature regime of the cryolithozone. Based on the example of studying these impacts for different cryolithozone areas, the causes of formation of possible emergency risks (both regional and local emergencies) are analyzed. Organizational and technical activities aimed at preventing, eliminating and managing risks developed on the base of monitoring studies of cryolithozone transformation, kinetics and mechanics of physical-geological cryogenic processes and phenomena are proposed.

Keywords: climate; cryolithozone; emergency management; monitoring; risk.

Introduction

In Russia, the cryolithozone occupies up to 60-70% of the territory, where up to 20% of the country's gross domestic product and over 22% of its export are produced. The infrastructure established here in the 20th century continues to evolve and expand, even with the difficulties caused by global warming. In this regard, academic science pays great attention to studying the dynamics and determining the patterns of cryolithozone transformation in the context of global climate change, as well as to improving the existing technologies of cryolithozone use and developing new ones. The paper is written based on the results of the studies conducted by the author in accordance with the SB RAS Program VII. 63. 2. "Natural and anthropogenic systems in Earth's cryosphere and their interaction" coordinated by V.P. Melnikov, a member of the Academy of Sciences.

Study methods

The problem of global climate change and its impacts on cryolithozone is a very urgent problem of our time. While in the middle of the 20th century the human impact on the environment was considered the main reason for the climate change, now it is firmly established that the climate is rhythmic and its rhythmicity is caused by the natural course of the Earth's development. We also adhered to this view in the course of studying the interaction between climate and cryolithozone for the case of Transbaikalia located within the southern periphery of the East Siberian cryolithozone. The retrospective analysis of the history of this interaction during the Pleistocene-Holocene period in one of the regions of Eastern Siberia, namely Transbaikalia, was carried out using:

- stratigraphic-genetic zonation of the Quaternary deposits and analysis of the results of studying the changes in natural conditions during the Pleistocene-Holocene period;
- the method of paleocryological interpretation of the Baikal climate chronicles that was developed by S.M. Fotiev;
- phytocenological analysis of the palynological testing of a core produced from a 1180 m deep borehole in the Charskaya basin. The analysis was conducted by F.I. Enikeev and V.I. Potoemkina;
- the method of reconstruction of the upper boundary conditions with regard to the transformation of the landscape-botanical conditions and their connection with snow accumulation.

The construction of cartographic models of cryolithozone during cryochrons and thermochrons of Transbaikalia was carried out according to the method proposed by V.T. Balobaev.

The retrospective analysis of the relationship between the history of climate development and cryolithozone during the period from the late 19th century to the early 21st century at the landscape level (the central part of the Chitino-Ingodinskaya basin and the surrounding mountains) was conducted using the archives of the Chita weather station. The cartographic models were developed using the method of the Department of Geocryology of Moscow State University. The method was established under the leadership of V.A. Kudryavtsev.

Research results

1. The obtained results of the studies demonstrated that the global climate change in the direction of warming contributes to the development of a slow but noticeable degradation of cryolithozone at a regional scale. This makes it considerably difficult to ensure the effective operation of buildings and structures. In addition to the climate impact, thermal cryolithozone pollution caused by anthropogenic pressure on the environment, in some cases, even in the arctic cryolithozone regions, is accompanied by a catastrophic development of cryogenic physical-geological processes and phenomena. As a result, industrial and civil structures, mine engineering structures, as well as some areas of linear structures cease to function for a long time.

The comparative analysis of the continental Chara climate archives and the aquatic (marine) Baikal climate archives enabled identification and assessment of synchroneity of changes in the climate characteristics in Northern Transbaikalia and Cisbaikalia. The air temperature during the synchronous periods in the historical past and at the present time in Northern Transbaikalia was lower than in Cisbaikalia by 3-6 degrees.

The determined paleodynamics of Transbaikalia cryolithozone suggests that its thickness during the Pleistocene-Holocene period was subject to significant changes, depending on the parameters of cryochrons and thermochrons. Maximum cryolithozone thickness, up to 2500-3000 m in Northern

Transbaikalia and 1200-1500 m in Southern Transbaikalia, was formed during the Taz and Sartan periods.

During the period of Kazantsevo thermochron, continuous low-temperature cryolithozone with the thickness of up to 500-600 m was preserved only in the mountainous areas of the Udokan and the Kodar Ridges. The thickness of Transbaikalia cryolithozone ranged from 50-100 m in the highlands, within the Kodar-Udokan geostructural zone, and the Transbaikalia cryolithozone was virtually absent in most of the tablelands.

According to the climate archives of the Chita weather station, during the period from the end of the 19th century to the beginning of the 21st century there were three periods when changes in mean annual air temperatures occurred in Central Transbaikalia. In the first period (1890-1920) the values of mean annual temperatures increased from -4.2 to -3.2, in the second period (1921-1960) they were close to the constant values changing from -3.2 to -3.0, and in the third period (from 1960 until present) there is a significant increase in the temperatures from -3.2 to -0.8 °C.

During the third period: a) in South-Eastern Transbaikalia, island cryolithozone transformed into rare-island cryolithozone; b) in the Central Transbaikalia, massive island cryolithozone became island cryolithozone; c) in Northern Transbaikalia, the layer of seasonal thawing of grounds increased by 20-30%, glaciers decreased in volume and in area by 30-40%, while giant icing fields transformed from perennial types into seasonal types.

Conclusions

1. The study of the cryolithozone dynamics in the context of global climate change and the analysis of the functioning of the natural-technogenic systems that are the most important for life sustaining, allowed us to determine the following major risk groups in the Trans-Baikal region: group 1 – agricultural facilities used to regulate water use in the conditions of desertification of the territory of Central Asia; group 2 – industrial and civil buildings; group 3 – thermal power facilities; group 4 – mine engineering facilities; and group 5 – linear structures.

2. The study of the effects of natural and anthropogenic impact on the functioning of natural-technical systems in cryolithozone demonstrated that in Transbaikalia the activation of kinetics and mechanics of cryogenic processes and phenomena, as well as processes of aridization of the territory have a zonal nature and increase from north to south. In southern areas, for example, we can currently observe intensive processes of desertification accompanied by a decrease in water content of rivers and by desiccation of lakes.

3. The problems mentioned can in some cases cause socioeconomic stress. To prevent it, we need to develop strategies aimed at ensuring effective economic development in the context of climate change and cryolithozone transformation. Its implementation should be carried out in stages with regard to scientific, economic and technical justification of priorities:

The first stage. Climatic zoning and the retrospective analysis of climate change must be accompanied by: a) small-scale maps of geocryological zoning for various purposes, marking potentially hazardous areas for the integrated socioeconomic development of the territory; b) medium-scale maps for predicting the development of cryogenic processes that might cause emergencies.

The second stage. Study of the transformation of climate and cryolithozone and the scale of their impact on the determined risk groups. At this stage, quantitative assessment of the significance of the conducted studies for the socioeconomic development of the territory should be made. The predetermined priorities should be taken into account.

The third stage. Development and implementation of activities for managing the processes of adaptation of natural and natural-technogenic systems of various risk groups in modern conditions.

Implementation of this strategy in the region scale should not have any time limits. It is associated with the fact that the interaction of the "climate - cryolithozone - engineering object" system can be multi-directional, which is caused by climate cyclicity and duration of the structure operation, from the first year to dozens or even hundreds of years. In this regard, the control actions targeted at the elements of natural-technical systems must be constantly adjusted and modified to ensure the preservation of their high effectiveness.

The prospective analysis of the climate development demonstrated that it is probable that we are currently almost at the peak of climate warming. However, a few centuries will apparently pass before we can observe its steady shift from warming to cooling.

The Calculation of the Dynamics of the Thawing Halo from the Horizontal Flare

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Horizontal flares are also operated on permafrost. The flare temperature is approximately 1000 °C. Horizontal flares are operated approximately for several days per month. Due to the intense thermal impact, permafrost thaws and then undergoes subsidences. To assess the dimensions of subsidences, it is necessary to know the dimensions of a thawing area; for this we resolve the problem of the thermal interaction between a flare and permafrost.

The purpose of the calculation of the thermal interaction between a flare and permafrost is the dynamics of dimensions and of the form of the thawing halo, and the temperature of the upper penoplex layer.

The temperature of fireclay during the flare operation is 800 °C; the length of the area with such a temperature is 10 m. Within the first year the flare is operated during three days per each two months and within the next years it is operated during three days per each four months. The end of the year is a warm time, the beginning of the year is a cold time. The calculation was made for 20 years of the flare operation. The lowest temperature in the winter period (nine months) is -28 °C; the highest temperature in the summer period is 13 °C (three months). Phase transitions occur in the ground within the interval from -0.1 °C to 0 °C. The horizontal flare is situated on a mound consisting of three different materials: the upper one is fireclay, the middle material is sand and the next one is penoplex that represents a thermal insulator.

The temperature field of grounds under the horizontal flare is described by a quasilinear equation of the parabolic type:

$$c(T)\frac{\partial T}{\partial \tau} = div(\lambda(T)gradT)$$

The calculation is made by the method of variable directions (Fig.1).

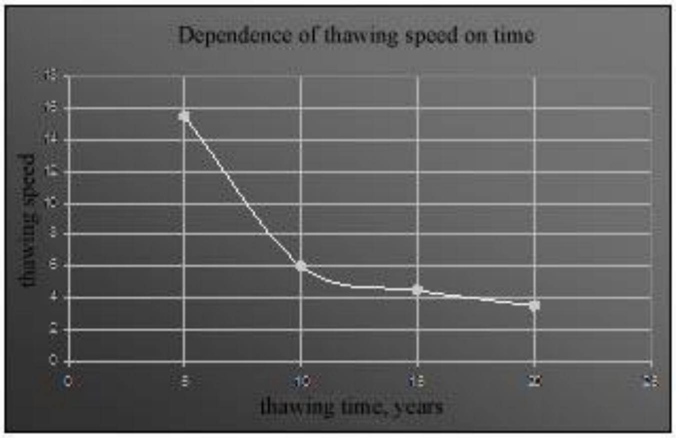

Figure 1. Thawing speed dynamics.

Thawing speed decreases with time.

Figure 2 represents a thawing area under the horizontal flare after 20 years long works for the insulation with the thickness of 0.0 m, 0.25 m and 0.75 m.

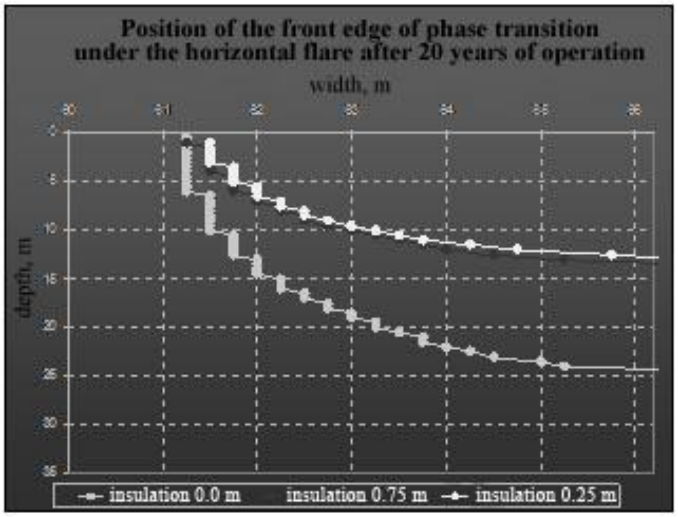

Figure 2. The dependence of the thawing halo on the thickness of thermal insulation. A half of the symmetric thawing halo is shown.

Figure 3 represents the temperature dynamics in the mound and in the ground for the first four months of the horizontal flare operation with the 0.25-m thickness of the thermal insulation.

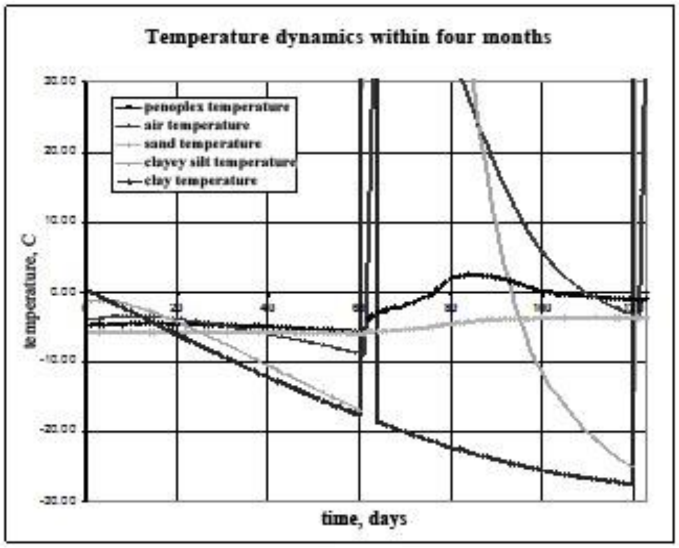

Figure 3. The dynamics of the ground temperatures and mound materials temperatures for the first four months of the horizontal flare operation.

Switching on the flare leads to an instant heating up of the clay up to 800 °C (this allowance is included in the statement of the physical and mechanical model); the sand under the clay (the clay thickness is 0.25 m) heats up rapidly as well. Switching off the flare leads to a slow cooling down of the clay and sand. Penoplex prevents permafrost thawing approximately within four first months. Two bends at the curve of the penoplex temperature are related to the flare switching on and the beginning of phase transitions in the sand layer adjoining the penoplex.

Figure 4 represents the temperature dynamics in the mound and in the ground within the first year of the horizontal flare operation with the 0.25-m thickness of thermal insulation.

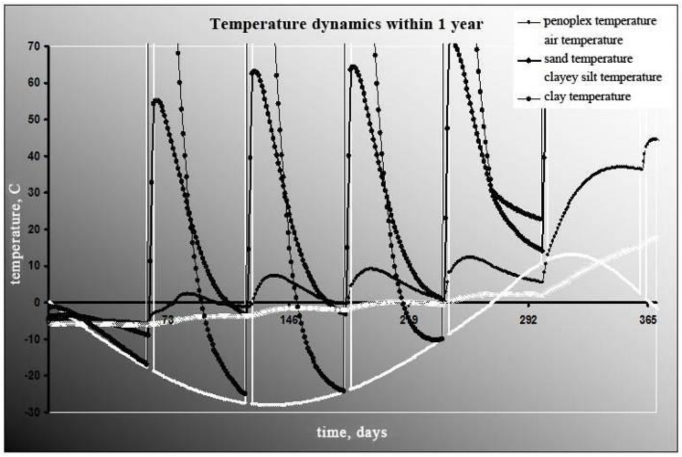

Figure 4. The temperature dynamics in the ground and in the mound materials within the first year of the horizontal flare operation with the 0.25-m thickness of thermal insulation.

The thicker the insulation is, the higher the temperature at its surface is, as the permafrost impact under the insulation and a thermal flow through the penoplex reduce, while the general thermal flow above remains the same.

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Secular Variations of Bottom Temperatures in the Barents and Kara Seas

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Keywords: Barents Sea; bottom temperature; GIS; Kara Sea; subsea permafrost.

The Barents and Kara shelves are remarkable by presence of subsea permafrost extending as deep as 120 m. The state and evolution trends of the subsea permafrost are recorded in sea bottom temperatures.

A special geo-information system, - a bathymetric and temperature GIS, - has been created for estimating bottom temperatures and subsea permafrost trends in the Barents and Kara seas.

The GIS database synthesizes sea depths and seawater temperatures and salinities collected by different institutions of marine research from Russia, US, UK, Germany, Norway, and Poland in the Barents and Kara areas, from 1898 through 1998. Altogether, data from more than 1,000,000 oceanographic stations have been selected for preliminary processing.

Studies of secular bottom temperature variations included several specific objectives:

- Designing a software and a procedure for checking oceanographic data;
- Selecting data on bottom water temperature, assuming that the sea bottom and the near-bottom seawater have the same temperatures;
- Mapping the bottom temperatures of the Barents and Kara seas;
- Estimating secular variations of bottom temperatures at two selected key areas, where subsea permafrost is present and for which the greatest amount of data is available.

In the existing international practice of collecting and sharing data, the same data are included repeatedly into databases obtained from different sources. Data are also often replicated within one and the same source. Thus, replica stations were specially searched and excluded from analysis. On further processing, data were checked for coincidence of location (to the accuracy of 0.5’ latitude and longitude) and temperature (to 0.001°C).

There were several steps in data processing. First, data that came from different sources and were originally presented in different ways were brought to a standard format, with conversion to standard measure units and correction of gross errors. The primarily selected depth intervals were those proximal to the common sea depths and to the sea bottom. The values that obviously transcended the possible limits of the parameters were likewise culled out at the first step. The accepted ranges were -2.00 to 35.00 °C for temperatures and within 9990 m for sea depths. Another criterion we checked at the first step was the sequence of increasing sampling depth [*Barents Sea 1990*]. If no reasonable temperature values remained in a station data set after the error values were culled out, the station was excluded from the database.

Then data that passed the first control were further checked for falling into the area of interest, and land data were culled out. At that step, we checked the depths of the stations and the deepest sampling intervals. The minimum and maximum sea depths were estimated at nine nodes of the bathymetric map next to the calculation point.

The following step consisted in selecting the data arrays restricted to bottom temperatures. On that basis, the spatial distribution of temperature means over the period 1900 - 1998 was calculated and a map of bottom temperatures was compiled (Fig. 1).

The compiled map is expected to be used as a GIS layer which represents the extent and state of subsea permafrost. According to preliminary analysis of the bottom temperature and permafrost patterns, subsea permafrost, if present, is rapidly degrading almost throughout the southeastern Barents Sea, where the bottom temperatures reach or exceed 3°C. Rapid degradation of subsea permafrost occurs also in gulfs and bays of the Kara Sea (Baidartskaya, Ob, and Gyda bays and Yenisei gulf), where the bottom temperature is likewise positive. Elsewhere in the Kara sea, permafrost is most likely in a quasi-steady state. There the bottom temperature is negative and approaches the thawing point for saline frozen soil.

The time-dependent variations in bottom temperatures were studied at two selected key areas for which the greatest amount of data was available over the entire period of observations: the southeastern Barents Sea and the Malygin Strait in the Kara Sea. Bottom temperature variations in these area have been plotted in decadal diagrams and their linear trends have been calculated. See example temperature patterns and the respective secular trends for southeastern Barents Sea in Fig. 2.

For comparison, we also plotted air temperature variations measured at reference weather stations in the same areas.

The bottom temperatures of the southeastern Barents Sea increased for ~0.4 °C from 1900 to 1998. The respective warming in the Malygin Strait (Kara Sea) was 0.2 °C. The bottom warming may be caused by air temperature increase and, possibly, also by additional input of warm Atlantic water into the Arctic ocean.

The obtained data can be used for qualitative estimates and modeling the state of subsea permafrost.

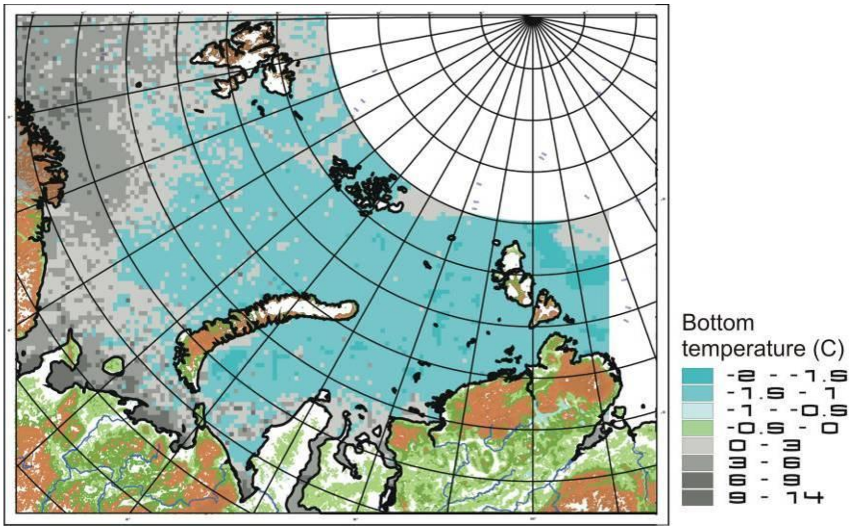

Fig. 1. Map of mean bottom temperatures.

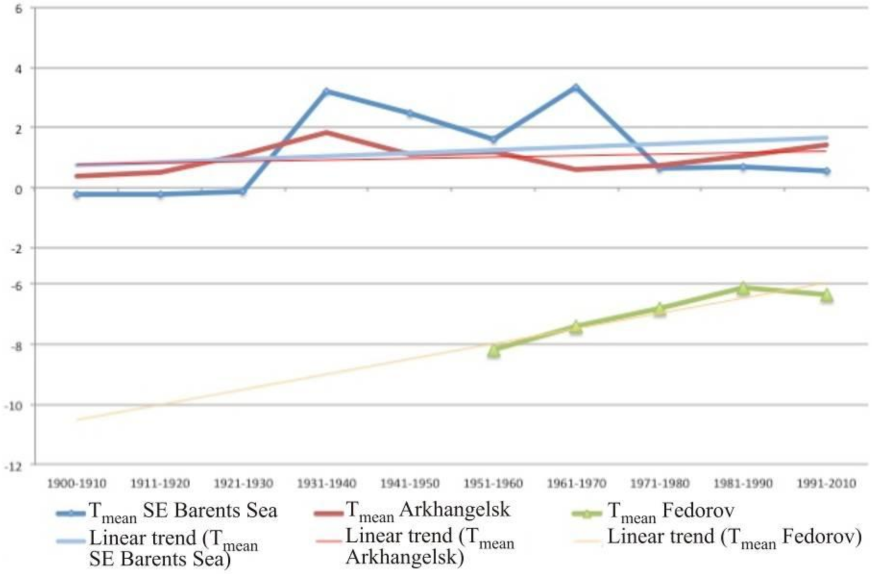

Fig. 2. Secular variations of bottom temperatures in southeastern Barents Sea and air temperatures from Arkhangelsk and Fedorov weather stations.

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Methods for Determining the Optimal Moisture Content of Snow for Construction of the Snow and Ice Roads

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Development and production of hydrocarbon raw materials is the main factor of growth in the traffic of technological and automobile transport in the regions of Russian North, Siberia and the continental shelf of Russia. It requires the creation of an effective transport infrastructure. At present, almost all the transportation is carried out by temporal winter roads within the period of the settled negative temperatures.

Construction of the snow and ice roads is a complex process conditioned by the interaction between devices of construction machines and snow. Key technological operations within this process are: dumping snow onto the roadbed, moistening and compaction of snow. On a mound, snow and ice roads are constructed using the technology of layer-by-layer buildup of a roadbed. This technology is divided into 5-7 different operations. One of them is snow moistening that can be carried out separately or in combination with the other operations such as dumping or compaction. Moistening can be carried out by two ways: bringing of water or thawing of snow. The task is complicated by the fact that it is hard to determine the necessary amount of moisture brought in, even knowing the optimal value of the snow moisture content.

The known methods for determining the snow moisture content can be divided into the direct and indirect ones. The essence of the direct methods is a division of the material examined into the dry substance and moisture. The essence of the indirect methods is measuring the values that are functionally connected with the moisture content of snow. Combining the methods of both groups is carried out along with the combined measuring of two or more parameters of the material examined.

Snow is a disperse system with ice crystals acting as the solid disperse medium and water as the liquid disperse phase. That is why the moisture content can be validly determined by the method of a centrifugation (centrifugal precipitation and filtration).

Widespread methods for direct physical determination of the moisture content are distillation and extraction methods. The disadvantage of the methods offered is a usage of the power fluid that interacts with ice crystals and the water film (covering them) that compose the snow mass. This changes the mass ratio of a three-phased snow system (ice+water+vapor) and complicates the quantitative assessment of the absolute moisture content of the material examined. Usage of the thermogravimetric method as the most accurate method in the other disperse media is not acceptable for snow.

The direct chemical methods for examining the moisture content that are based on the reactions known in analytic chemistry allow us to process the snow examined with a dry reagent reacting only with the water in the liquid phase. Gasometric method for mixing with calcium carbide: $CaC_2+H_2O \rightarrow Ca(OH)_2 + C_2H_2$ at that, the moisture content examined can be determined by measuring the volume of a gas precipitated (volumetric method), the pressure (manometric method); or weighing (gravimetric method). Reactions of calcium hydride with determining the quantity of the hydrogen precipitated: $CaH_2+2H_20 \rightarrow Ca(OH)_2+2H_2$. The solution of the sublimed metallic iodine, non-aqueous piridine and dry sulfurous anhydride in the absolute methanol is also used for determining the moisture content of numerous materials (solid, liquid and gaseous): $J_2+SO_2+2H_2O \rightarrow H_2SO_4+2HJ$. This method is universal. One of the disadvantages of chemical methods is the exothermicity of the process.

Moisture content is assessed by the indirect methods on the basis of measuring the mechanical characteristics of solid materials undergoing changes with changing moisture content: resistance to crushing, resistance to indentation of a metal needle, a cone or a knife; resistance to deforming effort; pressure needed for the compression of a constant mass in a fixed volume; shrinkage of material under the pressure of a piston in a cylinder etc. These methods are characterized by simplicity and low accuracy.

The disadvantage of the indirect methods is a need for obtaining the additional information on material density. Moreover, the measuring result is influenced by the content of the air and the water-soluble components (salt etc.) in the snow.

All the existing measuring methods presuppose the accurate assessment of the absolute moisture content of a material and do not involve determining the optimal moisture content for snow compression. They are all static and the technological process of constructing a snow and ice road requires determination of the moisture content at an indicated moment of time.

One of the promising methods for determining the moisture content of snow is a method of measuring the resistance between the electrodes that are submerged into the snow mass characterized by a zero resistance when it is absolutely dry and characterized by the resistance equaling one unit when it is maximally or optimally moistened. This method is not implemented yet, as it is necessary to detect the values of parameters of the electric field and the distance between the electrodes.

Resolving the issue of obtaining the differentiated assessment of moisture content per a time unit will make it possible to assign the optimal parameters of a moisture content to snow in order to construct a roadbed of the snow and ice road with the necessary parameters of the bearing capacity and density for the given road type.

Influence of Snow Cover on Freezing and Thawing of Permafrost in Nordenskiold Land, Spitzbergen, Svalbard

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During several years, researchers of the Institute of Geography, Russian Academy of Sciences, monitor the permafrost thermal regime and thawing depth on various absolute heights and different relief forms on Spitzbergen Island, Svalbard. The monitoring is mostly carried out in the vicinity of the Russian settlement of Barentsburg (Nordenskiold Land). Land cover conditions and their influence on the permafrost thermal regime, as well as active layer, are studied.

Climate conditions and trends

Climate conditions in Svalbard are characterized by relatively small variations of positive air temperatures in summer and rather large and frequent air temperature variations in winter.

In the warm season with predominantly positive air temperature (June-September), it increases during the last 27 years by 0.58 degrees; however, in the last 10 years it has decreased by 0.3 degrees. Increase of the mean air temperature in the cold season (October-May), according to the trend evaluation, is equal to 2.5 and 2.0 degrees for the two time spans respectively. For 1992-2001, mean air temperature for the warm season is +4.1ºC; for the cold season it is -9.3ºC. For 2002-2011, these values are equal to +4.3 and -7.9 degrees respectively.

Influence of snow on permafrost thermal regime

Autumn/winter season

Measurements of the ground temperature are carried out in boreholes at various altitudes and under different conditions of moss cover. The ground temperature was recorded by thermochrones placed to the depths down to 1 meter for a year, with automatic measurements every 4 hours. The thawing depth varied from 0.6 to 2.7 meters. Under maximum snow depth equal to 2 meters, minimum ground temperature at 1 meter depth is about -1ºC, while under snow depth below 0.5 meters the ground temperature drops to -6ºC. The soil surface temperature under 2 meters of snow cover doesn't decrease below -1.8ºC in the middle of winter.

Snowmelt season

Due to relatively short snowmelt season (as compared to the total snow season), the snow cover affects the permafrost thawing to less extent than its freezing. However, in the regions with large snow depth and not very high positive air temperature, the snow cover variations can be important for the ground thawing. During the snowmelt season, the main role of snow cover is thermal insulation of the soil surface from warmer air and keeping the temperature at the soil-snow boundary at 0ºC. The snow melting in the permafrost zone, especially on complicated relief, takes place gradually and inhomogeneously, and after some time, snow-free areas and snow patches co-exist in the territory. The larger is the distance from the snow patch edge on the snow-free area, the deeper is ground thawing. When evaluating the thaw depth, one usually suggests that the thawing at the given point starts only after the melting of the snow is finished.

The observed data demonstrate that under some snow patches, well before their disappearance, the ground thaws for several dozens of centimeters, which accelerates later thawing after the snowmelt finish. Under the snow patch of 40 cm depth, maximum thaw depth reaches 35 cm. This thawing could be caused by melt water with slightly positive temperature, filtering under the snow patch within the subsurface soil layer from outside the snow patch: all cases of ground thawing under snow were observed under snow patches of either relatively small size or located in narrow gullies near temporary water flows. At the same time, under wide snow patches located on uninundated slopes, no ground thawing took place. Fig. 1 shows typical vertical profile of the ground temperature under relatively small (about 10x15 meters) snow patch. The ground temperature varies from 0°C near the surface to positive values in deeper layers, then again becoming zero at the depth of 35 cm. During the field campaign of July 2011, several dozens of such situations were observed.

The discovered ground thawing under snow patches can change traditional views on thermal and phase conditions of the ground under melting snow cover, and on dynamics of permafrost thawing on mountain slopes.

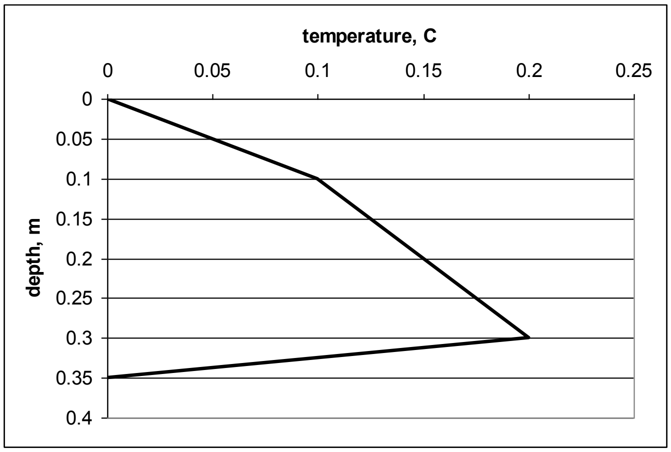

Figure 1. Ground temperature vertical profile under small-size snow patch near Barentsburg, Svalbard, in July 2011.

Amoeboid Protists in Permafrost Soils of the Kolyma Lowland

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In the course of studying protistofauna biodiversity in the samples of three types of permafrost soils (podzolized brown, gley and cryogenic) from the Kolyma Lowland, 107 assumed species of naked amoebas, 14 species of filose amoebas and 4 species of heliozoa were registered. Differences in morphological and species diversity of amoeboid organisms are observed in different permafrost soil types. The number and the species composition of protozoa found in the organic horizon and in the subsequent mineral horizons of the soil profile vary considerably in all the studied soils. There is a high percentage of rare organisms previously undescribed for soils among the found species. Apart from that, new species of amoeboid organisms were observed. Eurybiont species that are usual for soils and freshwater bodies of the entire world are also found in the samples.

Amoeboid protists found in soil are organisms combined into one "functional group" and similar according to the cell organization type (the presence of pseudopodia), despite the fact that they are very diverse and systematically heterogeneous [*Smirnov 2004*]. The group includes testate amoebas (*Teatacea*), axopodia protozoa (*Heleozoa, Radiolaria, Foraminifera*) and naked amoebas (*Gymnamoeba, Filozea*). Testate amoebas were not considered in the study, since the research of their fauna requires certain techniques.

More than 100 species of *Gymnamoeba* (Fig. 1) classified as 14 morphotypes, 12 species of filose amoebas and 6 species of dories (Table 1) were observed in the course of studying three types of permafrost soils (podzolized brown, gley and cryogenic) collected at the Kolyma Lowland. The majority of known families of free-living aerobic amoebas of the *Rhizopoda* type were revealed [*Page 1988*].

Samples of cryogenic soil (50 assumed species) were the richest in terms of morphological diversity of naked and filose amoebas. The number of assumed species in podzolized brown soils and in gley soils is roughly the same and less than in cryogenic soil (40 each).

According to the estimates of the researchers, a considerable part of the gymnamoebae species of soil biotopes is not described at all [*Smirnov 2004*], while the identification of the known species (a total of 206 species were described) requires complex techniques [*Page 1988*]. Therefore, to evaluate the biodiversity of naked soil amoebas, we used the morphotypes system [*Smirnov 2004*]. Naked amoebas morphotypes are a system of recognizing amoeba locomotoric form. Each morphotype is accompanied by a picture, a description of characteristic features and a list of species. Amoebas that belong to the *fan-shaped* type were observed only in cryogenic soil samples, and they had a dominating number. The majority of the observed species of *fan-shaped* morphotype (9 assumed species), according to our assessments, belong to the *Vannella* genus. The most wide-spread morphotypes in three studied soils were *acanthpodial, dactylopodial, eruptive.* Only a few small amoeba species (up to 25 μm) are distinguished in mineral horizons. Their morphotypes are: *eruptive, acanthpodial, monotactic, dactylopodial* and *branched*. Representatives of the acanthopodial morphotype are observed in the mineral horizon of all three studied soil types. Amoebas of acanthopodial morphotype were observed in all samples. 18 species were distinguished. Representatives of *Acanthamoeba* genus (7 species) dominate among them. Acanthamoebas are a widespread and the most typical genus of soil amoebas. In our research, acanthamoebas are observed both in upper organic horizons and in lower mineral horizons of soil profiles. Organisms of the *branched* morphotype are observed in all soils. Representatives of *Acramoeba* and *Leptomyxa* genera belong to it.

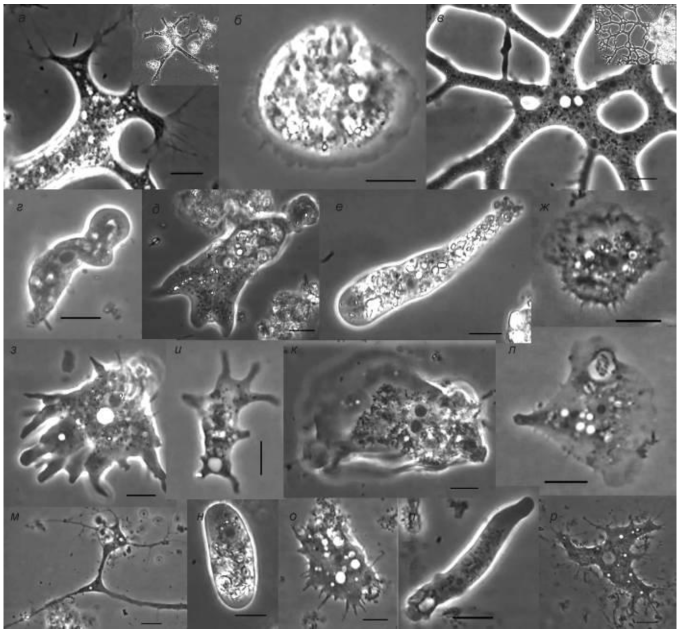

Figure 1 some representatives of *Gymnamoeba* in permafrost soil samples.

Naked amoebas revealed in the samples have small and average dimensions of amoebas - from 5 to 65 μm. The majority of the found species are within the range of 16–25 μm. Small dimensions represent a characteristic feature of the majority of terricolous amoebas.

Apart from that, heliozoa (organisms that are not typical of soil biotypes) were observed in the samples. However, due to the fact that tundra soils have a high moisture content, the presence of fresh water fauna representatives is rather natural.

Differences in morphological and species diversity of amoeboid organisms are observed in different permafrost soil types. The number and the species composition of amoeboid protozoa found in the organic horizon and in the subsequent mineral horizons of the soil profile vary considerable in all the studied soil samples. Due to its geographic location, the entire soil profile is in a frozen state throughout the most part of a year. Therefore, the organisms found in it are subject to the direct exposure to negative temperatures. Soil protozoa have a number of adaptation techniques for long-term survival in such conditions. First of all, this includes the presence of specific cryptobitic stages – rest cysts in the life cycle – that are accompanied by morphological, physiological and biochemical changes in the cell.

Table 1. The distribution of the number of the assumed species of naked amoebas in samples of permafrost soils from the Kolyma Lowland, according to morphotypes.

Morphotype	Podzolized brown soil		Cryogenic soil		Gley soil	
	T	Bfh$_2$	Ah-Bh	B$_1$	Ah	B$_1$
polytavtic					1	
orthotactic			1			
monotactic	4		4	1	2	
eruptive	2	1	3	1	6	
flabellate	3				2	
lens-like	11		2		5	
flamellian	2		3			
striate						
rugose			1			
lingulate	2		3		1	
lanceolate						
fan-shaped			12			
mayorellian			4			
dactylopodial	2		4	1	3	1
acanthpodial	3	3	5	3	4	1
branched	2		1		3	1
undetermined	3		3		1	
heliozoa			2		4	
filose	1	1	7		3	1
Total:	**35**	**5**	**55**	**6**	**36**	**4**

Our research showed that tundra soils are successfully colonized by heterotrophic protists, and revealed diverse and rich communities that are heterogeneous in composition and number in various ecological niches. There is a high percentage of rare organisms previously undescribed for soils among the found species. Apart from that, new species of amoeboid organisms were observed. Eurybiont species that are usual for soils and freshwater bodies of the entire world are also found in the samples.

Tundra permafrost soils are an unexplored area for future works to determine the world fauna of protozoa and to study adaptation capabilities of unicellular eucaryotic organisms.

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Application of Permafrost CH_4 Concentration in Cryolithology

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Introduction

Studying the core sets limitation on ability to determine the layers it consists of. Differentiating the section becomes easier when the benchmark features of some of them are clear. Growing data on peculiarities of the composition and structure besides floristic and faunistic findings allowed figuring out the features of formations to be used as the benchmark in permafrost evolution. The biogenic methane found in permafrost [*Rivkina et al., 2007*] evidences of the processes during sedimentation and cryolithogenesis. In this paper it is addressed among the other features of permafrost as the formation specific feature.

Materials and Method

The database of 400 samples of late-Cenozoic permafrost collected at Kolyma Lowland for the last 30 yrs was compiled. The samples were taken from the boreholes set nearby the well-studied outcrops characterized with paleomagnetic, cryolithology, paleonthology, spore-pollen and other researches, and thus the formation was predefined. For each record representing 0.05-0.3 m of the core of 0.05-0.1 m in diameter the grain size, Ca^{2+}-Cl^{-} concentration ratio (Ca/Cl), the dry residue, pH, total organic carbon (C_{org}) of air-dried samples, and methane concentration ($C(CH_4)$) of intact permafrost were the variables analyzed statistically. Analyzed were the 100 samples from Yedoma, 100 from Olyor formation, 40 from Holocene Alasses, 40 from Khalerchinskaya tundra sands, 30 from Holocene alluvium, 40 from Keremesit formation, including 20 samples from Maastakh sands, 20 from Holocene cover-layer, 20 from Kon'kovskaya marine formation, and 20 from the Pliocene Tumus-yar formation.

To define the remarkable variables within each formation the stepwise nonparametric discriminant function analysis based on the F-test was applied. The Wilkinson-λ criterion of significance was used.

Results and Discussion

The highest variance among all the sediment formations is found for sand and silt grains content, however it is due to the extreme values, as seen on the Figure. The largest interquartile range is typical for the $C(CH_4)$ and silt content. C_{org} and clay content was found insignificant for discrimination based on F-significance of 1. The criteria of significance for variables used are shown in the Table and level of classification of the sediments is shown in the Table.

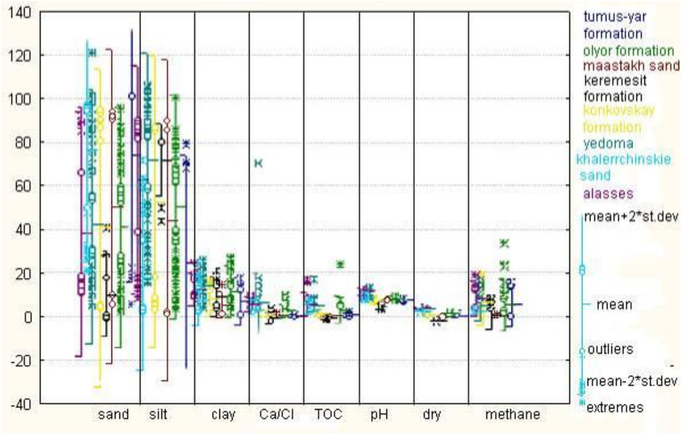

Figure. Variables characterizing features of the Late Cenozoic permafrost used in this study.

Table. Significance of variables used in discriminant analysis.

	$C(CH_4)$	Ca/Cl	Silt	Dry residue	Sand	pH
Wilkinson-λ	0.67	0.46	0.32	0.21	0.15	0.11
Classification accuracy, %	28	29	30	38	45	39

Based on Wilkinson-λ the variables are iteratively introduced to discriminant analysis. The $C(CH_4)$ has the potential to separate Yedoma, Maastakh sands and Khalerchinskaya tundra sands from other sediments. Ca/Cl – the indicator of marine or terrigenous genesis, has no large impact on the overall accuracy probably due to the relatively low number of marine samples. So does silt concentration as the result of the high silt content in all the sediments formations. Dry residue, which is the measure of salinity adds on another 8% to classification accuracy. The sand concentration serves good to distinguish Maastakh sands from Khalerchinskaya tundra sands, and separate Tumus-yar formaton from other sediments. The last variable used is the pH which in turn decreases the classification accuracy.

Calculated classification functions based on the roots of discriminant analysis equations for every sediment formation shows $C(CH_4)$ to be of the highest significance (0.7-1.2) among other variables (5.2-27.1). Lack of methane in sediments was previously shown to be the paleoindicator of permafrost dynamics [*Rivkina & Gilichinsky 1996*]. The proposed cryogenic mechanism of methane conservation documented basing on the lab and field studies explains natural occurrence of biogenic methane in permafrost [*Kraev 2010*]. Our study shows that methane concentration is effective for separating the Holocene cover-layer which cover Yedoma, and Yedoma from other types of sediments it is usually covered with or lie on. Same could be said for the Khalerchinskaya tundra sands, covering Olyor formation or Maastakh sands, however their sandy composition is rarely met among the deposits under review.

Nevertheless, for formations containing methane, this could not be the indicator to distinguish among them. Other variables used in our study have much higher coefficients of classification functions, with Ca/Cl and sand contain being the secondly significant for determination.

Same analysis has been conducted at the same set of samples grouped into 6 categories based on their genesis and cryogenesis. The analysis includes: syncryogenic alluvium, epicryogenic fluvilacustrine sediments, Ice Complex, Alas Complex, epicryogenic marine, syncryogenic deltaic deposits. Methane was among the 4 highest in significance variables in determining of the sediment genesis with classification equations coefficients of 0.04-1.66 for silt and clay contain, Ca/Cl, and dry residue for epicryogenic alluvium. Nevertheless, sincryogenic deposits had higher coefficients for $C(CH_4)$ (0.27-0.43) than epicryogenic (0.64-0.69).

Conclusions

Among the features conventionally used in deposits description the methane concentration stays among the most significant parameters characterizing permafrost. Absence of methane is often indicates the syngenetic formation, and could be applied to correctly stratify the core. When found in non-trace amounts, permafrost methane tends not to indicate the genesis, but permafrost formation characteristics, which could alter its formation rate, and the rate of its transition to permafrost state.

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Rock Varnish on Granitoids in East Antarctica: Product of Endolithic Pedogenesis?

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Introduction

Rock varnish and endolithic organisms being quite widespread phenomena on the Earth are very well studied apart however their interaction and possible cogenesis had never been particularly explored. Endolithic organisms – are important primary producers in the ice-free areas (oases) of Antarctica [*Friedmann 1982*] inhabiting structural cavities in the superficial rock interior. The other common feature of Antarctica oases is the red-brownish colour of solid rocks (granites, gneisses etc.) which is traditionally attributed to the presence of Fe-Mn-coatings on the surface (rock varnish).

Being initially described by A. Humboldt in the middle of the XIX century the rock varnish still remains one of the most disputable feature of superficial layers in solid rocks exposed to extreme conditions (deserts, polar regions, high mountains). According to R. Dorn [*1998*] there are at least 4 conceptual models of varnish formation: biotic, abiotic, polygenetic and silica binding. Most models accept accretion as the principal mechanism of varnish growth and ignore its possible in situ genesis. However, one of the first studies of varnish in Antarctica [*Glazovskaya 1958*] suggested that it is an autochthonous weathering product; this statement was further enhanced to the “staining” concept [*Campbell & Claridge 1987*]. It is more and more evident now that the varnish could have a complicated genesis and sometimes we deal with morphologically similar substances gathered under the uniform varnish “umbrella” but generated by different processes e.g. accretion, in situ weathering, pedogenesis etc.

Both phenomena – endolithic organisms and varnish – have a substantial potential to be studied by methods and methodology of soil science: endolithic organisms as a factor and varnish as a possible product of pedogenesis. The main objective of this study is to explore the interaction between endolithic organisms and solid rock and their possible role in rock varnish formation.

Objects

The samples were taken from the surface of granitoids in Larsemann (S69˚30’, E76˚20’) and Thala (S67˚60’, E49˚00’) oases in East Antarctica. Each sampling point included 3 major components: a) exfoliation crusts with endolithic community on its inner surface and varnish films on external surface, b) mineral thin fraction and endolithic biomass from fissure network under exfoliation crust, c) initial rock under crust, endolithic community and fine earth.

Results

Our explorations in coastal oases of East Antarctica at field and microscopic scales showed that such system as “endolithic organisms-rock-weathering products” has all features to be denominated as “soil”: (1) rock layer exposed to external abiotic factors; (2) this layer is inhabited by living organisms synthesizing and decomposing organic matter (OM); (3) being induced by biotic and abiotic factors the initial lithomatrix is transformed in situ, the transformation products (e.g. fine earth) are retained and/or taken away, the vertical heterogeneity (microprofile) is formed. Organo-mineral horizons of endolithic soil contain 0,2-3,3% C and 0,02-0,47% N. ^{14}C mean residence time of OM reaches 480±25 y BP, δ^{13}C= -23,7– -21,0 ‰. Major pedogenesis products are numerous Fe-C- Si-Al- S-Cl-Ca-Mg-containing bio-coatings which cover cavities inside the rock. Main binding material amorphous silica and Al with incorporated bio-mineral detritus. C content in coatings is 10-50%.

The morphology by scanning electron microscope and elemental composition of varnish on rock day surface correspond very well to those observed in endolithically generated organo-mineral coatings (Fig. 1): 1) the varnish films also contain biota (dead or resting), 2) biogenic botryoidal structures of varnish are similar to patterns observed in biofilms in interior of endolithic system, 3) both types of films (varnish and endolithic organo-mineral coatings) have strong amorphous Si-Al component; Fe, Ca and S are accumulated.

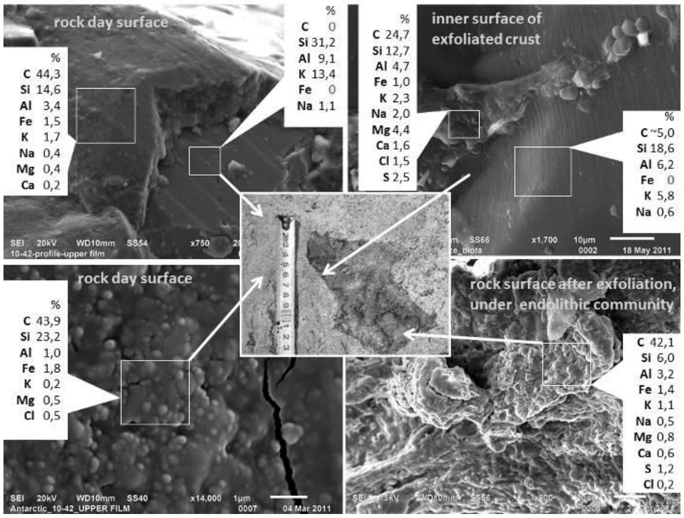

Figure 1. Rock varnish on the surface (left) and endolithic soils (right) and its elemental composition by the microprobe.

Thus, certain types of rock varnish could be the products of endolithic pedogenesis exposed after exfoliation and transformed by external factors. This hypothesis doesn’t claim to explain all rock varnishes (e.g. formed by accretion).

The formation and development of endolithic system (soil) in time as well as its elimination is presented on Fig. 2.

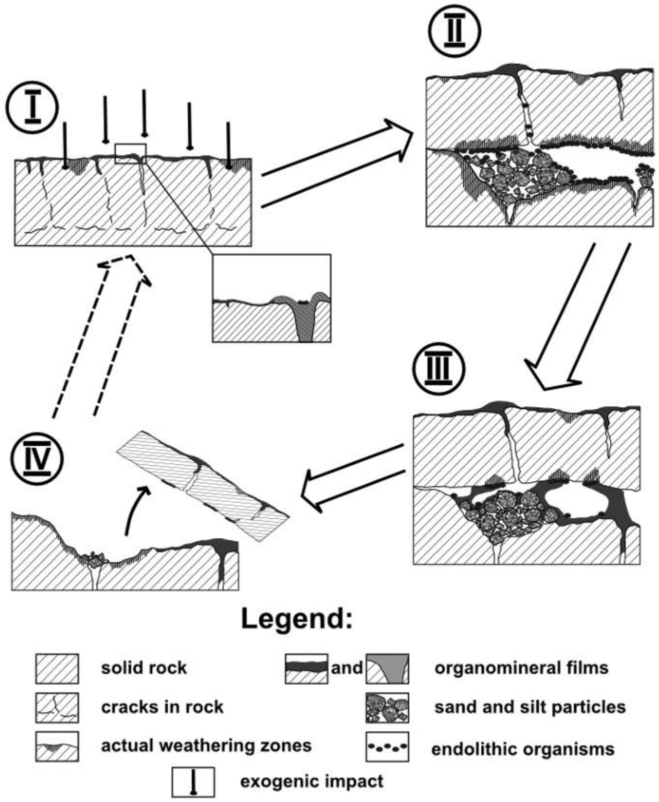

Figure 2. Hypothetic structure and transformation model of endolithic system.

Phase I describes exposed rock surface partly or completely covered by amorphous organo-mineral Fe-C-Al-Si-films of varnish. The rock and films experience the impact of exogenic factors; physical disintegration progresses, the network of microfissures is established including those subparallel to the day surface. The fissures are being inhabited by endoliths.

Phase II – functioning of endolithic community results in physical and biochemical weathering, the mineral grains are disassembled and arranged as a fine earth material, the cracks are enlarged. The endolithic biomass covers most surfaces of cracks and fissures and partly mineral grains within fine earth, the zones of intensive biochemical transformation of rock are formed.

Phase III – the weathering products are represented by organo-mineral films which cover interior surfaces of the rock especially under endolithic community. The growth of endolithic biomass is observed, the mass of fine mineral fractions increases as well as the enhancement of rock by fissures.

Phase IV – the contact between superficial crust and massive rock is weak enough to let the exfoliation induced by gravitation or wind erosion occur. The exfoliated crust with endoliths remains and biofilms being partly destroyed falls out into accumulative positions in a landscape. The fine earth is blown away by the wind and could be transferred on significant distances. After exfoliation the endolithically generated organo-mineral films are exposed to the exogenic factors. Some mechanisms making the film more “mature” are launched: the film is partly abraded and polished by wind, its organic component is transformed, some components (e.g. Fe) are oxidized; the mechanism of “classical” varnish accretion could also play a role in film increment and transformation. In this form, being a polygenetic formation, the exposed organo-mineral film appears to researcher of red-brownish varnish in Antarctica oases. The endolithically generated varnish could be partly or completely eliminated by wind abrasion which influences the colour of rock.

Conclusion

1. The system consisting of the following elements a) endolithic organisms, b) granitoid rock, c) weathering products has all features to be denominated as a “soil” where the initial lithomatrix is transformed in situ by biotic and abiotic factors, the transformation products (e.g. organo-mineral films and fine earth) are retained and/or taken away, the vertical heterogeneity (microprofile) is formed.

2. The major products of endolithic pedogenesis are organo-mineral films covering the surfaces inside the rock. Due to gravitation most of the coatings (films) are accumulated on the upper surface of the solid rock directly under the crust which will be exfoliated in the future. These coatings form a specific soil microhorizon (1to10 µm thick).

3. Certain types of rock varnish on granitoids in Antarctica appear to be the endolithically generated organo-mineral coatings, or in other words, the former/paleo horizons of endolithic soils exposed and transformed by exogenic factors after exfoliation.

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Monitoring of the Active Layer in the North of Middle Siberia

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Introduction

One of the main engineering and geocryological problems of recent decades is permafrost change caused by climate fluctuations. Over the last 30-50 years the temperature increased by 1°C but in some high latitude regions its increase reached 5°C [*Pavlov 2005*]. In the cryolithozone the warming induces, in the first place, changes in temperature regime of grounds and in thickness of a seasonally thawed layer, which, in its turn, leads to a decrease in load-bearing capacity of frozen-in foundations, to growth of frost heave forces and, accordingly, to development of deformations of buildings and structures.

The depth of a seasonally thawed layer is a "mirror" of permafrost. The development of seasonal thawing is caused by both external (climate, borderline conditions) and internal (composition and characteristics of a ground layer) factors.

Methods

The CALM program – Circumpolar Active Layer Monitoring [*Brown et al. 2000*] – was developed for assessing the dynamics of a seasonally thawed layer and its relationship with observed changes of climate. This program is implemented since the 1990s and presently includes about 170 observation stations [*Shiklomanov et al. 2008*]. Data about differentiation of seasonal thawing in various landscapes of various elevation are supposed to be of great value.

Monitoring of seasonal thawing at the site (index R-32) near Talnakh is conducted since 2005 [*Zepalov et al. 2008*]. Measurements are performed annually at the end of a warm period by a metal permafrost probe with a division value of 1 cm. The number of measured points is 121 (with an interval of 10 m). In 2010 and 2011 additional measurements were performed at the middle of summer (in July). In 2007, 2009, 2010 and 2011 site leveling was performed, which allowed the researchers to get the overview about relief changes – the so-called "surface breath".

Study area

The Talnakh site (R32) is located in the Norilsk area (Norilsk-Rybninsk valley bordered at the north by the Putorana plateau). The climate of the studied region is subarctic. The average annual temperature of the air during the period of observations is -9,8°C. The precipitation rate is rather low and reaches 300-400 mm [*SNiP 23.01.99, 2001*]. The site is located on the Valkovskaya lacustrine-alluvial terrace [*Sheveleva & Khomichevskaya 1967*], on a watershed, and represents a gently undulating surface with a small thermokarst lake and hillocks. The territory is located in a forest-tundra zone but the test area is characterized with tundra geographical complexes.

Results and discussion

The detailed studies of landscapes resulted in distinguishing 6 geographical complexes within the site:

1 – well-drained hummock-type surface covered with light forest composed of alders, larches, gramineous plants and sedge in the herb layer;

2 – spot-medallion tundra, with dwarf shrubs, sedge and mosses in fractions and on ridges;

3 – hummock tundra with spot-medallions covered with shrubs, dwarf shrubs, sedge and mosses;

4 – drainage ravines, thermokarst depressions, cotton grass-sedge-moss tundra;

5 – frost heave with dwarf shrubs, sedge and moss populations;

6 – thermokarst lake.

The growth of depth of a seasonally thawed layer is observed over the period of measurements (2005-2011). However, this trend is ambiguous, as it is possible to mark the years, when reduction in the active layer (2007 and 2009) was observed. The comparison of data on the seasonal thawing depth with the sum of positive degree-hours ("thawing index" - DDT) shows that climatic factor is the main one. Table 1 shows the change of the average thawing depth throughout the site and in basic types of landscapes and a sum of positive degree-hours for the period of observations.

Table 1. Average depth of thawing throughout CALM site

Year	DDT	1	2	3	4	5	Av.
2005	927	85	80	81	78	120	81
2006	964	105	91	91	89	79	91
2007	1107	98	92	93	85	79	90
2008	1073	108	95	96	89	87	94
2009	978	103	94	94	87	83	92
2010	793	103	89	91	97	85	93
2011	1046	109	93	96	95	87	96

As Table 1 shows, variation of the seasonally thawed layer depth over the observation period is about 15 cm. "Influence efficiency" of positive degree-hours varies from 0.08 cm/°C*hour to 0.11 cm/°C*hour. It should be noted that this parameter had the maximum value in a relatively cold (but not the most humid) summer of 2010, while in the warmest year of 2007 the "influence efficiency" was minimum. Thus, the relationship of the seasonally thawed layer depth and the thawing index is nonlinear and corrected by other factors (precipitation in a warm period, moisture accumulation in grounds at the end of the preceding thawing season, vegetation etc.). The warmest summer [*2007*] does not correspond to the greatest thawing depth, which is caused by favorable conditions for vegetation and an increase of its protective properties. The results of field measurements of the seasonally thawed layer depth in different conditions are given in Fig. 1; maximum depths are registered annually in the "warmest" geographical complex – within well-drained hillocky surface with alder-larch light forest.

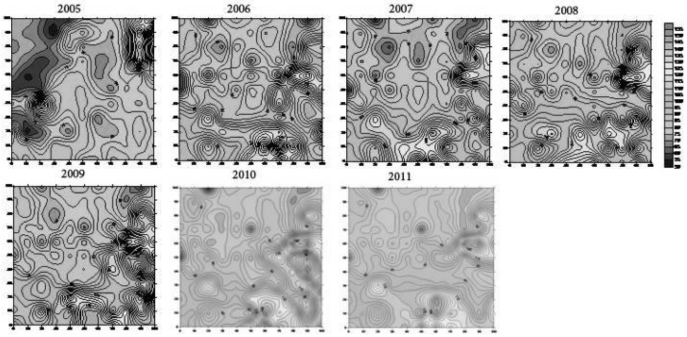

Figure 1. Map charts of permafrost table at the CALM site for the period of observations.

Surface leveling (relative to point 1) made it possible to find out the differences in settlements of thawing grounds for various geographical complexes; Table 2 presents comparative values for 2009 and 2011.

Table 2. Change of microrelief in basic landscape types.

Geographical complex	Mean elevation, m	Change of elevation, as compared with 2009, cm	Change of seasonally thawed layer, as compared with 2009, cm
1	66.36	8	6
2	66.97	9	-1
3	66.93	9	2
4	66.91	8	8
5	67.55	2	4
Entire site	66.91	8	3

It is seen from Table 2 that in 2011 the surface elevation in all landscapes, except for spot-medallion tundra, increased. It is connected with the fact that the summer of 2010 was very humid and rainy, the grounds were saturated with water before freezing and this led to an increase in the elevation of the surface through heaving. In summer during thawing of grounds moisture migrated mainly to the seasonally thawed layer base and this induced the decrease in consolidated settlement (through thawing of ice and compacting of thawed ground), that is why in 2011 the general surface elevation growth was observed, although that season was a slightly warmer than 2009.

Conclusions

Seasonal thawing of grounds (depth and settlement) depends not only on a thawing index but also on moisture regime in the current and preceding warm periods. The differences in the seasonally thawed layer depth can reach 30 - 40 %, depending on the landscape structure of a site.

Acknowledgments

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Thermal Erosion and Gullying in the Taz Peninsula

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Introduction

The reported data on thermal erosion and gullying are based on field studies in July 2009 at site UKPG-1, Yamburg Town, within cluster 126 of gas wells. The study area is a rapidly developed gas-condensate field, with numerous exploratory wells connected via pipelines to works where gas is prepared for transportation, and with many motor roads. The infrastructure facilities have been built following the first principle of Building Code [*SNiP 2.02.04-88 1990*], implying conservation of permafrost.

Destruction of vegetation and soil, as well as changes caused to the natural runoff of surface and ground waters into the active layer by making embankments for roadways and engineering structures induce additional swamping and moistening of soils and accelerate the thermal erosion and gullying processes.

Methods

During the field work, two gullies were documented: one (No. 1) already arrested (filled with sand) and the other (No. 2a) currently developing. The documenting targets in the latter included landscapes and lithology of soils at different points and thaw depths, measured from the head down to the fan. At the same time, wedge ice was studied in an outcrop of the Ngarka-Poilovoyakha River right bank, as well as a large peatland ice-wedge polygon system. The site is located on the river bank, 400 m west of the motor road turn to gas well cluster 122B.

The elevations above sealevel are from 18 m (river water table) to 30 m. Gully 2a is located at 65 º 57′ N, 75 º 52′ E. The local environment experiences considerable anthropogenic loads over a large part of the studied territory [*Grebenets & Pavlunin 2007*].

Results and Discussion

Gully No.1 located 150 m upstream of gully 2a along the Ngarka-Poilovoyakha has been already filled with sand and a tray for collecting and withdrawal of meteoric water was made on its gathering surface, in order to mitigate the erosion hazard. The gully outlet has been also filled and supported with a wall consisting of several rows of upright concrete slabs. The slabs are reinforced with a metal framework which, in turn, is attached to anchor piles positioned 7.5-12 m far from the wall.

Examination of the protective engineering structure and the territory around gully 1, as well as logging in boreholes drilled in its vicinity, gave the following results:

(a) the reinforced concrete slabs have been pressed 0.5 m outward (toward the river) under a static load from frost heaving;

(b) the piles that hold the metal framework likewise tilt toward the river;

(c) an ice lens has formed in fill-up soil at the foot of the support concrete slabs;

(d) a young river-ward draining gully, up to 0.5 m wide, is forming along thermal contraction cracks, 5-10 m west of the manmade tray. It may give rise to a new gully system unless the appropriate mitigation measures are undertaken in the nearest future.

The site of field studies is located on coastal terrace III which consists of Zyryanka Formation sediments deposited during the Kazantsevo interstadial and is locally overlain by peatland facies.

The catchment area of the gully is flat, with slope commonly no more than 3 - 5º. The plant communities are *Betula nana, Empetrum nigrum*, and *Citraria islandica* in the left side of the gully and mostly *Carex* in the right side.

The coastal terrace deposits are mainly more than 10 m of fine-grained sand, with scarce lenses and interbeds of silt-size sand. The sand is overlain by peat, 0.7-1.6 m thick along the western side of the gully and up to 3.1 m in the east, in its head part.

The outlet of gully 2a opens into a sand bar of the Ngarka-Poilovoyakha River (Fig. 1), composed of layered alluvial primitive soils and silt-sand alluvium with sporadic grass communities.

Fig. 1. Outlet of gully 2a.

The active part of the gully spreads 133.5 m downward [*Ivanov et al. 2007*].

The gully sides are subject to active thermal contraction cracking, slope processes (flow and slumping of edges and surfaces of slopes), and incision along the existing drainage pathway; the main gully is branching, with small side gullies incising further into its sides.

In the eastern flank of the gully, near the first gas line train, there is a nascent thaw sink which may evolve into another side gully and strip the support piles of the pipeline.

A perennial stream was discovered in the gully floor during the field work. We measured the mean thaw depth (active layer thickness), the gully width and depth, and the thalweg width. They were (on 18 July 2009) 32 cm, 560 cm, 80 cm, and 90 cm, respectively, at the gully head and increased progressively toward the outlet. Namely, 82 m far from the head, the measured parameters were: thaw depth 95 cm, gully width 19 m, gully depth 5.7 m, and thalweg width 0.4 m.

The gully changes markedly its appearance at the latter measurement site: its sides become steeper and more rugged, and sand accumulates on their surfaces. Another side gully, covered with grass, is forming at the site and is likewise developing its own waterway. The slopes become overgrown, mostly with sedge communities. Vegetation is not very thick in the middle of the gully but is more prominent near the fan (vegetation degree reaches 60-70 %). Soils change from peat (at the gully head) to sand slopes (near the outlet). The fan area has the following parameters: thaw depth 80 cm, gully width 28.4 m, gully depth 7.8 m, and thalweg width 1 m in the immediate vicinity of the place where it is washed out by the Ngarka-Poilavayakha. In its middle and lower reaches, the gully has a typical V-shaped transversal profile.

Studies in the riverside outcrop revealed a system of ice wedges (up to 4 – 6 m deep) in thick peat lying over ice-rich loamy sand and silt-size sand. The zones of thermal erosion nucleation were found out to occur within the ice-wedge system.

Conclusions

Gully 2a is developing very rapidly. It has reached its size actually for 5 – 6 years and is currently an erosional complex that poses stripping risks to the support piles of the pipeline. The thermal erosion is accelerated by uncontrolled water discharge from the gas-processing works. Furthermore, gullying is maintained naturally by high snow thicknesses and abundant floodwater.

Urgent mitigation measures are required to inhibit the growth of the young active gully system.

Erosion hazard arises along the numerous roadways that link the gas production sites of the Yamburg field: the neighbor areas become flooded and favorable conditions form for thermal erosion of loose silt-size sand and ice-rich frozen ground.

Acknowledgments

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The Ecological Problems of the Territory of Oil and Gas Industry in the Cryolithozone of the Middle Ob Area

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At the beginning of the 1960s the Middle Ob area began to be actively developed for exploitation of oil-gas fields. During this period the Tyumen Territorial Administration for Hydrometeorological and Environmental Monitoring carried out hydrological and hydrochemical observations on oligotrophic swamps of the Middle Ob area (Vasyuganskoe, Samotlorskoe). Despite the availability of numerous hydrological and hydrochemical data, they are not summarized in publications. Therefore, we analyzed and summarized materials of hydrochemical observations performed for small rivers fed by flows from swamps of oil and gas regions of Western Siberia, such as: the Lyamin, the Trom-Yugan, the Vakh, the Bolshoy Yugan, the Vasyugan. The watershed of these rivers contains large fields, such as Lyantorskoe, Samotlorskoe and many other stationary water objects.

Data for two observation periods – 1960-1970 and 1980-1985 – were summarized. These data included samples of 100 and more observations of basic elements of chemical composition (pH, total salt content, basic ions, ferrum content, color index as well as nitrate and nitrite nitrogens). After statistical processing of available data two types of river water were distinguished: type I (the Vasyugan and the Bolshoy Yugan rivers) with increased salinity (132 mg/l) and type II (the Vakh, the Trom-Yugan and the Lyamin rivers) with ultra-low salinity (40 mg/l), they are affected by swamp flows to the greatest extent, which influences pH, general salt content and ferrum content.

The difference in chemical composition of river waters of two types is explained by physical and geographical peculiarities of the watershed area: the left bank of the Ob features numerous low-land bogs that are characterized with increased salt content, weak acidic reaction (pH of up to 7). The right bank features prevailing oligotrophic (upland) swamps the waters of which are characterized with decreased salinity and acid environment (pH of up to 5.3), see Table 1.

Table 1. Spread of swamps in the Middle Ob area

River	Swamp type	Total salt content mg/l	pH	Fe, mg/l	Color index, degrees
Vasyugan	lowland	162	6.9	0.8	120
Bolshoy Yugan-	lowland	105	6.8	1.4	122
Vakh-	upland	50	5.6	1.6	70
Trom-Yugan-	upland	37	5.6	1.6	72

The composition of surface waters is significantly affected by the anthropogenic factor that is primarily associated with oil prospecting and extraction. Economic development and exploitation are accompanied by discharge of drilling muds and waste waters with increased content of sodium salts (chlorides and borates) and heavy metals. Extraction and transportation are often connected with accidental oil spills that lead to an increase in oil products content in swamps, lakes and rivers – water receivers.

Based on the performed differentiation of chemical content, it is suggested that river waters of type II with acidic pH can cause a fast pipeline corrosion. Accordingly, corrosion-resistant materials and measures for decrease in salinity of disposed drill waters are required.

For watershed territory of type I with weakly acidic pH the most negative impact on ecological stability of the oil production region is made by drill waters that are normally used for pumping oil and gas, which, in its turn, disturbs ecological balance and leads to formation of dead areas.

In order to minimize adverse consequences of the use of drill waters, the latter are subject to treatment reducing the content of reaction salts (sodium tetraborate) contained in drill waters.

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The damage evolution equation of frozen Lanzhou loess

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Instructions

The constitutive relationship is very important in the field of frozen soil research. Some scholars studied the constitutive relationship including the damage evolution rule [*He et al, 2000; Zhu et al, 2010*], which is deduced on the base of hypothesis.

The Computerized Tomography (CT) technology can quantitatively research the characteristics of testing layer of samples. Furthermore, it has the advantage of multi-layers scanning and undamaging. So many researches pay greater attention on it [*Ma et al, 1997; Yang & Zhang, 1998; Lai et al, 2000; Liu et al, 2002; Ge et al, 2004*]. In this paper, the damage variables are calculated and the damage evolution equation is studied according to the result of CT tests.

Data and Methods

The material used in this investigation is sampled from the Donggang town of Lanzhou City, named as Lanzhou Loess here. The liquid limit and plastic limit is 29.36% and 14.92% respectively. The particle distribution curve is shown in Figure 1. It is classified as CL based on the Unified Soil Classification System. All samples are remolded and water-saturated. The nominal size of soil specimen is 61.8mm in diameter by 125mm long. The water content and dry density is 22.8% and 1.63g/cm^3. The test temperature is -5.1, -1.7, -1.2 and -0.6°C respectively.

The equipment used in this test is SIEMENS SOMATOM X radial CT (Figure 2), belonging to State Key Laboratory of Frozen Soil Engineering. Its resolving power is 0.35 mm×0.35 mm, discriminable minimum volume is 0.12 mm^3, and density contrast resolving power is 0.3% (3Hu).

To each sample, 5 layers from the top down are scanned, during the process of uniaxial compress test. The stress-strain curves and CT value VS strain curves can be obtained.

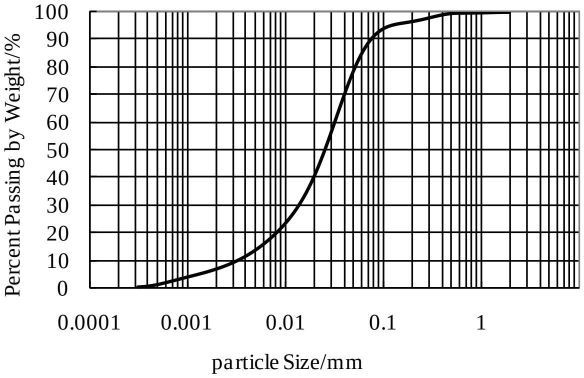

Figure 1. The particle distribution curves of test soils

Figure 2. The CT Scanning System with triaxial test apparatus

Results and Discussions

Figure 3 show the stress-strain curves of frozen Lanzhou Loess under different temperature conditions. Figure 4 show the CT value change curves. When the strain change in the range of 0~0.7%, the CT number increases lightly; When the strain change from 0.7% to 6.5%, the CT number is almost unchanged, and plastic strain begin occur; When the strain exceed 6.5%, the CT number decrease obviously, and damage begin occur; When the strain reach 10%, CT number decrease speedy, and failure in samples occur. So, as to frozen Lanzhou Loess, the yield strain is 0.7%, damage strain critical value is 6.5%, and failure strain critical value is 10%.

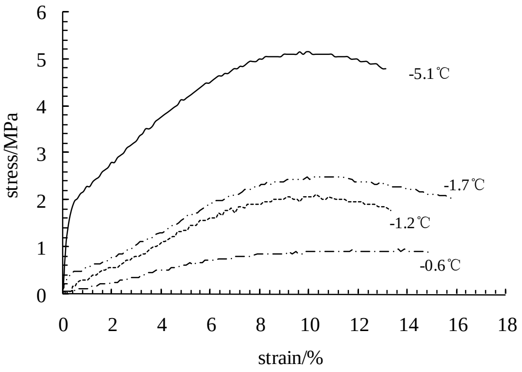

Figure 3 The stress-strain curves of frozen soil

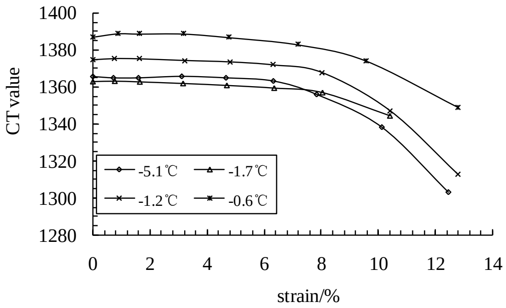

Figure 4 The CT value VS. strain curves of frozen soil

Then the CT value is used to define damage variable using following equation. The damage variables are shown in Figure 5.

$$D=\frac{1}{m_0^2}(1-\frac{H_j}{H_0}) \qquad (1)$$

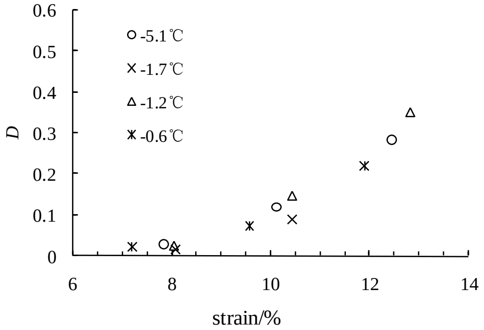

Figure 5 The relationship between damage variables and strain

The strain ε consists of elastic strain ε^e and plastic strain ε^p. Figure 3 shows that lower the temperature, higher the elastic mould. The plastic strain of each sample can be calculated by $\varepsilon^p=\varepsilon-\varepsilon^e$.

The continuous variable is defined as follow.

$$\varphi=1-D \qquad (2)$$

The relationship between continuous variables and plastic strain are shown in figure 6, which can be described by following function.

$$\varphi^2=a\varepsilon^p+b \qquad (3)$$

Where, a and b are material parameters, the value is shown in table 1.

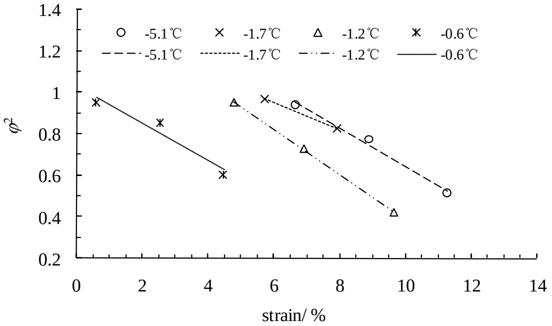

Figure 5 The relationship between continuous variable and strain

Table 1 The value of material parameter a and b

Temperature (℃)	-5.1	-1.7	-1.2	-0.6
a	-0.0933	-0.0654	-0.1094	-0.0903
b	1.5769	1.3436	1.4774	1.034

So the relationship between damage variable and plastic strain is as follow.

$$D=1-\sqrt{(a\varepsilon^p+b)} \qquad (4)$$

Above function is also the damage evolution equation for test frozen Lanzhou Loess.

Conclusions

According to the CT scanning result during the uniaxial compress test for frozen Lanzhou Loess, following conclusions can be drawn. As to frozen Lanzhou Loess, the yield strain is 0.7%, damage strain critical value is 6.5%, and failure strain critical value is 10%. The damage evolution equation can be described as $D=1-\sqrt{(a\varepsilon^p+b)}$.

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Joint Russian-German Research on Terrestrial and Subsea Permafrost in Siberia - Results, Potentials and Perspectives

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In the exploration of the Russian Arctic German-spelling names of scientists occurred since the 18th century. Geographers and geologists like Alexander von Middendorff, Ernst von Bär, Alexander Bunge, Eduard von Toll studied the frozen ground in Siberia and established by doing so permafrost research.

Today joint Russian-German research continues in Siberia, mainly hosted by the Mel'nikov Permafrost Institute (Yakutsk), the faculties of Geology, of Geography and of Soil Science of the Moscow State University (Moscow), the Arctic and Antarctic Research Institute (St. Petersburg), the Institute of Physicochemical and Biological Problems in Soil Science (Pushchino), and the Alfred Wegener Institute (Potsdam), the Institute of Soil Science (Hamburg University). The major scientific topics of this long-term research are permafrost archives, paleoclimate and landscape dynamics; coastal dynamics and subsea permafrost; permafrost degradation and modern changes of permafrost landscapes. More than 30 joint expeditions since 1993 took Russian and German scientists to Central and East Siberia (Figure 1).

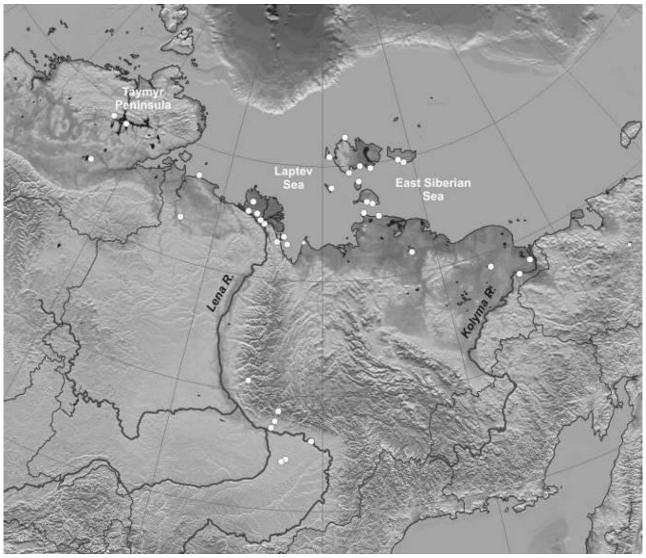

Figure 1 Study sites of Russian-German expeditions for permafrost studies since 1993 *(map compiled by G. Grosse)*

Past and Current Projects

Russian-German permafrost research was realized and will be continued within the frame of joint projects of Russian and German funding agencies (Table 1). In addition, several projects of young Russian scientist were realized within the frame of the Otto Schmidt Laboratory in St. Petersburg.

Table 1. Selected joint Russian-German permafrost research projects since the 90ies.

1993-1997: Frozen geochemical barrier: its influence on geochemical processes in permafrost landscapes (INTAS)
1994-1997: Environmental dynamics in middle Siberia during the late Quaternary (BMBF)
1998-2001: Late Pleistocene history reconstruction based on the massive ground ice origin in the Arctic coastal zone (INTAS)
1998-2002: System Laptev Sea 2000: Accounting of greenhouse gases and process studies to the methane cycle; Terrestrial climate signals in ice-rich permafrost; Microbial habitats and CO_2 flux in permafrost landscapes; Acoustic signals of submarine permafrost (BMBF)
2002-2004: Late Quaternary environmental evolution of the Verkhoyansk Mountains and its foreland (DFG)
2002-2005: Arctic coasts of Eurasia: dynamics, sediment budget, and carbon flux in connection with permafrost occurrence (INTAS)
2002-2005: Arctic coastal dynamics of Eurasia: classification, modern state and prediction of its development based on GIS technology (INTAS)
2003-2006: Dynamics of permafrost in the Laptev Sea Region: Permafrost soils and ecosystems; Water and energy balance of modern permafrost landscapes; Coastal dynamics and subsea permafrost studies; Permafrost and environmental dynamics during Quaternary climate variations (BMBF)
2003-2011: Permafrost dynamics in the Elgygytgyn Crater (BMBF, ICDP)
2004-2007: Quaternary vegetation history and climate reconstruction in North Siberia using plant macro fossils from permafrost sequences (DFG)
2006-2008: Permafrost dating by cosmogenic 36Cl and 10Be and its application to bio- and geoscience (INTAS)
2009-2011: Joint German-Russian laboratory for studies of environmental dynamics in the terrestrial Arctic (Biological Monitoring – BioM) (BMBF)
2009-2011: Joint Russian-German Research Group: Assessing the Sensitivity of the Arctic Coastal Dynamics to Change (HGF JRG 100)
2011–2014: Polygons in tundra wetlands: State and dynamics under climate variability in Polar Regions (POLYGON) (DFG-RFBR)
2011-2015: PAGE 21 - Permafrost and its Global Effects in the 21st Century (EC, FP 7)

Realization

Beside yearly fieldwork in Siberia, the cooperation was realized by mutual visits of Russian and German scientist supported by the foundations from both countries. The complex studies resulted so far in about 100 international publications as well as numerous joint papers published in Russian. Several diploma, PhD and habilitation theses could be successfully realized due to the joint science cooperation.

The long-term tradition in investigation of permafrost features and processes and in education of young permafrost researchers as well as the comprehensive regional knowledge and experiences in Russia is successfully combined with modern analytical approaches, a well-organized system of financial support for research projects and a small but highly motivated permafrost community in Germany.

Results

Based on a newly developed trans-disciplinary approach to study the late Quaternary permafrost archives detailed reconstructions of past arctic mainland environments were firstly applied in West Beringia but also used in Alaska and NW Canada. The general potential of permafrost archives includes spatial (circumarctic, high arctic to boreal zones) and temporal (Mid Pleistocene to modern) environmental gradients. Lateral cross sections of coastal and riverbank exposures contain valuable information about permafrost degradation during interglacial periods, the aggradation of ice-rich sequences during glacial periods, and extreme changes in periglacial landscapes during the late Quaternary.

Several geochronological methods including conventional and AMS radiocarbon dating of fossil plant and bone material, luminescence dating (OSL, IRSL) of quartz and feldspar grains, ^{234}Th/U dating of frozen peat, and ^{36}Cl/Cl dating of ground ice were applied on permafrost archives in Siberia.

The stratigraphy of the permafrost sequences was determined by litho- and cryostratigraphical classifications. Numerous sediment parameters were measured for differentiation between horizons in individual exposures, for local and regional stratigraphic correlation of permafrost sequences as well as for reconstruction of accumulation and transport conditions. The Russian methodology in cryolithology and cryofacies analysis according to E.M. Katasonov and N.N. Romanovsky was applied and further developed.

Using hydrochemical and stable isotope analyses, several ground ice types and ice-wedge generations were classified. The isotope signatures of ice wedges contain information about temperature variations, evaporation conditions and precipitation sources during different periods of its formation.

Based on total organic carbon data, ice contents and bulk densities information, average organic carbon inventories for different stratigraphic units were estimated. The resulting landscape average is about 25% lower than previously published permafrost carbon inventories.

The Yedoma Ice Complex is considered as a specific cryogenic facies typical for cold stages of late Pleistocene Beringia. Yedoma deposition was favored by a cold, dry climate that precluded widespread glaciation of lowlands and low mountain ranges, and resulted in syngenetic permafrost growth for several tens of thousands of years. The formation of large polygonal ice-wedge systems and sequences of ice-rich silty deposits tens of meters thick was closely related to the persistence of stable, poorly drained and flat to gently sloping accumulation areas in arctic and subarctic lowlands.

For paleo-ecological reconstructions various fossil bioindicators were studied including pollen, plant macro-remains, insects, ostracods, testate amoebae, diatoms, chironomids, and mammal bones. By combining these data sets, we assembled a complex picture of the climate, landscape and vegetation dynamics of the studied regions during the Quaternary past. Derived paleo-information includes: mean annual air temperatures, mean winter temperatures, mean July temperatures, precipitation, humidity, soil climate and chemistry, hydrology and hydrochemistry of waters. Using transfer functions for pollen, plant macro remains or chironomids, the numerical estimation of paleoclimate data (temperature and precipitation) is possible.

A comparison of proxy-based paleoenvironmental reconstructions with the simulations performed by an Earth system model of intermediate complexity (e.g. CLIMBER-2) shows good accordance between the regional paleodata and model simulations, especially for the warmer intervals.

Coastal dynamics and subsea permafrost of the near-shore zone are of special interest since the land-sea interface at permafrost coasts is mainly influenced by long-term climate condition such as sea level low stands during glacial periods or inundation of the shallow east Siberian shelf during interglacial sea level high stands. The investigations of formerly terrestrial, after inundation submarine permafrost extends the permafrost archive below the modern sea. In 2005, the COAST drilling transect at Cape Mamontov Klyk (Western Laptev Sea) brought valuable data on both the late Quaternary history of this region and detailed temperature and sediment properties of subsea permafrost. Geophysical methods (e.g. electrical resistivity) are increasingly used to observe the transition from ice-free marine deposits to underlying ice-bearing subsea permafrost, and to estimate its degradation rates. Coastal erosion rates are subject to remote-sensing methods and applied to estimations of land-to-sea fluxes of e.g. organic matter and nutrients.

Intensive modelling has been carried out related to the formation and composition of coastal and subsea permafrost and gas hydrate stabilities since about 400,000 years. The specific structure and possible degradation along with climate variation and in relation to tectonic structures resulting in varying terrestrial heat flow has been modelled.

Outlook

The biogeochemical aspect of organic matter and its characteristic in frozen deposits will be a research topic in the future joint project “Carbon in Permafrost - Formation, Transformation and Release” To gain information about recent periglacial processes, remote sensing and GIS data will be used for change detection of permafrost landscapes and coasts. The successful bilateral permafrost research will be continued and jointly extend to ongoing and future international research programs, projects and networks such as GTNP, RCN permafrost carbon, and the yedoma, thermokarst and subsea permafrost mapping proposals.

Isotopic composition of the inactive ice wedges at Yitulihe in the Da Xing'anling Mountains, Northeastern China

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The inactive ice wedges at Yitulihe (50°32′N, 121°29′E, 730 a.s.l.) in the Da Xing'anling Mountains, Northeastern China probably represent the southernmost position of ice wedges in the Northern Hemisphere. The Yituliheis located in the southeastern margin of the Eurasian permafrost, therefore, the ice wedges are unique to trace the isotopic significance. Here, we briefly present the isotopic information (Fig. 1).

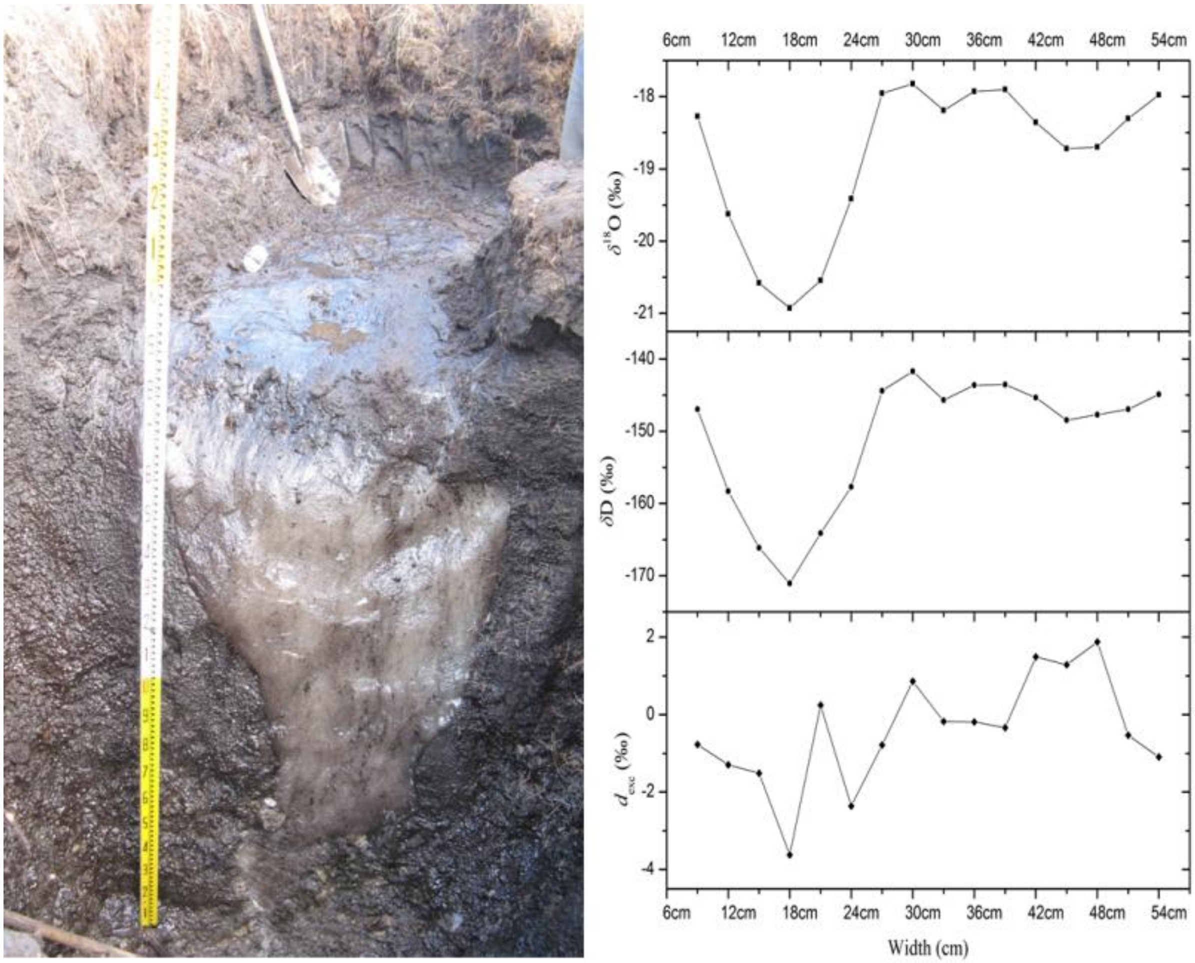

Fig. 1. Ice wedge in Yitulihe and the isotopic compositions (modified from Yang and Jin, 2011). A horizon of 54cm ice wedge was retrieved at depth of 130-140cm and cut into slices at 3 cm interval.The width refers to the distance from the left edge of ice wedge. The analytical precision is ±0.1‰for δ^{18}O and ±1‰ for δD.

As shown in Fig. 1, the Yitulihe ice wedge exhibitsδ18O between-20.9‰ and -17.8‰ and δD values between -171.1‰ and -141.7‰, with mean values of -18.8‰ and -151.0‰, respectively.The d excess averages to -0.4‰, ranging between -3.6‰ and 1.9‰. The co-isotopic relationship is $\delta D=8.67\delta^{18}O+12.21$ ($r^2=0.982$)[*Yang & Jin, 2011*].Here, we givea regional LMWL ($\delta D=8.23\delta^{18}O+9.54$, $r^2=0.987$) for modern precipitation according tothe data of 11 GNIP stations located within and adjacent to air mass trajectories affecting Northeastern China.This LMWL is close to the previously published result forNortheast Asia ($\delta D = 8.38\delta^{18}O + 19.15$) [*Lee et al., 2003*]. The ice wedge clustered to the lower left part ofthe GMWL, and the regional LMWL(Fig. 2) in our research.

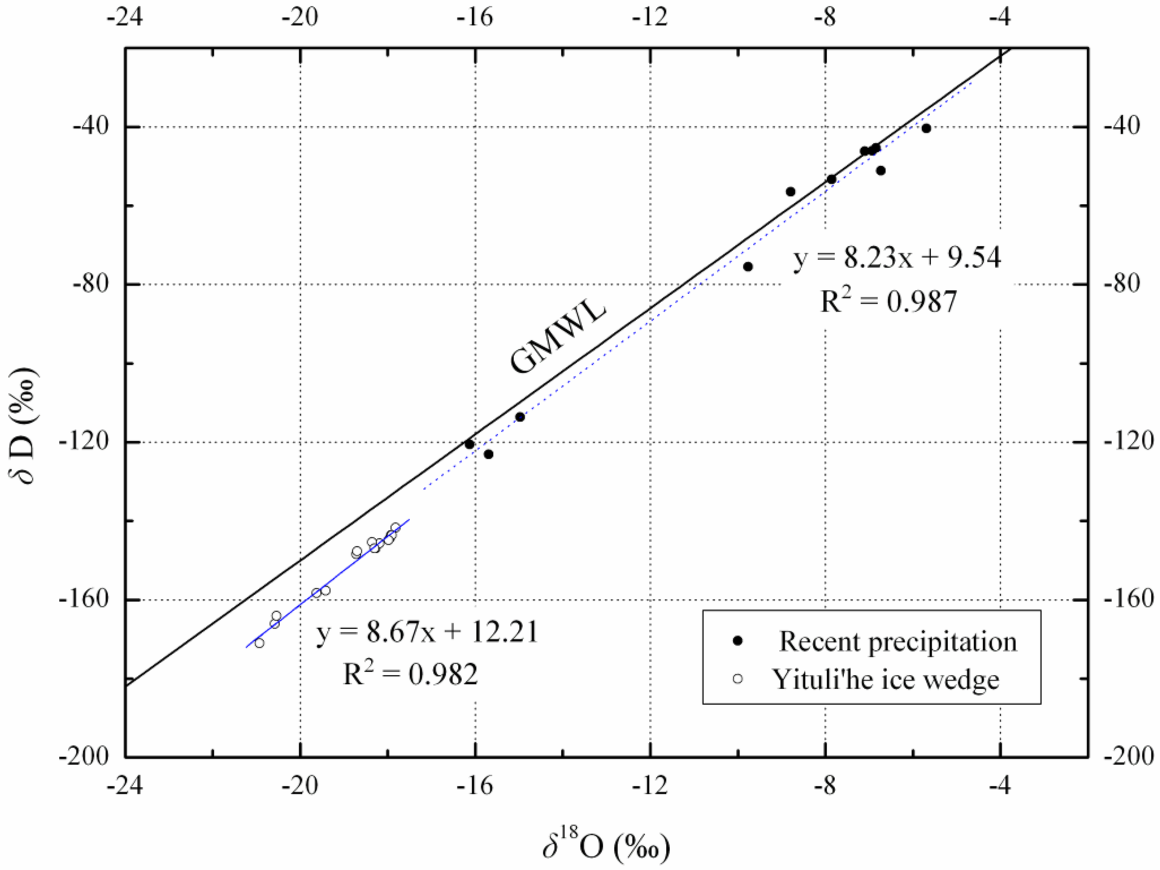

Fig. 2.δ^{18}O-δD diagram ofwedgeiceatYitulihe,Northeastern China.The11 GNIP stations include Bagdarin, Khabarovsk (Russia), Cheongju,Pohang (South Korea), and Changchun, Harbin, Jinzhou, Qiqihar, Shijiazhuang, Tianjin and Yantai (China).

In the northern part of China, seasonal variation of δ^{18}O and δDshowed a winter depression pattern, andthe temperature effect is dominant, particularly in wintertime [*Yamanaka et al., 2004*]. For example, Qiqihar, the closed GNIP station to Yitulihe, show low winter (Dec.-Feb.)values of -24.0‰ for δ^{18}O, -186.3‰ for δD,and 5.4‰ for the d excess, while high summer (May-Sep.) valueare-9.1‰ , -70.0‰ and 4.2‰ for δ^{18}O, δD and d excess, respectively. This temperature dominant effect could be confirmed by the ice wedge with low isotope composition and d excess. Thus, the low dexcess at both sites is not due to secondary fractionation processes. Additionally,the slope of 8.67 for ice wedge samples inδD-δ^{18}Oplot confirms that secondary fractionation processes likely not affect the ice wedge samples at Yitulihe. Therefore, we might interpret the isotope composition in Yituliheice wedge as climate-relevant archive.

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Using Streamflow Characteristics to Explore Permafrost Thawing in Northern Swedish Catchments

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Introduction

The recent and rapid warming of the Arctic leads to warming and thawing of permafrost. Since the subsurface flow pathways of water in arctic landscapes are highly influenced by the presence (and absence) of permafrost, such catchment-scale changes in permafrost coverage should be evident in streamflow records. Expected influences by permafrost thaw on streamflow based on modeling studies include an increasing contribution of groundwater to streamflow, which should affect streamflow most during low and receding flows. Low flows, generally assumed to consisting mainly of groundwater inputs, are expected to increase as permafrost thaws. During catchment drainage, streamflows are also expected to recede more slowly due to increased groundwater storage capacity of catchments. These changes in both minimum discharge and recession flow characteristics during the last century have been observed in river discharge records from across the Arctic [*Lyon et al. 2009, Rennermalm et al. 2010*]. In this study we use these two streamflow characteristics as proxies for permafrost thaw to explore their capacity to characterize hydrological catchments as "sentinels of change" in northern Sweden.

Study area and methods

Permafrost in northern Sweden

Northern Sweden has experienced a warming climate and increases in winter precipitation over the last 100 years, both contributing to conditions that should promote permafrost warming and thaw. Observations of alpine and ecosystem protected peatland permafrost show that the permafrost in northern Sweden is close to 0°C and warming or thawing in today's climate. However, large-scale spatial distributions of permafrost are poorly known in the area and therefore changes at the catchment scale are hard to estimate.

Data and methods

Long-term discharge data from 17 hydrological gauging stations on unregulated streams were analyzed for trends in both annual minimum discharge and recession flow characteristics. The locations of the catchments are shown in Figure 1. Daily discharge data from the Swedish meteorological and hydrological institute with time spans of between 101 and 26 years (all ending in 2010) were used for the analyses. The widely used Mann-Kendall test was applied to detect trends significant at 95 % confidence level for both the minimum discharge and the recession flow characteristics. For the minimum discharge analysis the day with the minimum discharge for each year was chosen. For the recession flow analysis, a power-law parameterization of the rate-of-change in stream discharge was used, written as

$$dQ/dt=-aQ^b \qquad (1)$$

where Q is volumetric discharge, t is time, and a and b are fitting parameters. Following a linearized solution to the Boussinesq equation, a can be related to physical properties of the catchment [*Brutsaert 2005*], and b is a constant value depending on the time since the onset of drainage and reservoir properties and is in this application set to 1, following Lyon et al, [*2009*]. Expected changes from permafrost thaw at the catchment scale for these two flow characteristics are an increase in minimum discharge and an increase in a over time, respectively.

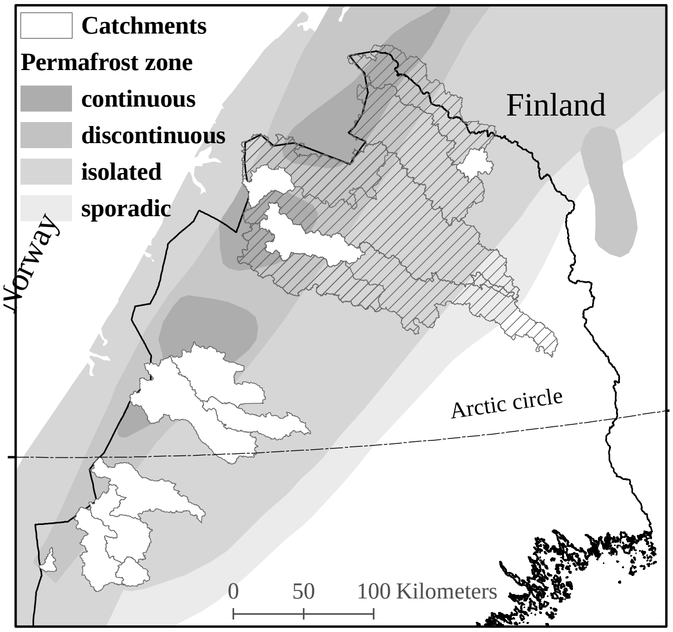

Figure 9. Location of the studied catchments in northern Sweden. Permafrost zones from Brown *et al*. 1998.

Results and discussion

Results

In nine catchments the minimum discharge has increased significantly during the measurement period, and in only one catchment is there a significant decrease (Table 1). For the recession flow characteristics, the parameter a has increased in seven of the catchments, decreased in two, and in eight catchments there is no significant trend over the measurement period. Two catchments show significant increases in both proxies, and three catchments show no increasing trends in either of the proxies. Catchments with more permafrost [*from Brown et al. 1998*] show more increasing trends in recession a, while no similar correlation was found for the minimum discharge trends.

Table 2. Observed trends in minimum discharge and recession *a* parameter, along with length of observational record and coverage with continuous and discontinuous permafrost. Significant trends in **bold**.

Catchment	Length (yrs)	Min. Q trend (mm/yr)	Recession *a* trend (%)	Permafrost (%)
Ö. Abiskojokk	26	**-0.969**	**2.829**	99
Tärendö 2	27	-0.056	**1.672**	34
Gauträsk	32	**0.656**	-0.592	25
Killingi	36	**1.364**	-0.393	59
Kaalasjärvi	36	-0.148	1.370	81
Karesuando	39	**1.115**	**-1.149**	49
Mertajärvi	52	**0.851**	**0.432**	0
Lannavaara	53	0.220	**1.217**	40
Tängvattnet	54	1.324	**0.234**	100
Karats	69	0.190	0.000	2
Junosuando	73	**0.340**	0.379	48
Niavve	86	-0.146	-0.205	75
Abisko	93	-0.035	**0.633**	91
Stenudden	95	**1.102**	**0.041**	57
Solberg	100	**0.418**	**-0.122**	24
Skirknäs	100	**0.428**	0.949	0
Laisvall	101	**0.384**	0.000	25

Discussion

These results are mechanistically consistent with physically-based modeling results, where it has been shown that minimum flows as well as seasonal variability in discharge is expected to decrease for hydrogeological permafrost systems subject to thaw [*Frampton et al. 2011*]. Also, the results are consistent with the geological setting as the catchments considered span the spatial limit of permafrost extent. As such, this study illuminates the potential for using hydrologic observations to monitor changes in catchment-scale permafrost. Further, it highlights the potentially orthogonal information available with regards to permafrost when considering two independent flow characterizations. This opens the door for further research to isolate the mechanisms behind the different trends observed for these two hydrological proxies and to gauge their ability to reflect actual permafrost conditions at the catchment-scale.

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Engineering Protection of Pipelines from Hazardous Engineering-Geological Processes in Northern Regions

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The necessity to develop the designs of area engineering protection from hazardous permafrost processes and phenomena activated under technogenic impacts usually occurs in the process of construction and operation of pipelines and along-route site facilities. The situation is complicated by the significant variability of engineering-geological conditions along the pipeline route (alternation of sites with thawed ground and permafrost, presence of icy, strong-heave and softened grounds etc.). In this situation future material-technical expenditures aimed at the maintenance of the operational reliability of pipelines and along-route site facilities also depend much on the quality and the volume of the technical decisions taken.

The engineering protection design is developed stepwise, starting from the analysis of the facility and ending with the selection of specific technical measures.

Basic data analysis and typification of engineering-geological conditions of the pipeline route

Basic data analysis is the preliminary work stage in the process of development of the engineering protection design for pipelines and along-route areal facilities. These data include the information on the profiles along the route, plans, reports on engineering-geological research, data on architectural and construction solutions and other documentation.

The pipeline route is typified on the basis of the basic data analysis, by engineering-geocryological conditions, with the identification of typical geocryological sections-columns. The main parameters taken into account in the process of typification are determining in terms of the impact on the bearing capacity and the stability of the pipeline base. This is differentiation of thawed and permafrost grounds, the division of permafrost into seasonally thawed and frozen, the identification of permanent snow patch, talik and ground ice sites, the identification of sections composed of icy grounds, running grounds etc.

Route zoning is conducted on the basis of geomorphological and technological peculiarities at the initial work stage: the sites of crossing of watercourses, ravines, existing pipelines and motor roads are identified.

The pipeline route is zoned with the identification of sites with developing (or potentially hazardous sites) negative permafrost processes.

Development of technical solutions

The specific complex of measures is provided on the basis of the above-listed work results of the preliminary stage, depending on the pipeline laying method. This complex is aimed at mitigation or elimination of adverse impacts of the specific processes.

Various engineering protection technical solutions and measures (including those confirmed by patents) were developed in Fundamentproekt OJSC. They are substantiated by the forecast thermotechnical, strength and deformation calculations as well as by the operational experience in provision of the stability and of the operational reliability of underground pipelines, overhead pipelines and along-route areal facilities from a wide spectrum of hazardous processes. These include erosion and thermal erosion, landslides, stone streams and solifluction, cryogenic ground heave, thermokarst, bogging, underflooding etc.

The following main measures are most frequently required technical solutions used for engineering protection of underground pipelines and along-route areal facilities in various geomorphological and geocryological conditions.

- Surface water discharge (including multi-layered water discharge on along-route areal facilities with the construction of buried motor roads, the intra-site storm drainage and off-site diversion ditches), with application of water-discharge trays and ditches of various configurations mounted with the use of various materials, such as geogratings, flexible concrete mats (UGZBM), steel electric longitudinal welded pipes and drainage mats;
- stabilization of river bed and floodplain parts on watercourse crossings with the use of different erosion-preventive materials of the spatial geograting or flexible concrete mat type;
- protection from the surface erosion and suffosion processes in the grounds of the pipeline trench backfill with the use of a series of geotextile materials as well as with the use of reclamation materials of the biomat type;
- thermal stabilization of grounds of the underground pipeline base at the crossings with existing pipelines with high temperatures of the transported products; Various types of seasonally operating cooling devices and heat-insulation materials are used as thermal stabilization measures, and ice-ground curtains are constructed for protection from underflooding with intrapermafrost ground waters.

Conclusions

The engineering-geological conditions in the northern regions are characterized by diversity and variability. Consequently, there is no universal system for engineering protection designs development. Each design is developed individually for the specific region with its own geocryological, geological, climatic and other peculiarities.

Preservation of the natural water and heat balance of the area is the main purpose of engineering protection. The measures described above make it possible to complete this task and also provide for the stability and the bearing capacity of pipeline bases for the whole operational term. They are economically efficient and reliable, and also environmentally safe.

The development of the efficient geotechnical monitoring network with a manual or an automated measurement method is obligatory for each specific case. The area should be equipped with the required number of elements (thermometric wells, hydrogeological wells, deformation signs etc.) for the period of pipeline and along-route areal facility construction and operation, in order to ensure monitoring of the state of facilities and prevent emergencies.

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Monitoring of Underground Waters in Yamalo-Nenets Autonomous Okrug

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Abstract

Monitoring of the underground waters of Yamalo-Nenets Autonomous Okrug is an integral part of the state monitoring of the subsoil condition. The underground waters of both the natural and natural-technogenic water bodies are the object of study. Disturbed conditions are characterized by changes in their level, temperature and hydrochemical regime. Predicted resources and operable reserve of underground waters, production and use of potable, mineral and industrial waters and their contamination are also studied within the framework of the underground waters monitoring subsystem.

Keywords: concentration of mineral nutrients; degradation of frozen grounds; fresh groundwaters; infiltration recharge; monitoring; permafrost-geological conditions; talik areas; wastewater quality.

The monitoring of underground waters studies their natural or disturbed condition which is caused by impact of various technogenic sources. The natural condition of underground waters is characterized by natural regularities of formation of the hydrodynamic and hydrochemical regime. The natural condition of underground waters gets changed due to the impact of different economic activities (mining operations, extraction of underground waters; erection and operation of water reservoirs and melioration systems; urban agglomerations, wastewater disposal areas etc.).

The monitoring of the underground waters of Yamalo-Nenets Autonomous Okrug is an integral part of the state monitoring of the subsoil condition. Underground waters of both the natural water bodies (ground water basins or artesian water basins, non-operated underground water deposits and deposits of other natural resources, different river basins) and the natural-technogenic bodies (operated underground water deposits and deposits of other natural resources, urbanized areas, areas of technogenic pollution etc.) are the objects investigated.

The degree of development of the predicted operable resources of the hydrogeological basins of Yamalo-Nenets Autonomous Okrug is low. As regards Ural folded hydrogeological area and the West-Siberian artesian basin, this degree is 0.1% and 0.5%, respectively. This means that the area in question has huge resource potential with respect to reserve of fresh underground waters. This potential is distributed over the territory of Yamalo-Nenets Autonomous Okrug in a non-uniform way. The underground waters confined to the areas located to the North of the Arctic Circle are most often frozen. Hence, the resource potential is not high in this region.

According to the data delivered by Yu.K. Ivanov and V.A. Beshentsev, a rather intense deterioration of quality of underground waters is typical for a number of municipal water intakes. For example, the pH value has decreased from 6.8 to 5.8, the iron concentration has increased from 4 mg/l to 6 mg/l at the water intake of the Gubkinsky town during five years. Concentration of mineral nutrients dispersed in underground waters is governed by adsorption and ion exchange in natural sorbents and ionites which maintain this concentration low in potable underground waters and provide self-purification of groundwaters. An intense water intake causes take-up of ill-conditioned suprapermafrost waters through the talik areas because formation of underground water resources in the Northern part of West Siberia is to a great extent governed by the bog infiltration recharge. Thus, the water intake facilities located in the permafrost area depend on special conditions when properties of the frozen grounds, which play the role of ion-exchange filter screens, are one of the underground water protection factors.

Methodological instructions on systematic monitoring of temperature conditions of the grounds, water in the well mouths and the balance regime in the area of formation of the operable reserve shall become a part of the program of monitoring of the cryolithozone of the region in question. A trend of natural degradation of the frozen grounds in the Northern part of West Siberia has been noticed. The results of processing of the data of the geocryological monitoring indicate that an increase in temperature of the grounds to a depth of 15 m in natural conditions has been registered during the last 15-20 years. Considering the eventual temperature increase trend of 0.075 °C per year (this corresponds to an increase in air temperature of 4° C in the middle of the next century), the confluent type of the permafrost in the high temperature cryolithozone areas (Vorkuta, Novy Urengoy) will become non-confluent, whereas the temperature of the grounds in the low temperature cryolithozone areas (Tiksi, Khatanga) will increase from -7 ° C ... -9 ° C to -4 ° C ... -5 ° C . Service life of the buildings and structures will decrease a few times. This will result in numerous deformations in them and their total destruction. Stability of the structures can be ensured mostly by artificial cooling of the ground foundations and artificial thawing. Development of the project "The cryolithozone monitoring" has a special importance in the light of study of the climate and cryolithozone warming.

All these measures will allow one to determine dependencies of the permafrost and hydrogeological parameters and forecast changes in the water quality.

More than 65% of the water which is taken for consumption in Yamalo-Nenets Autonomous Okrug (excluding the water used to maintain the layer pressure) is used as domestic and potable water. This is why the water sources used for potable water supply must comply with the sanitary and hygienic requirements. As to the total water intake amount, about 43%

of the water used is disposed in water bodies. About 47% of the total wastewater disposed in surface water bodies is contaminated and contains harmful substances which damage water bodies.

Requirements for the quality of the wastewater subject to disposal are defined in compliance with OST 39-225-88 "Water for flooding oil pools. Quality requirements" developed by the Ministry of oil industry , "The methodological recommendations for disposal of domestic waste water in the oil and gas production regions of West Siberia" [*Ministry of Health of the RSFSR 1991*] and RD 51-31323949-48-2000 "Hydro-geo-ecological monitoring at operation waste water injection sites" developed by Gazprom OJSC.

The problem of deteriorating quality of the potable water supply sources is accompanied by the problem of ensuring reliable water intake conditions. Some of the existing water intake structures need overhaul and increase in their capacity.

The underground waters of the West-Siberian artesian basin are presented mainly by the liquid phase in the largest part of the Okrug. The potable water supply sources are presented by two major aquifer systems, namely, the miocene-quoternary and the eocene-oligocene aquifer systems. The natural properties of the mentioned aquifer systems located in the Okrug are notable for low mineralization and poor chemical composition. As regards color and turbidity, the underground waters often exceed the maximum permissible concentrations mentioned in the regulations for potable water.

Yamalo-Nenets Autonomous Okrug occupies 4.5% of the territory of Russia. Huge deposits of natural hydrocarbon raw materials are located here. Today, 90% of the total amount of the gas produced in the Russian Federation is produced in the Okrug. The Okrug is the only center of the development of the Russian gas industry for many years to come.

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Seismic surveys at the Marre-Sale permafrost monitoring station (Yamal)

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Abstract

The structure and state of permafrost in the area of the Marre-Sale permafrost monitoring station in the western coast of the Yamal Peninsula were studied by seismic surveys in 2008-1010. The work included multi-component acquisition on the surface and in shallow water, as well as vertical seismic profiling in 100-m or deeper boreholes, with the use of special methods and instruments designed at the Earth Cryosphere Institute SB RAS (ECI SB RAS), Tyumen, Russia.

Keywords: *P* and *S* waves; permafrost table; seismic cross section of permafrost; seismic properties of rocks.

The Marre-Sale permafrost monitoring station is located in the western coast of the Yamal Peninsula. This is a principal source of monitoring information from the Russian permafrost zone which furnishes background data to be used for reference in development of the northernmost West Siberian petroleum province. Furthermore, it is one of few sites of long-term monitoring where permafrost can be studied in terms of its evolution under the current global change.

The geological-geocryological cross section of the Marre-Sale site, especially its upper portion with high ice contents, is a type section for a large part of the western and central Yamal and the Kara Sea and Baidaratskaya Bay shelves. The local topography consists of several pronounced geomorphic levels: a shelf sandy laida and the Marre-Yakha River floodplain, a lake terrace composed mainly of sand and silt with numerous plant detritus lenses and, finally, coastal plain III, with loamy sand and sandy loam in the upper section and numerous enclosed ice bodies of different thicknesses and configurations.

The site, with its diverse permafrost conditions exhaustively investigated by different methods, including drilling to 100 m or deeper, was chosen as a place where to set up and test new seismic acquisition techniques for many geocryological applications.

There have been several lines of studies.

Downhole vertical seismic profiling (VSP) in cased and non-cased boreholes was carried out to collect reference data against which to check surface measurements and to estimate the properties and the state of permafrost. The quality of permafrost as a degree of its sluggishness was measured using a new approach [*Melnikov et al., 2010*] based on Poisson's ratio patterns (μ). Poisson's ratios can be a proxy of sluggishness associated with the amount of unfrozen water because they are known to exceed 0.46 in unfrozen water-saturated sand and clay; the μ values above 0.46 mark cryopegs (brine lenses). An example of such a cryopeg at the depths 20-23 m inferred from seismic evidence and then discovered during drilling is shown in Fig. 1.

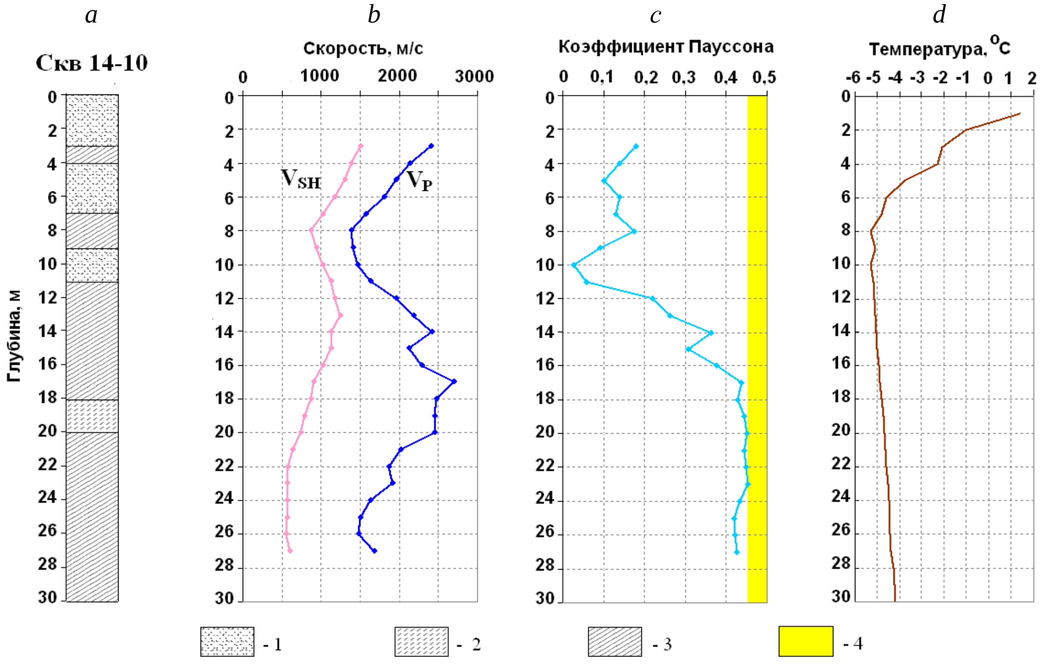

Fig. 1. Downhole VSP data. 1 – sand, 2- loam, 3- clay, 4 – Poisson's ratios in unfrozen water-saturated ground

a – cross-section (bore-hole #14-10); b – wave velocity, m/c; c – Poisson ratio; d – ground temperature, °C

Another experiment run in the vicinity of the borehole aimed at developing and updating the techniques of surface seismic surveys for the permafrost structure. The data acquisition was by the method of high-resolution shear-wave reflection (SWR) profiling with *SH* (horizontally polarized) phases designed at the Earth Cryosphere Institute SB RAS [*Skvortsov et al., 2011*]. The excitation was at the permafrost surface in order to remove the active-layer-related low-velocity component. Several reflectors identified in the SWR time series were correlated with downhole VSP data.

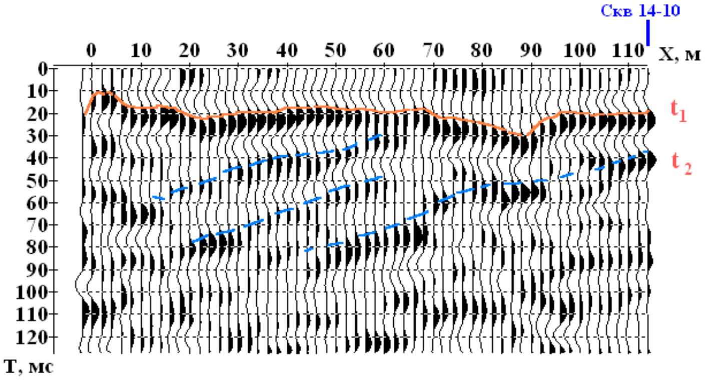

Fig. 2. An SWR cross section.
t_1 – loam surface at depth 10 m,
t_2 – top of a cryopeg at depth 20 m.

Profiling work was also undertaken in inner shelf and in the Marre-Yakha mouth. The feasibility of surveys in shallow water was tested first at the Bolvansky permafrost monitoring site in 2005 and then at the Marre-Sale site. It has been found out that bottom surveys using shear-wave (*SH*) refractions and reflections are the best way to image the permafrost structure in shallow-water conditions, for which a special acquisition technique was developed [*Skvortsov et al., 2011*]. See Fig. 3 for an example of an *SH* refraction section across a talik under the Marre-Yakha mouth (Fig. 3).

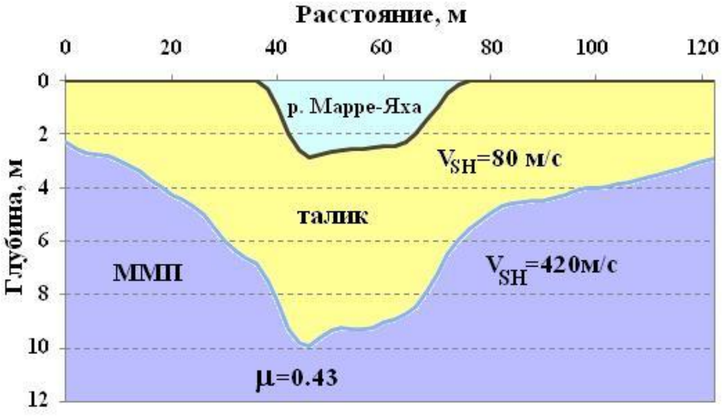

Fig. 3. *SH* refraction cross section of the Marre-Yakha mouth.

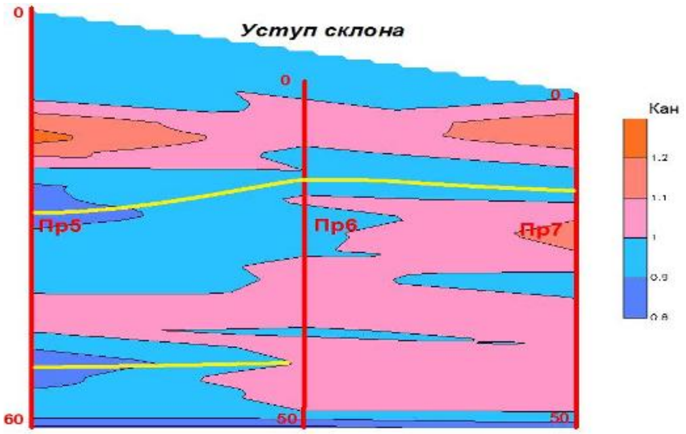

Fig. 4. Distribution of *P*-wave anisotropy coefficient K_{an}. Yellow lines are extension axes.

One more line of studies aimed at improving the methods of multi-component multi-azimuth acquisition likewise elaborated at the Earth Cryosphere [*Skvortsov et al., 2006*]. This kind of surveys applies to study slope stability and related space-time predictions proceeding from stress and strain patterns inferred from distributions of seismic parameters. Figure 4 shows a pattern of *P*-wave anisotropy (K_{an} coefficient) along the permafrost table on a coastal cliff, with two zones of extension prone to rupture.

Acknowledgments

We greatly appreciate the logistic and financial support of the studies from the management of VSEGINGEO.

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Diagnosing Future Projections of Permafrost

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Introduction

Permafrost currently underlies more than 20% of the Northern Hemisphere's land area and plays a significant role in many physical processes such as terrestrial hydrology and biogeochemical cycling. In recent decades ground temperatures have been increasing and active layers have been deepening in many regions, thus posing questions about the fate of near-surface permafrost (i.e. the upper 3.5m of the ground). Using the recent set of reanalysis products along with the suite of available Coupled Model Intercomparison Project (CMIP5) simulations, we assess the future extent of near-surface permafrost. Permafrost extent in CMIP5 models is a function of, firstly, the surface climate of the model, and secondly, the ability of the land model to simulate permafrost for a given climate. We separate these two effects by using an indirect estimator of permafrost that is driven purely by climatic indices from each CMIP5 model (the Surface Frost Index; SFI) and compare it to permafrost extent directly diagnosed from soil temperatures.

CMIP5 Models and Experiments

CMIP5 Models

The CMIP5 models are fully coupled Atmosphere-Land-Ocean-Sea Ice climate models. Horizontal resolution ranges from order 2.8 degrees to less than 0.7 degrees across all the models. The complexity of the land models also varies greatly. Most land models operate on a layered basis with a heat diffusion equation and the number of soil/ground layers ranges from 3 to 23, while column depths range from as shallow as 3m to as deep as 44m. In these cases, the overlying snow sub-models can be a single layer or have up to 5 layers. Some models apply a force-restore structure for computing ground heat storage. Currently there is data available from up to 15 of the CMIP5 models (BCC-CM-1, CanESM2, CCSM4, CNRM-CM5, CSIRO-Mk3-6-0, GFDL-ESM2M, GISS-E2-H, GISS-E2-R, HadCM3, HadGEM2-ES, INMMC4, IPSL-CM5A-MR, MIROC5, MIROC-ESM, MPI-ESM-LR, MRI-CGCM3, NorESM1-M).

CMIP5 Experiments

They simulate the historic time period 1850-2005 and then apply four representative concentration pathways (RCP's) of future emission scenarios. These scenarios are named according to the radiative forcing levels they impart at the year 2100. They range from the low emission case RCP2.6 in which it is expected there will be some mitigation over the period of interest, through to the aggressive emissions case of RCP8.5 where there is an additional 8.5Wm^{-2} of forcing by 2100. The intermediate cases are RCP4.5 and RCP6.0. RCP4.5 and RCP8.5 are required experiments for CMIP5 so not all models have performed all experiments, nor have all models reported all permafrost relevant data such as soil temperatures.

Diagnosing Permafrost

Indirect Methods

We applied simplified indirect methods of assessing permafrost sustainability based on the surface climate of the CMIP5 models. The methods we use are the Surface Frost Index [*SFI, Nelson & Outcalt 1987*] and the Kudryavtsev Method [*Kudryavtsev et al, 1974*]. These two methods use air temperature and mean winter snow thickness to assess the likelihood of permafrost existing under equilibrium steady-state conditions for the given climate situation. We also use global reanalysis data from the past 30 years to assess the skill of these methods in defining permafrost. The four newest reanalysis data sets, ERA-Interim, JRA, NASA-MERRA, NOAA-CFSRR are used; they are at high resolution, from 1.25 degrees to 0.34 degrees. The reanalyses verify well against each other and observations.

Direct Methods

Soil temperatures from the CMIP5 models are used to assess the level of the permafrost table. The mean and maximum temperature at 3.5m depth (or the closest available soil node) is also determined.

Results and Summary

The surface climates simulated by the CMIP5 models varies considerably in both temperature and snow amount. Applying the indirect SFI method, which aims to identify both continuous and discontinuous permafrost, for present day estimates of climate from CMIP5 models is shown in Figure 1. Continuous permafrost areas are captured well by most models but there is little agreement over discontinuous zones and several model climates even overestimate extent, particularly in Scandinavia and the Tibetan Plateau.

When using direct methods of permafrost diagnosis, the biases contained within the CMIP5 climate simulations impact the computed soil temperatures, but the skill of any given land model in capturing permafrost also plays a significant role. The independent influence of these two factors can be demonstrated via normalizing the permafrost area by a climate index. We will expand upon the role of these two factors in our presentation.

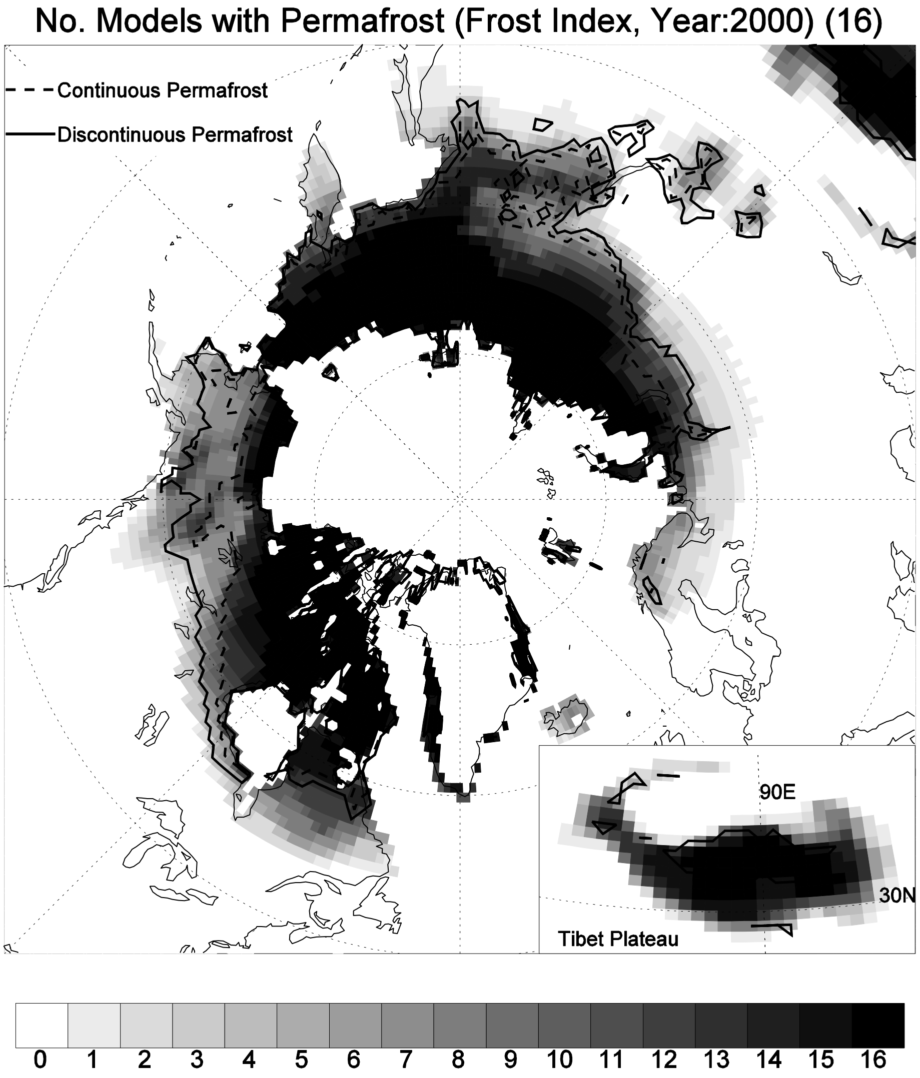

Figure 1. Number of CMIP5 models (out of 16) that suggest sustainable (continuous or discontinuous) permafrost at the year 2000 according to the Surface Frost Index method. There is a large range in estimated area amongst models. Current IPA Permafrost Map boundaries of continuous and discontinuous permafrost are also shown.

Several robust conclusions can be drawn from out analysis and these are :

1) CMIP5 models contain climate biases which can impact their future trajectory of permafrost area. Over the present day permafrost region half of the models have a cold bias of -0.5C or more for the reference period of 1986-2005. Normalized mean winter snow depth over this region varies across models from 0.21m to 0.44m. Such biases need to be accounted for when making regional projections.

2) The response of diagnosed permafrost area in land models, relative to climate forcing, is consistent under all RCP warming scenarios for all CMIP5 models. However, the rate of permafrost decline in individual land models relative to surface climate change varies widely, thus indicating that land model structure plays a significant role.

3) Under the RCP8.5 scenario, direct and indirect diagnoses indicate that at year 2100, permafrost will not be sustainable over almost all Alaska, but permafrost will probably persist north of 71N, across the majority of the Canadian Archipelago, portions of the East Siberian uplands and parts of the Tibetan plateau.

Further analysis will be presented at TICOP.

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The Study of Segregated and Massive Ice Outcrops on the Valkovskaya Terrace

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Introduction

The work describes the results of field study of ground ice in the Norilsko-Rybninskaya valley, within the Valkovskaya lacustrine-alluvial terrace formed in the Late Pleistocene - Holocene age after the drainage of the cold fresh-water basin that existed in the Sartan cryochron. The detailed descriptions are given for injected and segregated frost mounds and for massive ice.

In July 2011 icy outcrops were studied on the Valkovskaya terrace in the Norilsko-Rybninskaya valley in order to obtain the data on the lower geocryological belt. The temperature of rocks falls till –4° - -5°C within the second (Valkovskaya) and the third above-floodplain terraces of the Norilskaya River, while the permafrost thickness varies from 30 to 150-200 m [*Sheveleva & Khomichevskaya 1967*].

The central part of the Norilsko-Rybninskaya valley is occupied mainly by ice-rich clayey silt ($\boldsymbol{i}_i$ = 0.3-0.6) underlain by compact and ice-free Valkovskaya banded clay, and by sand, sandy silt and gravel-pebble grounds in submontane parts.

The permafrost roof rests at the depth of 0.5-3.5 m. Taliks occupy about 30% of the area (under the river and large lakes) [*Grebenets & Ukhova 2008*].

The following is typical of the Valkovskaya terrace: wide development of thermokarst (mainly in massive and wedge ice) and the active formation of segregated-migration frost mounds after the drainage of rather extensive thermokarst lakes.

The field observations were aimed at the study of minor ground ice outcrops or ice-rich horizons outcrops in thermokarst depression slopes.

Research methodology

The field observations included traverse descriptions of the dish-ridge topography genetically associated with ground ice thawing-out (thermokarst), morphometric measurements of frost mounds, outcrop cleaning, and sampling for laboratory studies of ground and ice.

Results and discussion

The first outcrop was located in the upper part of the eastern-exposure slope, where grass and moss vegetation prevailed.

The second outcrop was located at the western slope of one of the thermokarst lakes; inter-lake surfaces are occupied by birch and larch light forest. It represented an ice wall with multiple inclusions of clayey particles and thin plates as if flowing in the ice (Fig. 1).

The boundaries between the layers in the first outcrop are near-horizontal and very clear; it should be noted that alternation of clay horizons is observed in the section. They are typical in case of slow sedimentation of clayey silt or sandy silt and peat in permanent dynamically calm conditions (for example, in lakes). This testifies to the gradual drainage of the ancient fresh-water basin with the regressive levels formation.

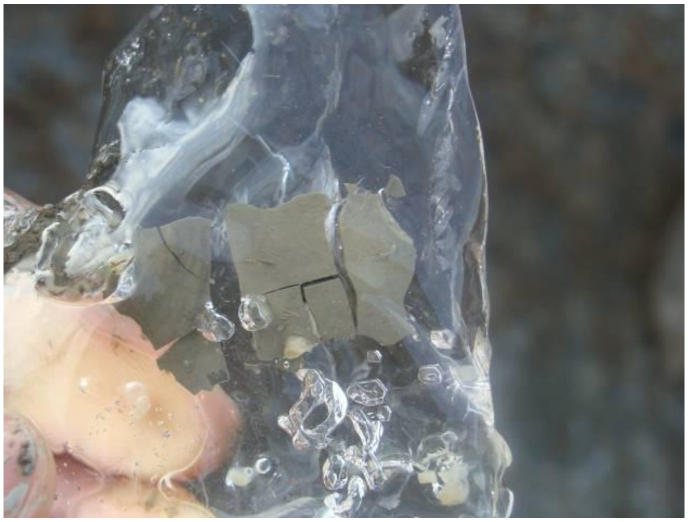

Figure 1. Ice ground of the frost mound core, Norilsk surroundings, July 2011

The contaminated ice (see Fig. 1) intersected in the form of a 1.3 m thick layer in the lower part of the second outcrop is covered by a complex of lacustrine and biogenic deposits (age - the end of the Upper Pleistocene - Holocene): a) compact light-blue clay of a glaucous tint with lens-shaped cryogenic structure (ice lenses from 3 mm to 2.5 cm in dimensions) is intersected under the 0.5-0.6 m thick ice massif; b) highly-peated dark-brown clayey silt with massive cryogenic texture (the thickness makes up 0.6-0.8 m) rests above; c) further, glaucous-gray clayey silt is intersected with the lacustrine ice lens (up to 13 cm thick), the ice is contaminated, with multiple inclusions (0.1-0.15 m thick); d) a brown medium-decomposed buried peat interlayer (up to 0.1 m thick); e) further 0.2-0.3 m - a horizon containing compact light-blue clays of a glaucous tint, with organics inclusions;

the horizon is gleyed, segregated ice schlieren are up to 3 cm thick; and f) the icy horizons are covered by a thin sandy silt layer from above (the sandy silt is light-brown in color; it is light, dusty and yielding when thawed).

The listed horizons (a-f) are covered by grass sod and a peat horizon (thawed in the upper part) in the top part of the outcrop.

The ice contained almost no air inclusions in this outcrop (rare bubbles were round and formed concentrations in the form of near-horizontal layers) and was almost transparent. This excluded the variant of its atmospheric origin immediately. According to D.A. Streletskiy, this is an injection frost mound, its roof, to be exact (because the main part of the mound must contain almost no ground particles). Close bedding of the ground water level at this point testifies to that as well.

The following mechanism of hydrolaccolith formation is associated with the fact that the roof of the frost mound icy core is approximately at the same hypsometric level as the thermokarst lake located nearby: the process began from the moment of the thermokarst lake drainage. During the cold period, stratum freezing starts from the surface and from the sides near the contact with permafrost.

In the ground over-moistured due to lake drainage, a closed system with intensifying hydrostatic pressure is formed in connection with water press-out from the crystallization front [*Popov, Rozenbaum & Tumel 1985*].

Massive ice outcrops were described in one of the cirques at the thermokarst lake bank (3.2 km to the east from the bridge across the Norilskaya River). The lower and the middle parts of the cirque are occupied by mud slides - the material removed in the process of ground ice thawing. The upper layer represents peated, gray-brown medium-decomposed grass sod with a low moisture content. Its thickness grows to the middle of the cirque (from 10 to 30 cm). Below there is a gray-brown dusty clayey silt layer slightly peated in the top part, with a large number of vegetation root inclusions; intensively weathered in the outcrop, with lumpy structure and with a reddish tint. The latter testifies to the horizon ferruginization. Its thickness grows to the middle part of the cirque as well (from 20 to 130 cm). Further below there is a transient horizon (up to 60 cm thick) from the ground to the relatively continuous ice sheet. The ataxic cryostructure and iciness $\boldsymbol{i}_i$ = 0.5-0.8 are observed in it. The ice hosts compact greenish-glaucous-gray consolidated clay joints, but stratification or other structural or textural peculiarities are absent. The boundary between the upper clayey silt horizon and the ice is clear. There are no visible faults within the underlying ice sheet. The distances between ground inclusions gradually (with dipping from the transient layer) grow till 30-40 cm, and the dimensions of these inclusions are from 0.5-1 to 6-8 cm. Slightly inclined vertical banding is observed in the ice due to air bubbles (from 0.2-0.3 cm to 0.6-0.8 cm in dimensions). The ice is non-salinized, clear, rather transparent and has a light-bluish tint: ground inclusions can be seen 50-60 cm through it. It is assumed that the formation of thick massive ice within the valley is associated with the freezing of water-saturated sandy silt and clayey silt strata and water press-down to the aquiclude – the compact Valkovskaya clays. Such type of deposits and high ice content are characteristic of wide valley areas. Multiple building and structure deformations, including those of the largest motor and railway bridge across the Norilskaya River, are registered [*Grebenets & Ukhova 2008*].

Conclusions

The nature of bedding, the shapes and the volumes of ground ice in the Norilskaya River valley are associated in many ways with the gradual regression of a huge fresh-water basin that existed at this area during the Sartan cryochron (the Late Pleistocene), and with further freezing of the deposits accumulated in a huge cold fresh-water basin that existed during that period. The following types of ice are the most typical: segregated (schlieren); buried glacial ice (in mountain and submontane areas); massive (at the contact with compact Valkovskaya clays - bottom deposits of the water body); segregated-injected ice of modern frost mounds, and modern wedge ice confined to soil frost cracking areas.

Acknowledgments

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Preliminary Assessment of Frozen Ground Stability and Associated Exploration Hazards in the Russian Northeast

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1. The assessments of engineering-geological conditions, including the assessment of frozen ground stability, are becoming ever more urgent due to a new stage of economic development of the Middle and Eastern Siberia. The information compiled by the present day (e.g. The Contemporary Engineering Geological Map of Russia, scale 1:2,500,000, 2010) and applied GIS technologies permit numerical evaluation of engineering and geological conditions of the region and hazards under its exploration. The territory is characterized by prevailing distribution of the class of natural frozen ground, everywhere occurring of dynamic cryogenic processes, and prevalence of the active layer (suprapermafrost) water.

2. The subsurface (engineering-geological) layer is composed of frozen rocks, semi-rocks, and frozen dispersive ground with cryogenic structural bonds. The frozen dispersive ground is of the most concern in terms of stability. This class of frozen ground is subdivided into two types with different strength characteristics: solidly frozen and plastically frozen ground. The deformation properties of these ground types are defined by their temperatures (Fig. 1). The low temperature (below −5°C) ground is related to the solidly frozen type, and is characterized by high strength properties. The high temperature (above −5° to 0°C) ground is related to the plastically frozen type. It is characterized by a low strength, up to the loss of elastic properties. The rock and semi-rock strength properties depending on temperature variations are changing in a considerably less extent.

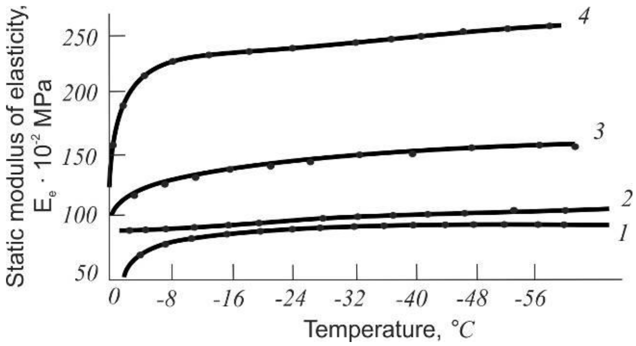

Fig. 1. The dependency of the static modulus of elasticity of the frozen ground on temperature (ultrasonic test): 1 – peat; 2 – ice; 3 – peaty sand; 4 – sand (by L.T. Roman, 1987).

3. A continuous changing of ground temperatures, and therefore the ground strength properties, as a result of the climate change is known. In order to accomplish an operational assessment of engineering resources (stability) of the territory, we propose to use several coefficients of stability: lithological (S_l), cryogenic (S_c), and overall (S_o).

The Lithological stability is measured by the ratio of the distribution area of rock and semi-rock ground (A_r) to distribution area of dispersive ground (A_d): $S_l = A_r / A_d$.

The Cryogenic stability is assessed (only for the dispersive ground) by the ratio of the distribution area of solidly frozen ground (A_s) to the sum of areas of thaw ground (A_t) and plastically frozen ground (A_p): $S_c = A_s / (A_t + A_p)$.

The Overall stability is assessed as a sum of lithological and cryogenic stabilities, because the cryogenic factor increases an engineering stability of the territory in the conditions of low temperatures: $S_o = S_l + S_c$.

4. The coefficients of the ground stability for Middle and Eastern Siberia are listed in the table 1.

Table 1. The coefficients of the ground stability for Middle and Eastern Siberia.

Geomorphological region	Lithological stability			Cryogenic stability			Overall stability
	A_r (%)	A_d (%)	S_l	A_s (%)	A_t + A_p (%)	S_c	S_o
Middle Siberia	60	40	1.5	25	15	1.7	3.2
Eastern Siberia	75	25	3	20	10	2	5

5. The obtained data attest that the cryogenic component plays a prominent part in the assessment of the overall ground stability for the territories. The areas of distribution of thaw and plastically frozen ground are constantly expanding under the conditions of the continuous mean annual temperatures rise. The areas of distribution of frozen ground with the temperatures –5...–7°C are entering the hazardous zone with a risk of a strength loss. In such conditions, the rise of temperatures of the solidly frozen ground, occurring at the threshold of plasticity, by decimal parts will result in irreversible changes of the ground elastic properties. The calculations show that the extension of the area of the plastically frozen ground distribution for the following 30-50 years, under preserving the present-day surface air temperatures, will occupy a considerable part of the area between the isotherms –5...–7°C. This will decrease the stability coefficient of frozen ground by 1-1.5 for this territory and, therefore, equalize, by overall stability, the areas of thaw and frozen ground distributions.

Taking this into account, we propose to refine the engineering-geological conditions of the territories by compiling in advance a special set of maps including a Map of Quaternary Deposits, a Map of Ground Temperatures, and an Engineering-Geological Map in the scale 1:1,500,000 or 1:2,500,000.

The Network of Young Permafrost Researchers of Russia (Tasks and Prospects)

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Introduction

As is known, more than 60% of the area of Russia is located in the permafrost zone the economic development of which is underway. Generations of geocryologists already solved many important tasks but even more tasks require solution. The diverse series of engineering and nature-protecting problems is solved or will be solved in the nearest future by young engineers and scientists working in different organizations and companies. The permafrost response to climate change remains understudied. The study of the interaction of economic activity objects and permafrost is considered important due to the development of oil and gas, mining and transport infrastructure in the Russian North.

In the modern world the young generation of the Earth cryosphere researchers actively participates in the solving these problems and improves its level significantly thanks to the materials available in Internet. The integration of knowledge on permafrost and geocryological processes in the Russia's information space can be executed only by means of succession of methodological approaches and all-round cooperation not only at the international level but also at Russian level. The interaction between permafrost researchers is required and valuable in the process of study of hard-to-access districts in the conditions of departmental dissociation of geocryological data. Such cooperation can be executed by virtue of the Permafrost Young Researchers Network (PYRN) formed by the International Permafrost Association (IPA) in 2005.

On the Permafrost Young Researchers Network in Russia

The Russian group was formed several years after the formation of the international Network. It was aimed at the union of the potential of all Russian permafrost researchers in order to popularize and spread the scientific knowledge on the cryolithozone and increase the activity of the Russia's "permafrost" youth. Such consolidation is fulfilled by the forces and the actions of young researchers only with the support of more experienced and wiser senior colleagues. The Russia's Permafrost Young Researchers Network unites the specialists from different spheres of geology, geography, design, construction and operation of buildings and structures. Nowadays, the number of the Network members reached more than 200 people from 50 organizations of Russia. This is more than in any other country of the world.

The members of the Russia's Permafrost Young Researchers Network organized the first PYRN-Russia Workshop “PYRN in Russia: from frozen to thawed state” in Pushchino on the 23rd-25th of October 2009 for 20 young permafrost researchers from Moscow, Pushchino, Saint Petersburg, Syktyvkar and Yakutsk [*Bonnaventure 2009*]. Some students and postgraduates examined the ideas of the Network at the Grand Geographical Festival in Saint Petersburg State University and at the 17th International Scientific Conference "Lomonosov" in Moscow State University in 2011 [*Shmelev 2011*]. The subjects discussed within the framework of the round-table conference "Experience Exchange: Polar Education and Knowledge Propaganda" aroused a great interest of students and participants of the 4th Conference of Russia's Geocryologists in 2011 [*Kraev 2011*]. The solution for the issues of grant support, the report tender and of the professional seminar concerning young participants of the 10th International Conference on Permafrost in Salekhard in 2012 became the responsible assignment for the Permafrost Young Researchers Network members. The members of the Permafrost Young Researchers Network of the Earth Cryosphere Institute SB RAS plan to conduct the youth's scientific seminar since 2012 three times a year in the Tyumen Scientific Center of SB RAS.

The work of the Russia's Permafrost Young Researchers Network is aimed at involvement of the youth in research of permafrost problems and in work in accordance with the specialization with the use of the knowledge received in the process of studying in universities and institutes. While participating in the Permafrost Young Researchers Network, a young specialist can self-fulfill and gain the support of like-minded fellows.

Targets and tasks

The network tries to form a single Russian information-communication field for cryosphere researchers within which information and experience could be exchanged and contacts could be found for cooperation in the scientific and the production spheres. Consequently, the following organizational tasks arise:

- Formation of a single Russian-speaking scientific-popular information site (website) with continuous information replenishment.
- Formation of a regional network and assignment of representatives from organizations dealing with permafrost problems.
- Organization of measures improving the qualification level of young permafrost researchers (conferences, master classes and lyceums).
- Assistance to young permafrost researchers in reception of various types of grants.
- Assistance in the employment of students and graduates of profile higher-education institutions in accordance with the specialization in "permafrost" organizations.
- Development of a program of additional seminars for the school course that are dedicated to the Russian North's nature (for example, http://ine.uaf.edu/werc/projects/permafrost/).
- Assistance of mass media in the reception of relevant information on the cryosphere.
- Language barrier overcoming (learning of foreign languages at the conversational and the written levels).

Website creation is a priority. It will be an information portal where the following required information could be easily published or found:

- news in the cryosphere world;
- vacancies;
- conferences;
- field studies, field schools and expeditions;
- organizations where students can have practical training;
- scientific projects, probations and grants;
- scientific materials (books, articles, reports, courseworks, graduation and thesis works);
- personal scientific research in the heading "About my research";
- permafrost seminars (Permafrost Institute, Pushchino, Moscow State University, Institute of the Earth's Cryosphere, RAS Institute of Geography, RAS Institute of Geoecology);
- journals of the State Commission for Academic Degrees and Titles on the permafrost subject in which authors can publish articles accepted for thesis defense and in grant reports;
- access to journals in various libraries of Russia and the world;
- equipped laboratories;
- foreign language courses in "permafrost" organizations for improvement of the conversational and the written levels with the emphasis on the permafrost terminology.

Moreover, the following can be published:

- photos of laboratory, field and experimental works that can be used for writing of articles and monographs with the reference to the author;
- albums with scientific material (figures, graphs and tables);
- permafrost research videos.

The solving of tasks is aimed at the stimulation of the scientific-technical activity and the improvement of the qualification level of young specialists: at gaining the experience of public performance, the skill to formulate questions and answers, participation in discussions; establishing creative and business contracts between colleagues of various generations and knowledge spheres.

Lack of permanent technical and financial support is one of the obstacles (that needs to be overcome in the nearest future) on the way to formation of a profile scientific-popular information portal. Considering the current reality, the information portal works in the simplified variant through the social network "V Kontakte" (http://vk.com/pyrn_russia).

Conclusions

Nowadays, the concept, the mission, the purpose and the tasks of the Permafrost Young Researchers Network were defined; the core consisting of the representatives of organizations executing the two-way communication between their colleagues and the Network was formed; the organizations database was created; the site structure was formed; meetings are conducted every month in Moscow for the discussion of organizational questions, news, problems and prospects.

The permafrost young researchers association faces a lot of unsolved problems: specifically, popularization of the Network in remote regions of the country (in Western and Eastern Siberia and the Far East). A gap is observed in the activity between young specialists and students of the Russia's European part and the regions behind the Urals. The Network is poorly known there, and this means that the activity of local permafrost researchers is not elucidated [*Urban 2011*].

The subscription for the postings of the Permafrost Young Researchers Network participants is possible at pyrn-russia@googlegroups.com. Registration atwww.pyrn.org is required if you want to become a part of the international network.

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The Method of Separation of Materials by a Supersonic Cryogenic Agent Jet

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A cryogenic agent jet ejected by a special nozzle effectively cuts any material of different thickness because the liquefied gas penetrates into microscopic cracks where its volume intensively increases, and the material gets torn from within. Efficiency of the process depends on pressure (from 400 kg/cm^2 to 4000 kg/cm^2), temperature (from 150 °C to –179 °C) and the distance to the material.

A cryogenic agent is a substance used as a working fluid in cryogenic systems. Cryogenic agents have a boiling temperature below −120˚C. Pure gases such as helium, nitrogen, oxygen, argon and some carbohydrates (methane, ethane) are usually used as cryogenic agents.

In terms of the cryogenic technology, there are different temperature levels corresponding to different boiling temperatures at a pressure of 1 atm. These levels are named after the chemical elements with the corresponding boiling points. For example, the temperature level of 90 K is called the oxygen level, the temperature level of 77 K is called the nitrogen level, the temperature level of 35 K is called the neon level, the temperature level of 25 K is called the hydrogen level and the temperature level of 4.2 K is called the helium level.

At low pressure, a cryogenic agent jet removes stubborn coatings from fragile surfaces more effectively than any other tool.

Moreover, a supersonic jet of a cryogenic agent does not create any waste, nor staining. When heated, the non-toxic supercooled blade just gets dissolved in air. The harmful dust that appears during cleaning and cutting can be directly removed from the contact point.

Advantages of use of a supersonic jet of a cryogenic agent for cutting materials:

- Ability to cut any materials and metals;
- High-speed cutting;
- Almost unlimited thickness of material or metal to be cut;
- High quality cutting of thick metal;
- The relative safety of the process.

Disadvantages of use of a supersonic jet of a cryogenic agent for cutting materials:

- High cost of the equipment;
- After 5-6 seconds of cutting, a thin sheet of a metal can literally go to pieces due to its fast cooling to extremely low temperatures.

Application area

NASA uses the Nitrojet cryogenic cutting (see Fig. 1) for precision removal of heatproof coating from internal surfaces of solid rocket boosters of the shuttles in the John F. Kennedy Space Center. The navy uses this technology to remove anticorrosive coating (see Fig. 2) from decks, keels, antennas and protective caps for radars.

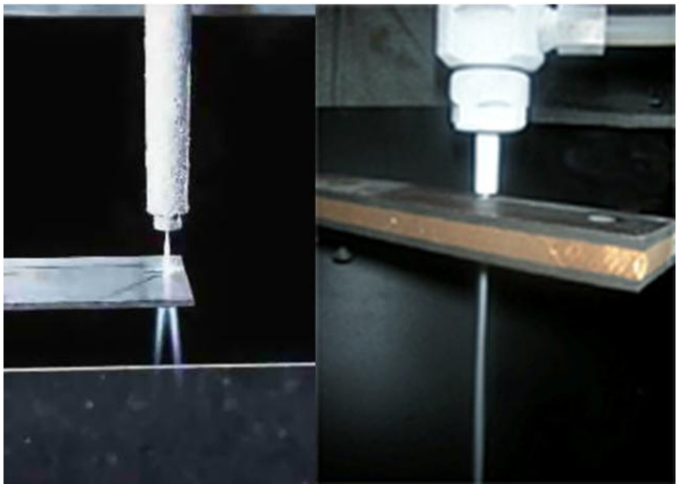

Figure 1. Cryogenic cutting. A liquid nitrogen jet is ejected at high pressure, cuts solid material like a hot knife cuts butter and then vanishes in the air.

Figure 2. Removal of coatings by a supersonic jet of a cryogenic agent. A liquid nitrogen jet is ejected at high pressure, cuts solid material like a hot knife cuts butter and then vanishes in the air.

This technology is also being tested in the aerospace industry, in manufacture of semiconductors, dyestuffs, polyurethane products and in packing of meat.

Marcela R. Stacey has a B.S. in engineering from Idaho State University and collaborated with Dennis Bingham in the cryogenic cutting technology at Idaho National Engineering Laboratory, Idaho Falls, Idaho. Dennis N. Bingham has a Ph.D. in engineering, receiving graduate degrees from Brigham Young and Clemson universities.

Cryostratigraphy of a Yedoma (Ice Complex) in Seward Peninsula, Alaska

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Introduction

Yedoma (Ice Complex) is a Late Pleistocene periglacial formation of syngenetic permafrost with large ice wedges and abundant organic matter that developed in unglaciated terrains [*Baulin & Murzaeva 2003*]. Since the Late Pleistocene, most Yedomas have been degraded by thermokarst and thermal erosion processes [*Shur et al. 2009*]. Yedoma landscape in its contemporary state is composed of typical geomorphological features related to the action of several processes of permafrost aggradation and degradation. It includes numerous thermokarst lakes, drained thaw lakes basins, ice-wedges, thermokarst mounds, or baydjarakhs (erosional remnants formed as a result of wedge-ice melting), low-gradient streams, and erosion-thermokarst valleys and plains (alas valleys and alas plains) with occasional pingos [*Stephani et al. 2009*]. Understanding the dynamics of this periglacial landscape and the material properties is necessary for modeling its evolution in the context of climate change. The objectives of this study were to determine the cryostratigraphy of Yedoma sections, and measure the material properties of the cryostratigraphic units. The study site was located in the northern part of Seward Peninsula which lies on the coastal plain of the Chukchi Sea on the west coast of Alaska.

Methodology

The topography of geomorphologic sub-units within an area ~0.5 km^2 was measured by optical leveling surveys (Fig. 1). Transects 1 (382 m) and 2 (358 m) crossed a thaw lake basin drained 16 years ago and connected by a gully to a lower and larger partially drained lake basin. Transects 3 (235 m) and 4 (200 m) reached two thermokarst lakes. The bathymetric profile across lake 1 (Fig. 1) was measured using a sonar and hand-held GPS. Core-drilling was done in 21 locations along microtopographic transects 1 and 2 with a hand-held auger engine equipped with a SIPRE core barrel (7.5 cm-diameter). The permafrost cores retrieved were described in terms of the assemblages of cryostructures (patterns formed by ice lenses and inclusions in frozen soils) and sediments that defined cryofacies, and ultimately cryostratigraphic units [*French and Shur 2010*]. Samples of frozen soil were brought back to the laboratory for testing. Gravimetric ice content of 90 samples was measured by oven-drying at 90˚C for 72 h. Organic matter content was measured on 17 samples by loss on ignition at 500˚C for 16 h. Particle size distribution of 16 samples was determined according to ASTM procedure (ASTM D422-98) and their statistics were calculated using Gradistat [*Blott & Pye 2001*].

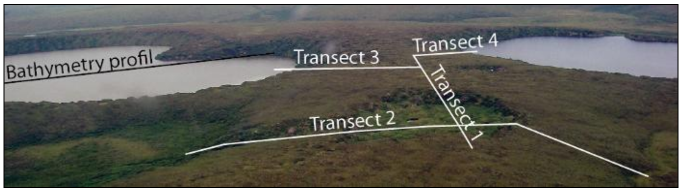

Fig. 1. Location of microtopographic and bathymetric transects.

Results and discussion

Topographic profile, core-drilling operations, and description of permafrost cores using the cryofacies method showed that cryostratigraphy changed with the geomorphologic sub-units within an area of ~0.5 m^2. In the contemporary state of Yedoma landscape, the higher surfaces typically represent the remnant of original Yedoma deposit. At distance ~200-275 m along transect 1 (Fig. 2), such Yedoma remnant with gentle slopes was observed. There, the active layer (~ 0.4 m-thick) was underlain by an ice-rich (average 142 %) layer dominated by suspended cryostructure and coarse silt. It was interpreted as the intermediate layer [*Shur 1988*] with its typical cryofacies (Fig. 3) and comprised the top of an ice-wedge network. Ice wedges, extending less than couple meters within the underlying layer, were characterized by a whitish color and indistinct vertical foliations (low sediment content) and interpreted of Holocene generation. Below the intermediate layer lied an ice-rich cryofacies (116%) characterized by a dominant microlenticular cryostructure (typical of Yedoma) within coarse silt with fine rootlets and high organic content (8 % average gravimetric content). This layer comprised larger ice wedges characterized by well-developed foliations and dark color due to the higher sediment content of the ice. This layer was encountered in boreholes across the study site, indicating that the layer covered the entire area (0.5 m^2).The bottom extent of the ice-wedges within this layer was not encountered; however, the difference between the lowest and highest occurrence of wedge ice in boreholes drilled in this layer indicated that they were at least 19 m high. Moreover, difference in elevations between the upper part of the layer and the bottom of the lake (up to 8.4 m-deep) gave an estimate of the minimal vertical extent of ice-rich sediments with large ice wedges in the study area (~0.5 km^2) (Fig. 1). This difference in elevations indicated that the ice-rich deposit was at least 36 m-thick. This layer was interpreted as the original Yedoma deposit with large syngenetic ice wedges.

In drained lake basins, such as along transect 1 (Fig. 2), the ground surface conditions and the cryostratigraphic units above the original Yedoma deposit were different than those of the elevated surfaces of Yedoma remnant. The ground surface was covered by thermokarst mounds (baydjarakhs). In the drained lake basin, the intermediate layer was never encountered in boreholes; however, a silt layer up to 3 m-thick overlaid the Yedoma silt deposit or Pleistocene ice wedges. The thickest part of the layer observed in boreholes was located in the basin center and it was decreasing towards its periphery. This layer was characterized by mainly two types of cryofacies that were on average significantly less ice-rich (average 56 %) than the intermediate layer (average 142 %) and the Yedoma deposit (average 116%). The most ice-rich cryofacies of this layer had a dominant irregular reticulate and/or layered-lenticular cryostructure while the least ice-rich had no visible ice to the naked eye (porous invisible cryostructure) (Fig. 3). These types of cryofacies are typical of sediments that have thawed and subsequently refreeze, and which are known as taberal deposits [*Shur and Zhestkova, 2003*). In the drained lake basin, the upper layer was interpreted as a taberal deposit formed by the sediment that had thawed below the lake (talik) and had refrozen after lake drainage. A taberal deposit that had replaced the intermediate layer above the original Yedoma deposit was also observed on elevated surfaces of Yedoma remnant affected by thermokarst.

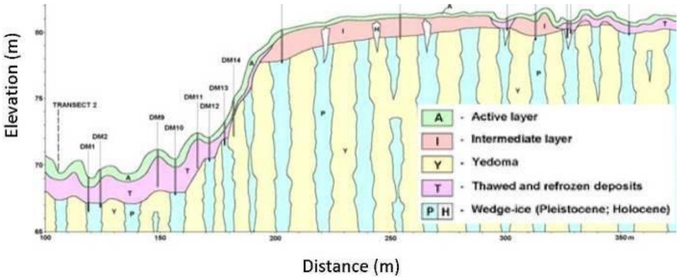

Fig. 2. Topographic profile along transect 1.

Understanding the distribution of the cryostratigraphic units associated with various geomorphologic sub-units in the landscape, allows estimating the spatial distribution of ground ice over extended areas. Thus, in the study area, surfaces covered by drained lake basins, drainage gullies and Yedoma remnant that are affected by thermokarst are expected to be characterized by an upper subsurface layer that is on average relatively ice-poor (taberal layer, 56 % average gravimetric ice content), while flat surfaces of Yedoma remnant should have a very ice-rich upper subsurface layer (intermediate layer, 142 % average ice content) over the original ice-rich Yedoma deposit (116 % average ice content) that is at least 36 m-thick.

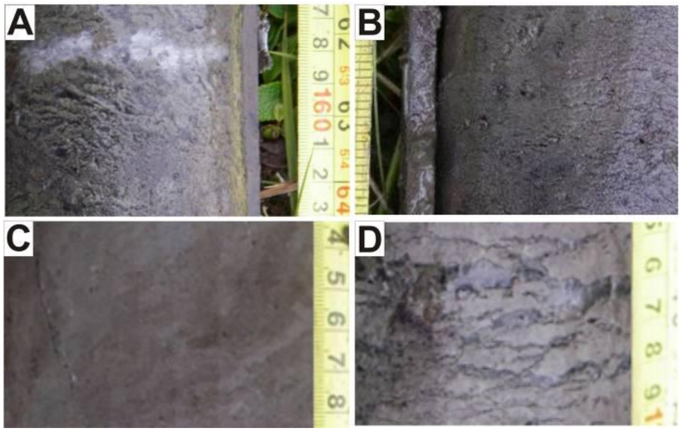

Fig. 3. Typical cryofacies. A) Intermediate layer, B) original Yedoma deposit, C) Ice-poor cryofacies of taberal deposit, D) Ice-rich cryofacies of taberal deposit (scales in cm).

Acknowledgments

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Old Organic Matter in Siberian Permafrost Deposits and its Degradation Features

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Introduction

During the late Quaternary, a large pool of organic matter (OM) accumulated in the arctic permafrost zone. Because of the potential re-introduction into the biogeochemical cycle from degrading permafrost, the OC inventory of ice-rich permafrost deposits and its degradation features are relevant to current concerns about the effects of global warming.

The objectives of this paper are (1) to deduce the quality and quantity of OM stored in the studied sediments and (2) to infer the paleoenvironmental conditions of the source biota. Therefore, standard sedimentological and a molecular marker (biomarker) approach are applied.

Methods

The study site is located on the west coast of the Buor Khaya Peninsula (N 71.6°, E 132.2°, Fig. 1), Yakutia (Russia). In Table 1 the used methods are summarized.

Table 1. Applied methods

Parameter	Analyses and methods
Radiocarbon age	AMS ^{14}C
Grain size	Diffraction Particle Size Analyzer
Bulk density	Gas pycnometer
OM characteristics (TOC, C/N, $\delta^{13}C$)	Element analyses Mass -spectrometry
Isotope signature of ground ice ($\delta^{18}O$, $\delta^{2}H$)	Mass -spectrometry
Biomarkers (brGDGT, archaeol, *n*-alkanes)	HPLC-MS GC-MS
Hydrobiochemistry (Acetate)	Ion chromatography

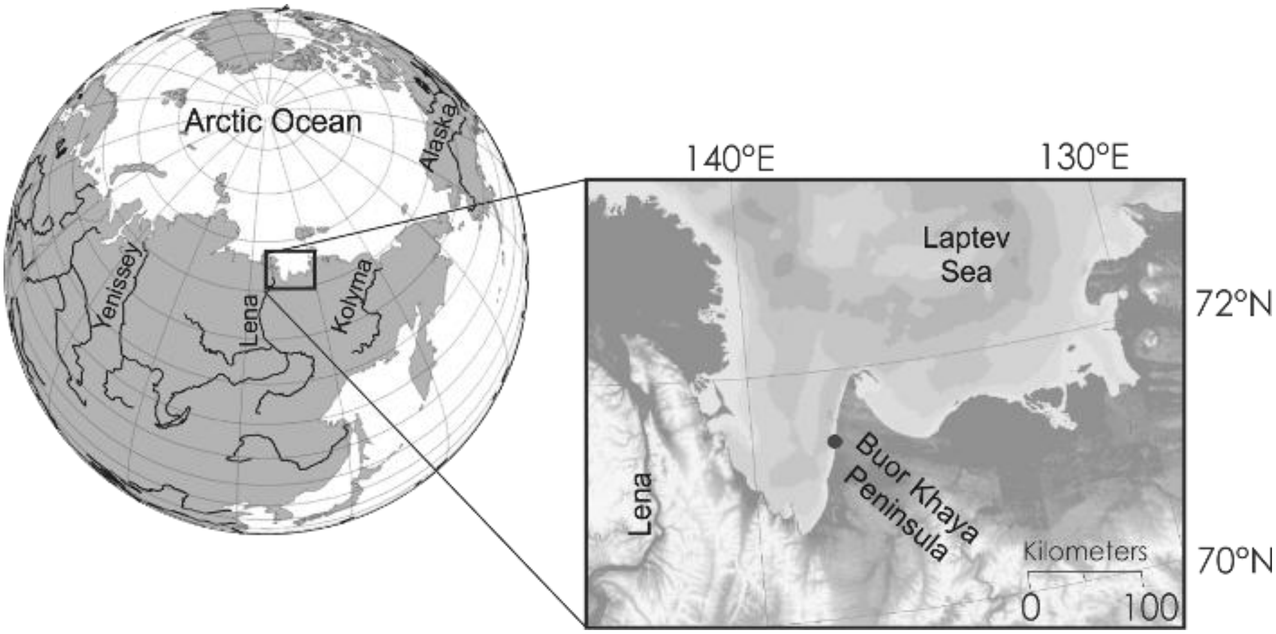

Figure 1. Location of the Buor Khaya Peninsula and the study site

Results and Discussion

Stratigraphically, two sediment units are distinguished. The first unit is composed of late Pleistocene ice-rich permafrost (Yedoma). The second unit consists of Holocene thermokarst deposits. The mean bulk density is ca. 1 10^3kg/m^3. The average total organic carbon (TOC) content is 2.4 wt% for Yedoma, 2.8 wt% for thermokarst deposits. The OM is low degraded (mean C/N 10) for mineral sediments. Hence, the deposits accumulated at relatively fast rates and the OM underwent a short time of decomposition before it was incorporated into permafrost. The volumetric organic carbon contents of the Yedoma and thermokarst deposits are 13 ± 11 kg/m^3 and 22 ± 11 kg/m^3, respectively. This quantity is inside the range of comparable deposits studied by Schirrmeister et al. [*2011*]. $\delta^{13}C$ reveal a terrestrial signal dominated by C3 plants (mean -26.5 ‰).

Ground ice $\delta^{18}O$ and $\delta^{2}H$, average ratios of about -32.46 to 19.59 ‰ and -241.80 to -155.93 ‰, respectively reveal cold temperatures during its formation especially for Yedoma deposits. Ground ice in thermokarst deposits indicate warmer conditions (-20.91 to -18.13 ‰ for $\delta^{18}O$ and -162.16 to -148.56‰ for $\delta^{2}H$) compared to Yedoma, but at the lower part Yedoma reflects a remarkably warm isotope signal of –-22.26 to – -20.44 ‰.

Using branched bacterial glycerol dialkyl glycerol tetraethers (brGDGT) as fossil biomarker according to Wejers et al., [*2007*], estimations of absolute temperatures are possible. Negative brGDGT temperatures reveal feasible results for permafrost. A contradictory fact is that Holocene thermokarst deposits reveals the lowest brGDGT temperatures (-7 °C thermokarst deposits average).

Originating from methanotrophic microorganisms, archaeal lipids like archaeol can be used as a proxy for methanotroph communities. The concentration suggests a response of archaeal communities to temperature and humidity changes in the past [*Pancost et al. 2011*]. The higher archaeol content in the thermokarst deposits (156.76 ng/g sediment) indicates larger archaeal communities, which is related to a drier and warmer climate.

The *n*-alkane proxies (compound preference index (CPI) and average chain length (ACL)) reveal a low microbial degradation (mean CPI 11) and as source higher (vascular) land plants (mean ACL 28). The source proxy for waxy hydrocarbons (P_{wax}) shows values >0.7, which is interpreted as a high input of higher land plants.

The occurrence of acetate >1 mg/l, which is an ideal substrate for microorganisms, indicates minor degradation in the permafrost and that the sediments were frozen very quickly.

Conclusions

OM parameters such as the total amount of organic carbon and the C/N ratio and acetate concentrations indicate labile carbon. The studied deposits contain a significant carbon pool of 13 ± 11 kg/m³ (Yedoma) and 22 ± 11 kg/m³ (thermokarst). Moreover, biomarker *n*-alkane proxies reveal a higher land plant source signal and a minor degradation state of the OM.

Stable water isotopes of ground ice and archaeol concentration reveal cold climate during the late Pleistocene and a comparatively warmer temperature during the Holocene. The biomarker temperature is a promising tool and could be a supplement to the temperature signals inferred from water isotopes, but our data illustrates that the absolute GDGT temperature interpretation is not appropriate for the studied deeper sediments.

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Ice-rich Permafrost and the Rehabilitation of Tundra on Alaska's North Slope: Lessons Learned from Case Studies

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Background

Alaska's North Slope oilfields are situated above 70° North in a region underlain by permafrost to depths of 600 m and with active layers typically less than 50 cm thick. Since oil production began in 1977, a complex of production facilities, pipelines, and over two thousand wells have sent more than 15 billion barrels of oil to refineries on the west coast of the United States. All of this has occurred under the scrutiny of multiple federal, state, and regional agencies tasked with overseeing environmental regulations. These regulations include requirements to rehabilitate tundra damaged by industry.

In general, post-excavation revegetation of sites on Alaska's North Slope is a slow process, requiring more than 20 years due to the slow growth of plants [*Streever et al. 2003*]. While more research might improve revegetation methods and rates, this report focuses on changes in the active layer that affect rehabilitation sites.

The two situations most commonly requiring rehabilitation efforts are (1) abandoned sites where gravel originally placed to provide a stable building foundation (i.e., a "gravel pad") has been removed, and (2) sites where cable and pipeline burial have required excavation.

As recently as ten years ago, planners suggested that gravel removal would cause thawing of the near-surface, ice-rich permafrost, leaving behind shallow ponds in the shape of the previously existing gravel pad. Conversely, planners were less concerned about melting ground ice and subsidence in backfilled trenches, because it was generally accepted that simply "mounding" soil over backfilled trenches would easily address trench subsidence. Over the past ten years, experience has shown that assumptions made about the importance of melting ground ice were incorrect for both gravel removal sites and backfilled trench sites.

Subsidence and Rehabilitation Sites

For rehabilitation sites where gravel has been removed, up to 30 cm of gravel was sometimes left in place to prevent the creation of unwanted ponds. However, experience has shown that sites subside unevenly following gravel removal, leaving behind a surface that is often slightly lower than the surrounding tundra grade but with both high and low areas and an unusually thick active layer.

While no sites on which gravel has been removed to tundra grade have collapsed to create ponds over the entirety of the original footprint, even the relatively minor subsidence that does occur results in soils saturated with water during the first and second summer after gravel removal. However, within two years after gravel removal, melt collapse of ice wedges creates drainage networks that remove unwanted water (Fig. 1).

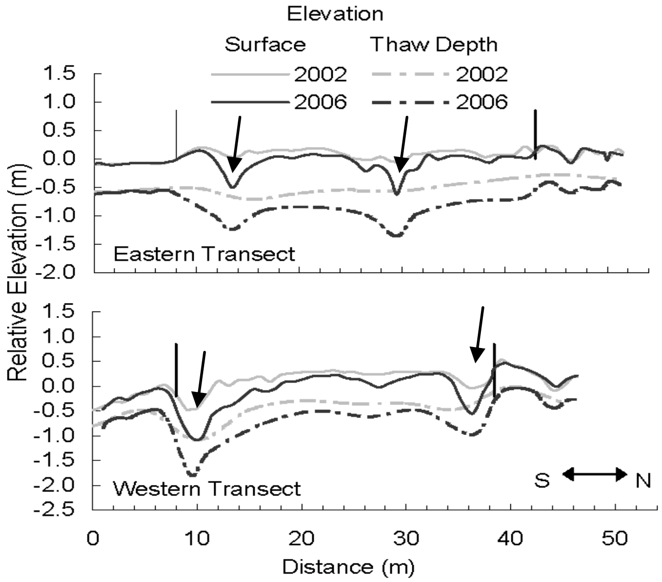

Fig. 1. Subsidence and change in active layer thickness at the Mobile Kuparuk Airstrip gravel removal rehabilitation site, showing both overall site subsidence from 2002 until 2006 and development of melted ice wedge troughs (arrows) that drain saturated soils. Vertical bars mark the northern and southern edges of the site, with undisturbed tundra outside of the bars.

As is the case with excavated gravel pad sites, trenches that are excavated and backfilled tend to subside after construction and ice wedges intercepted by trenches tend to melt. At the same time, the active layer thickens near the edges of trenches and the active layer in the backfilled trenches themselves tends to be deeper than those of surrounding undisturbed ground. However, perhaps because trenches form linear features that cross the landscape and are capable of capturing surface flows, melting of near-surface ground ice can be more extensive than that normally seen on gravel pad removal sites. More than 1 m of subsidence has been seen at some trench sites and subsidence can continue for at least a decade after construction. Melted ice wedges do not drain subsided trenches, apparently because of the depth of subsidence. Furthermore, ice wedge melting can extend outward from trenches into the surrounding tundra (Fig. 2).

Land managers have tried different methods to control thermokarst degradation of trenches, including repeated backfilling using mineral soils brought in during the winter season or transported in during the summer season on trucks designed for tundra travel (i.e., trucks with very low ground pressure). The only method that has worked with reasonable consistency involves placing backfill into subsided trenches to regain elevation loss followed by capping of the backfilled trenches with tundra sod (i.e., soil with intact plants harvested from nearby donor sites). The tundra sod appears to limit further ground ice degradation, probably by providing insulation, increasing albedo, and cooling through evapotranspiration during summer months.

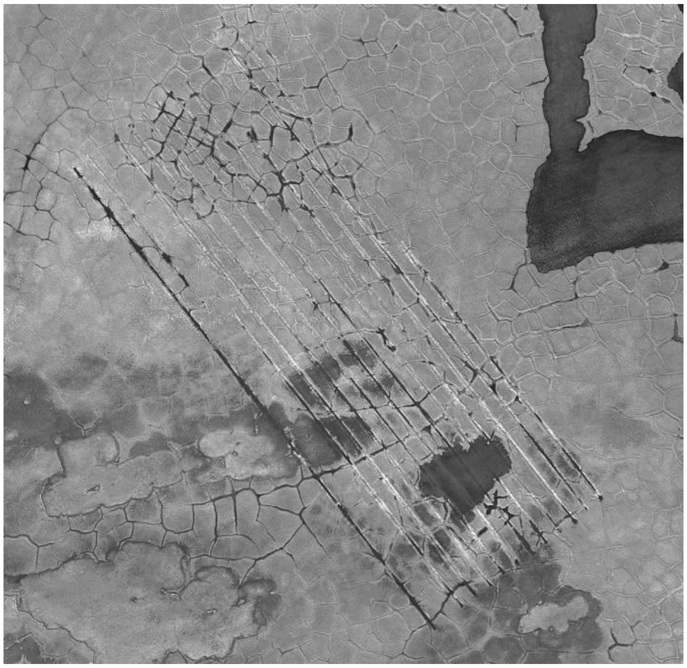

Fig. 2. A 2011 photograph of a site where trenching equipment and methods were tested in 2002. Subsidence continued even after repeated backfilling, as can be seen at the trench on the left side, and ice wedge troughs had extended laterally from some of the trenches.

Conclusions

On North Slope gravel removal rehabilitation sites, thawing of near-surface permafrost has not presented the difficult challenges that were anticipated a decade ago. In fact, soil saturation that seems to be associated with limited thaw subsidence is often offset by drainage channels created when ice wedges melt on gravel removal restoration sites. In a sense, the challenge created by thawing of near-surface permafrost is solved by the melting of ice wedges. Conversely, on trenching sites thaw subsidence appears to be a greater problem than was anticipated a decade ago, not only creating on-site subsidence but in some cases also extending beyond the trench edges into the surrounding tundra.

Well-designed and replicated experiments might yield useful results and could define relationships between the degree of thaw subsidence likely to occur in a given location, the existing pre-excavation ground ice conditions, and the planned rehabilitation activity. However, the value of case studies and well-documented field observations should not be overlooked. As the North Slope oilfields continue to mature and the number of rehabilitation sites increases, an improved understanding of the dynamics of near-surface ground ice on rehabilitation sites will increase in value. Because of the paucity of data from well designed and replicated experiments, improved understanding will have to come from case studies and well documented field observations. An effort to systematically understand the information available in well-documented case studies is warranted.

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Permafrost Soil Warming Induced by Elevated CO_2 and Increased Summer Rainfall

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Summary

Increases in soil moisture due to anthropogenic forcings may increase soil temperatures independently of air temperature increases by strengthening the snow thermal rectifier effect. Plant physiological forcing associated with CO_2 increases from 285 ppm to 857 ppm, or increases in summer rainfall of 25%, caused 1-2 °C soil warming in many Arctic permafrost regions. Experimental manipulations and comprehensive Arctic soil observations should investigate this mechanism.

Introduction

Twenty-first century anthropogenic forcings may cause changes in hydrology in permafrost regions. For instance, soil moisture could increase independently of air temperature due to reduced transpiration resulting from elevated CO_2 [*van Groenigen et al., 2011*], or increased summer rainfall, which is generally predicted at high latitudes under climate change. The snow thermal rectifier effect is a strong control on permafrost soil temperatures [*Lawrence & Slater 2010*], but its interaction with soil moisture has not been extensively studied. Here, we investigated whether increased soil moisture from elevated CO_2 or increased summer rainfall could cause soil warming in addition to that of caused by increases in air temperature.

Methods

We performed a series of equilibrium experiments with the Community Land Model 4 (CLM4) [*Lawrence et al., 2011*] with prescribed leaf area and prescribed pre-industrial atmospheric conditions. Some modifications to high-latitude soil hydrology corrected unrealistic hydraulic diffusion through frozen soils in CLM4. The primary experiments were: (**1**) increasing CO_2-physiological concentrations from 285 ppm to 857 ppm; (**2**) increasing June through September rainfall from 100% of pre-industrial values to 125%; and (**3**) increasing June through September rainfall from 75% of pre-industrial values to 100%. We also repeated Experiment **1** with perturbed physics to isolate mechanisms linking soil moisture and temperature changes: (**A**) soil thermal conductivity prescribed independently of soil moisture saturation; (**B**) no heat of fusion for freezing and thawing in the soil; and (**C**) both (**A**) and (**B**).

Results

All experiments caused increases of soil moisture of 10-20% in many regions. The increases occurred most widely in Experiment **3**, as the drier soil conditions with 75% of summer rainfall allowed more potential moistening with increased water availability. Increases were also more widespread in Experiments **2**-**3** than **1**, as the significant presence of transpiring vegetation was not necessary to mediate the soil moisture increases.

In all experiments without perturbed physics, these increases of soil moisture were associated with 1-2 °C mean annual soil warming in some permafrost areas of northeast Siberia, northern Canada, and northern Alaska (Figure 1). Analysis confirmed that increased soil moisture alone was responsible for these temperature increases, via two mechanisms: increased heat of fusion associated with freezing and thawing [*Goodrich 1982*], and increased soil thermal diffusivity.

Analysis

In the perturbed physics Experiments **A** and **B**, the warming resulting from soil moisture increases from elevated CO_2 was about half that found in Experiment **1**; in Experiment **C**, the warming was eliminated. The heat of fusion and soil diffusivity mechanisms caused complementary seasonal-vertical patterns of soil temperature and soil heat flux changes. The increased heat of fusion caused summer cooling and winter warming throughout the top 4 m of soil, associated with increased heat convergence to the thaw front and divergence from the freeze front. The increased soil diffusivity caused near-surface summer cooling and winter warming, with opposite effects near the bottom of the active layer at 2 m. In both cases, the magnitude and duration of warming exceeded that of cooling, and the deep soil below about 5 m experienced an annually constant warming.

All experiments without perturbed physics showed increases in seasonal energy flux exchange between the soils and the atmosphere of 2-4 W m^{-2} in gridcells experiencing greater than 1 °C warming. This was independent of summer Bowen ratio changes, as the latent heat decreased and sensible heat increased in Experiment **1**, while the opposite occurred in Experiments **2**-**3**. In the perturbed physics Experiment **C** where no soil warming occurred, no increases in seasonal flux exchange between the soils and the atmosphere occurred. In Experiments **1**-**3**, increases in absorbed solar radiation of 0.5-2 W m^{-2} occurred in the spring and summer due to accelerated snow melt (a positive feedback to the soil warming) and soil darkening associated with moistening.

Discussion

We are currently repeating these experiments in the context of responsive leaf area and a transient RCP 8.5 atmospheric forcing scenario. Preliminary results show that allowing prognostic leaf area increases cause slight reductions in soil moisture increases but also enhance acceleration of spring snow melt, causing little net change in predicted soil warming.

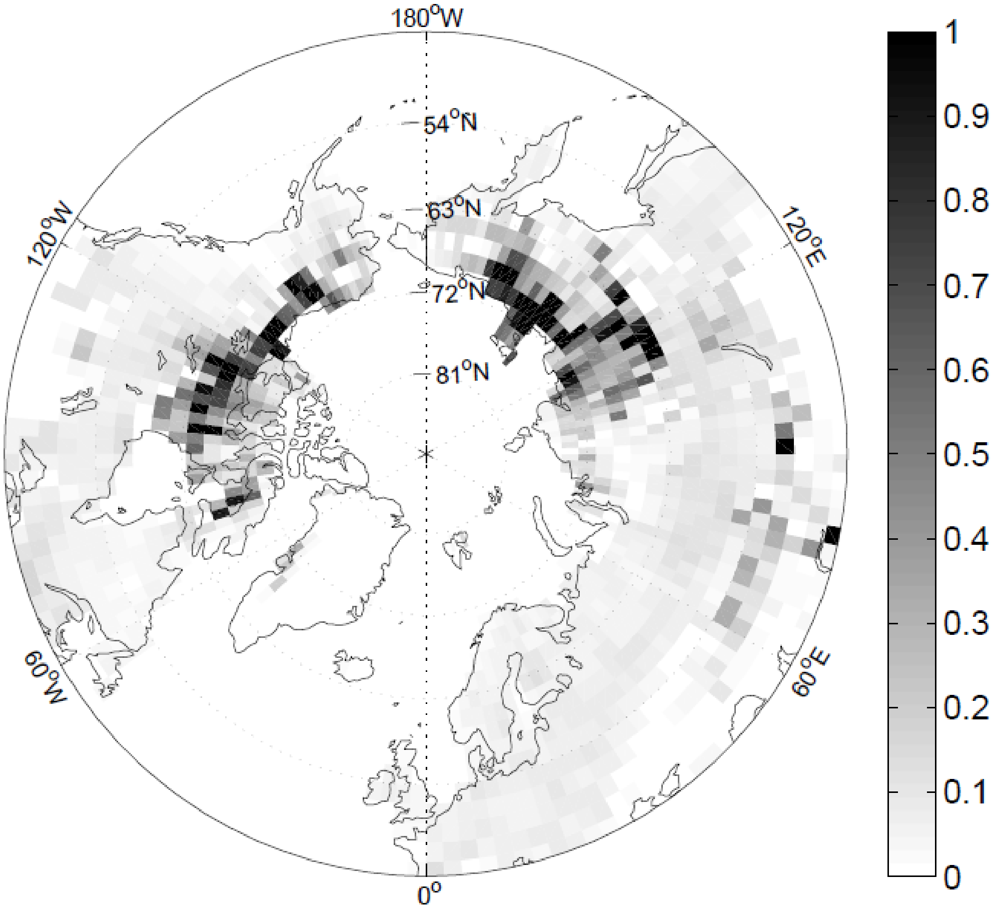

Figure 1. Annual- and vertical-mean soil temperature increases (°C) associated with increasing CO_2-physiological concentrations from 285 ppm to 857 ppm under otherwise pre-industrial conditions

Realistic responses may be influenced by additional biogeochemical mechanisms that are currently poorly represented in global terrestrial models like CLM4: changes in soil organic matter or moss content in response to soil wetting, and changes in vegetation species prevalence in response to soil wetting and elevated CO_2.

The mechanisms identified here linking anthropogenically-forced soil moisture increases to soil warming could be associated with increased mineralization of permafrost soil carbon, representing a positive feedback to climate change. Moreover, increases in CH_4 and N_2O emissions are likely, as soil warming is coincident with soil moisture increases. Future experiments should investigate these possibilities. Also, more comprehensive soil moisture observations in permafrost areas are needed to constrain the future vulnerability to these mechanisms of warming.

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Modelling Peatland Land Surface Processes, Vegetation Dynamics and Methane Emissions for Lena River Delta Region

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Introduction

Northern peatlands and permafrost associated with large soil carbon stocks are responsible for a high proportion of natural methane emissions. Rising temperatures will affect the carbon balance of high latitude ecosystems. The great number of the peatland permafrost ecosystems concentrate in the Lena River Delta Region. In the project we were studied the dynamics of active layer depth, water table position and vegetation in the Lena River Delta Region peatlands using Lund-Potsdam-Jena: Wetland hydrology and methane (LPJ-Why-Me) global vegetation model. Also we were explored possible effects of future regional climate change on the Lena River Delta ecosystems. The results were showed methane emission form the Lena River Delta Region give not significant contribution to global methane budget. We were provided algorithmic and physical analysis of LPJ-Why-Me with aim of correctly using of the model for local sites.

The radiative forcing due to methane — the second largest of the long-lived greenhouse gases after carbon dioxide — and its Global Warming Potential (GWP), which is about 20 times higher than the GWP of CO_2 [*IPCC 2001*], demonstrate the significant contribution of methane to warming of the atmosphere. The global atmospheric methane concentration has risen from a pre-industrial value of about 715 ppb to a current value of about 1774 ppb [*IPCC 2007*].

Due to high sensitivity of the arctic soil carbon reservoir to increasing temperatures and to the large surface area, arctic regions are most critically influenced by changing climate. In thawed permafrost soils, methane is produced by specially adapted microbes under anaerobic conditions and released into the atmosphere. Extensive thawing of permafrost will release the carbon contained in the soils, hence further affecting the global carbon cycle. Model scenarios predict a severe degradation of permafrost in the Northern Hemisphere, including a northward shift of the permafrost boundary as well as an increase in active layer depth [*Lawrence & Slater, 2005; Zhang et al., 2007*].

Background

Peatland environments of the Arctic are natural sources of the climate relevant trace gas methane. These environments represent the largest accessible carbon pool where more than 14 % of the global terrestrial carbon is accumulated. Although it is definite that Arctic tundra significantly contributes to the global methane emissions in general, regional variations in GHG fluxes are enormous. CH_4 fluxes of polygonal tundra within the Siberian Lena Delta, for example, were reported to be low, particularly at open water polygonal ponds and small lakes which make up around 10 % of the delta’s surface [*Liebner et al., 2010*].

Different permafrost and vegetation processes, which are responsible for the decomposition of organic matter and the generation of greenhouse gases, is influenced by changing environmental conditions. For the understanding and assessment of recent and future carbon dynamics in high latitudes we is studied the peatland land surface processes, and the vegetation dynamics of peatland permafrost area of the Lena Delta Region, Siberian Arctic.

The **LPJ-WHyMe** (Lund-Potsdam-Jena-Wetland Hydrology and Methane) is modification version of the LPJ global vegetation model for to simulate permafrost dynamics, peatland hydrology and peatland vegetation. We have experience using of modelling methane emissions in a mechanistic particularly the model [*Sudakov 2010*]. Also, LPJ-WHyMe simulates methane emissions using a mechanistic approach, although the use of some empirical relationships and parameters is unavoidable. The model simulates methane production, three pathways of methane transport (diffusion, plant-mediated transport and ebullition) and methane oxidation [*Wania 2007*].

Future projections for ecosystem dynamics can be made using models of comparable complexity to LPJ-WHyMe [*Lawrence & Slater, 2005; Euskirchen et al., 2006*] and results from LPJ-WHyMe. We can use LPJ-WHyMe to examine the changes seen in land surface processes based on the Earth System Models results using the IPCC emission scenarios.

Results

We used LPJ-WHyMe to examine the changes seen in land surface processes in the Lena River Delta Region based on PlaSim results using the IPCC SRES B1 and A2 emission scenarios. These two scenarios were chosen to represent a conservative future scenario, B1, where atmospheric carbon dioxide concentrations by the end of the 21st century have risen to 550 ppmv and a more dramatic scenario, A2, where carbon dioxide concentrations reach 856 ppmv by 2100. As the computational time needed to run LPJ-WHyMe increased by introducing the methane model, we limited future projections for methane emissions to the SRES A2 scenario.

In LPJ-WHyMe simulations forced directly by climate output from IPCC SRES A2 and B1 scenario runs of the PlaSim, permafrost area and soil temperatures remain more or less stable throughout the first hundred years of simulation. Soil temperatures at 25 cm depth under the A2 scenario increased faster in all latitudinal bands during the second half of the 21st century. The bidecadal increase under the A2 scenario will be increase of more than 2.2°C.

Future projections of water table positions for the A2 and B1 scenarios look very different. One potentially important issue for the simulation of future water table changes concerns changes in drainage such as channel formation or collapse of permafrost plateaus. As far as we are aware, these processes are not yet captured by any model. It should therefore be kept in mind that simulated peatland drying in this study is caused by a decrease in precipitation minus evapo-transpiration under a constant drainage regime.

Under forcing by PlaSim climate output, total annual net primary-production from LPJ-WHyMe increased under both scenarios. The SRES B2 scenario showed the strongest increases. Much higher increases were found under the SRES A2 scenario. The researched are stay wetter than other areas outside the summer period, which could be beneficial to wetland plant functional types. Other factors leading to higher net primary production in some areas under the SRES A2 scenario are higher temperatures and atmospheric carbon dioxide concentrations.

When conducting the LPJ-WHyMe runs for the future projections of land surface processes, methane emissions were calculated at the same time. Hence, the identical runs used for the land surface processes can be used here to explore future methane emissions. The studied areas show increases methane emissions from 40.4 gCH_4yr^{-1} to 65.4 gCH_4yr^{-1} (SRES B1) by 2100 and from 56.3 gCH_4yr^{-1} to 80.6 gCH_4yr^{-1} (SRES A2) by 2100. All peatland CH_4 fluxes - 500-600$TgCH_4yr^{-1}$ by 2100 however methane emissions from the Lena River Delta Region - 80.6 gCH_4yr^{-1}. So, it isn't give contribution to global methane budget and climate positive feedback.

Conclutions

In the result of project work we have carried out the working plan. We provided detail analysis of LPJ-Why-Me scheme. We looked the scheme of LPJ-Why-Me can be apply inconsistently, so it’s necessary take account of error of simulations. We have tested and validate LPJ-Why-Me for the Lena River Delta Region. For it we have used available observations from Russian–German research at the Lena River Delta Region as well as ESA DUE PERMAFROST project has provided us the remote sensing data. We used for the calculations and comparisons the Planet Simulator (Model of Intermediate Complexity from University of Hamburg and Max-Plank Institute for Meteorology) suitable for climate and paleo-climate simulations and time scales up to ten thousand years or more. It was used in couple with LPJ-Why-Me for examining the changes seen in land surface processes of the Lena River Delta Region based on the IPCC SRES B1 and A2 emission scenarios. The LPJ-Why-Me calculations showed permafrost temperature, water table position and net primary production will increase by the end of 21st century. We were estimated contribution of methane emissions from the Lena River Delta ecosystems to global methane budget and variability of the positive feedback of the climate system. The calculations showed methane emissions from the Lena River Delta are not significant for global climate warming.

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Changing Permafrost and Arctic Population: a quantitative assessment for the Russian Arctic

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Introduction

The Russian Arctic is an important environment because of its combination of economic significance, urban population and thawing permafrost. Ten percent of the world's supply of oil, and 25% of the world's natural gas is located in the Russian Arctic. There are also large mineral extractions industries. Overall the Arctic contributes five percent to the world economy and the Russian Arctic contributes two-thirds of this. Due to its economic importance these areas have significant populations. Populations throughout the Russian Arctic have fluctuated considerably between the 1960s and present day, with an overall decline since the early 1990s. One characteristic of the Russian Arctic population is that it is distinctly urban. The urban population accounts for 1,335,500, or nearly three-quarters of, the total population of 1,854,000 people living across the Russian Arctic [*Goskomstat Rosii 2002*]. Urban areas require substantial and reliable infrastructure. A majority of Russian Arctic infrastructure is built on permafrost according to the first (passive) construction principle which relies on bearing capacity of the frozen ground. In Russia permafrost underlies about 66% of the total area and has undergone significant changes over the past decades due to climatic warming. This has resulted in significant increases in permafrost temperatures, northward retreat of the southern permafrost boundary, and degradation of the ice-rich permafrost. This study focuses on the assessment of population, which has the potential to be adversely affected by ongoing changes in permafrost conditions and the related stability of the human infrastructure. The analysis is based on the results of a quantitative assessment of bearing capacity of the frozen ground and census data for five administrative areas in the Russian Arctic bordering the Arctic Ocean. These administrative areas include the Nenets Autonomous Okrug (AO), the Yamalo-Nenets AO, the Taymyr AO, the Republic of Sakha (Yakutia), and the Chuckchi AO.

Methods

To evaluate the effects of permafrost infrastructure changes on population we used an empirically based permafrost-geotechnical model [*Streletskiy et al. 2012*] together with population data from the Russian 2002 census [*Goskomstat Rosii 2002*]. The estimates of the bearing capacity of the standard foundation pile were based on climate-dependent permafrost characteristics. Our results are based on a particular climate data set. Different climate data sets create uncertainty in modeling bearing capacity. Our model was forced by daily air temperature and precipitation data from NCEP/NCAR Reanalysis 1 for two decadal time periods of 1965-1975 and 1995-2005. 1965-1975 was chosen to represent a base year because there was a considerable about of construction during this period. 1995-2005 represents the contemporary time period. Details on modeling procedure and input data can be found in Streletskiy et al. [*2012*].

To analyze the population effected by changes in infrastructure stability we used 2000-2002 Russian census data from Goskomastat Rosii 2002. Although the latest Russian census was conducted in 2010, the data was not available at the time of our analysis. Since rural populations are probably least affected by infrastructure stability, we focused our analysis on 102 urban centers of various sizes. The analysis of population distribution in relation to changes in permafrost infrastructure stability, between reference periods centered on the years of 1970 and 2000, was conducted within ArcGIS.

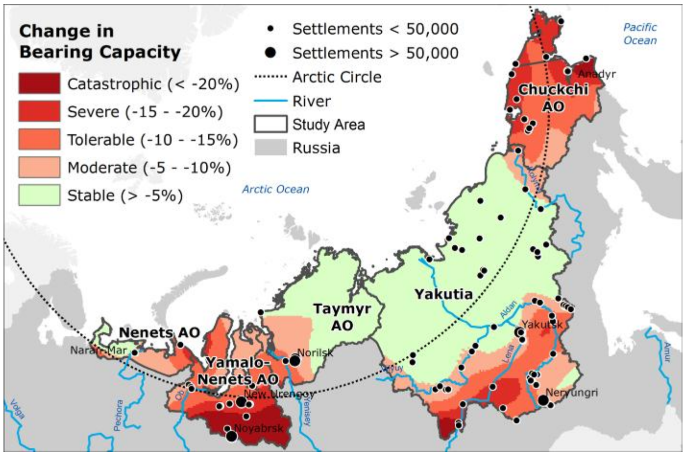

Figure 1. Percent change of bearing capacity between the two time periods. Percent decreases are divided into categories related to hazard potential identified by Russian engineering practices that consider climate variability and change during construction [*Khrustalev 2000*].

Results and Discussion

Based on the quantitative analysis of the Russian census the urban settlements were divided into four categories based on their populations: less than 2,000 people (31 settlements); between 2,000 and 10,000 people (44 settlements); 10,000 and 50,000 people (21 settlements); and above 50,000 people (6 settlements). The six largest settlements represented half of the total population of the study area. Percentage-wise, 33% of the population, or 435,400 people, were located within the 10,000 to 50,000 category. 16% (215,800 people) were in the 2,000 to 10,000 category. Only 2% comprised the 31 settlements with populations less than 2,000. It should be noted, that even smallest settlements considered for analysis were distinctly urban. This reflects the Soviet development policies of 1960s-1970s, with people concentration in apartment blocks and complexes consisting of mid-rise buildings of standard design. From the permafrost-geotechnical model in Streletskiy et al. (2012) infrastructure stability changed most in southern Yamalo-Nenets AO, north and east Chuckchi AO, and southwestern Yakutia. Other areas affected, though not as drastically were in eastern Nenets AO, northern Yamalo-Nenets AO, far western Taymyr AO, southeast Yakutia, and western Chuckchi AO. The biggest urban areas with the largest changes in stability were Noyabrsk and Novyi Urengoy. Norilsk, Neryungri, and Yakutsk all experienced moderate changes.

Table 1 Distribution of Present Population for Urban Settlements by Change in Bearing Capacity.

Percent Change in Bearing Capacity	Chuckchi AO	Nenets AO	Taymyr AO	Yakutia	Yamalo-Nenets AO	Study Area
Less than -20%	5,200	0	0	9,300	151,500	166,000
Between -15% and -20%	32,600	1,800	0	10,300	164,700	209,400
Between -10% and -15%	8,300	0	51,800	86,200	70,400	216,700
Between -5% and -10%	0	25,400	199,500	428,200	0	653,100
Greater than -5%	0	0	1,100	89,200	0	90,300
TOTAL	46,100	27,200	252,400	623,200	386,600	1,335,500

Table one shows the affected populations in the study area. The largest population experienced between -5% and -10% potential changes in bearing capacity. This category consists of the most settlements 33, and around 650,000 people. The categories of less than -20% and between -15% and -20% combined accounted for about 375,000 people and 28 settlements. The greater than -5% classification accounts for the smallest population of around 90,000 people and 22 settlements.

The area of most concern was that of Yamalo-Nenets AO. It had the largest populations living in the most affected areas of change, and it also has considerable natural gas and oil infrastructure. Three settlements alone in this area accounted for a population of around 150,000. In Noyabrsk, one of the largest cities in Yamalo-Nenets AO nearly 100,000 people were affected. And in nearby Muravlenko, close to 40,000 people were affected.

In contrast out of the 102 settlements studied, only 22 had greater than -5% change. The majority of these were located in northern or central Yakutia. The six settlements that experienced the least change were Tiksi, Northern, White Mountain, Deputy, and Ust-Kuyga. The population of these settlements combined was less than 20,000 people. The number of people affected by negative changes to infrastructure stability far exceeds the number of people affected by positive changes in infrastructure stability.

Conclusions and Further Research

Comparison of infrastructure stability and population centers the following conclusions can be drawn:

- There were considerable decreases in infrastructure stability in regions with high populations. The most notably are Noyabrsk, Novyi Urengoy, and Norilsk, which are also important to the economics of the region. Northern Yakutia was an area that did not see substantial infrastructure stability loss. It had a much smaller population.
- Overall 166,000 people lived in areas of less than –20% change in infrastructure stability. 209,400 lived in areas with between –15% and –20% change. 216,700 lived in areas with between -10% and –15% change. 653,100 lived in areas with between –5% and –10% change. 90,300 lived in areas with greater than –5%. More population is located in negatively affected areas than positively effected areas.
- Additional work, examining socio-economic and technogenic factors, is needed to also look at the role of maintenance and aging infrastructures.

Acknowledgments

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Ball Valves Shafts for Operating in Severe Conditions

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Today worm gearing serves as the basis for the overwhelming majority of valves hand shafts, both in Russia and abroad [*Nabiev 2010*]. Despite the results achieved in the sphere of the worm gear manufacture technology by leading native and world manufacturers and the successful design arrangement of the shaft, the reasons requiring shaft development on the basis of other gear units include the low performance of a warm gear (≈ 40%), the limited load capacity and the significant starting torque influencing specifically negatively the shaft reliability in severe operating conditions, and the high specific metal content of the shaft.

The report describes the results of valves shafts development on the basis of use of the precessional pan gear [*Syzrantsev et al. 2008, Syzrantsev et al. 2009, Syzrantsev et al. 2011*] providing for the transmission ratio from 22 to 65 in one speed at the multi-paired (up to 8…12 pairs) teeth contact in gearing, with high performance (88…90%) and smooth operation. The developed shaft has increased (up to two times) torsion torque and 40%-reduced metal content with the same load capacity, in case of the identical mass and driving torque on the basis of worm gearing. Gear teeth and gear wheels roll but not slide relative to each other in the process of work, as compared to worm gearing. As a result the gear has a significantly lower starting torque and remains operative in severe operational conditions (at temperature -60° to +60°).

Figure 1 shows the kinematic and the construction diagrams of the shaft, and Figure 2 shows the shafts manufactured for a ball valve DU-300.

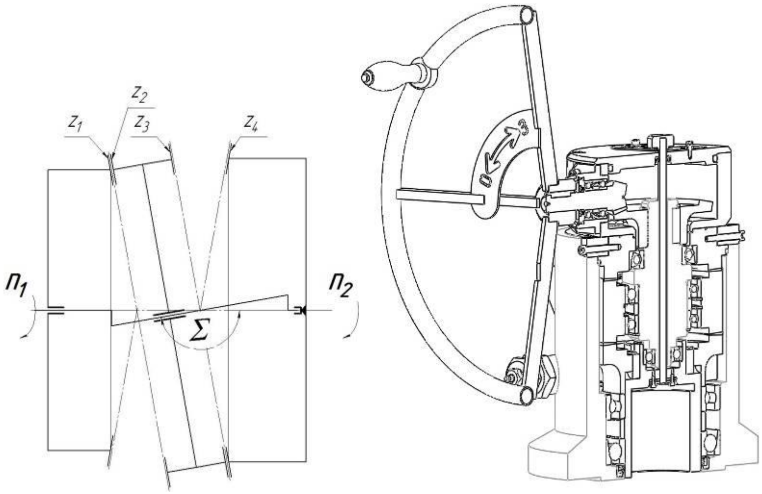

Figure 1.

Figure 2.

The shaft represents a double-reduction gear unit. The first speed is bevel gear with the transmission ratio $u_1 = 5{,}1$. The second speed is pan gear with biconvex/concave teeth with the transmission ratio $u_2 = 65$. The shaft for pipeline valves corresponds to TU3791-004-09153509-2011. Certificate No C-RU.AB72.D.01007 TP057158. TOMFLON EPM50 lubricant is used. The torsion torque at the ball valve makes 24000·M in case of the effort on the control wheel grip 180 N.

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The Problems of Designing the Heat Insulation for Bases of Vertical Steel Cylindrical Tanks Constructed in the Cryolithozone

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The scope of design of hydrocarbon production and transport facilities grows from year to year. Moreover, the construction areas move further to the north, to hard-to-reach areas with long-term cryolithozone ("permafrost"). Hydrocarbon storage tanks are one of the most heavy-duty and complex structures for design. There is already positive experience of a crude storage construction with up to 50,000 m^3 tanks available, and Gazprom is planning to build a 160,000 m^3 tank for liquefied natural gas storage in Yamal.

Nonetheless, the normative-technical base for this problem is developed very poorly and requires harmonization with foreign standards. There are almost no experimental studies conducted. There is also negative experience despite several successful projects completed. Departmental disunity hinders full scientific information exchange. Many oil companies formed their research and design institutes that hinder the disclosure of any negative information from the corporation. Moreover, contracts are accompanied by signing the agreements on information non-disclosure. In these conditions there is no way to hope for full scientific discussion. The situation is complicated by the fact that there are no answers to the arising questions in foreign standards and scientific literature either.

The specialists designing structures and diagnosing tanks in the cryolithozone know several tens of accidents occurred during the recent five years. We think that the main problem consists in construction of the heat-insulating layer between the structure foundation and the foundation grounds. The extrusion-type cellular polystyrene is frequently used as the heat insulator nowadays. The heat insulator layer reaches 50 cm and is placed between the foundation and the ground. The pressure transferred to cellular polystyrene can reach 0.3 MPa, depending on the construction area and the vertical steel tank type. All accidents we know are associated with tank settlement in the process of operation, hydraulic testing, or at the construction stage already. It is known that one owner of the settled tank ordered a design of compensators for receive-transmit pipe branches with a 40 cm travel. Tank operation with such base deformations is prohibited by any standards requirements. The witnesses of vertical steel tank settlement confirm that the base deformation process is frequently accompanied by leakage of a significant water volume from under the bottom even in winter. In rare cases the bases "go upwards" in case of the hydrostatic load removal, but they never turn back to the design position.

Tanks are usually designed by several contractors. Metalworks, foundations and systems hindering ground thawing are designed independently. Unfortunately, egregious violations are made in the process of assemblage of the whole structure design. It is known that one customer introduced changes into the technical assignment and a foundation ring was designed instead of a pile foundation, and the heat insulation layer was left for the previous structure. In this connection, the loads on the cellular polystyrene layer grew by several times, and this led to the development of impermissible vertical steel tank settlement. Construction and assembly works are frequently violated, especially in case of base construction in winter. The analysis shows that incorrect assessment of the rheological properties of the extrusion-type cellular polystyrene is the reason for accident occurrence.

Today, extrusion-type cellular polystyrene Styrodur of BASF production is one of the most known products in the market. According to the DIN EN 1606 standard requirement, it has the permissible compression strain up to 250 KPa for the long-term load of 50 years and the relative deformation of <2%. Multiple analogues of our country occur. Similar materials are already used for construction of motor roads, aerodromes etc. After several accidents of its deformation the designers started inquiring warranty letters from heat-insulating materials manufacturers, concerning the permanence of the polystyrene strength properties in case of long-term operation. And they got the answers meaning that since the density and the heat conductivity coefficients of native and foreign materials are approximately the same, the rheological characteristics must correspond approximately as well. This uncertainty is inadmissible in case of design of such heavy-duty structures as tanks, when the cost of the product stored is commensurable with the cost of the whole structure, not to mention the probability of the environmental harm in case of an accident. Apparently, the materials with higher strength, although with higher heat conductivity, for example cellular glass, can be used prior to the clarification of the question on the possibility of polystyrene use in thermostabilized bases.

Since the properties of foamed extrusion-type polystyrene are defined mainly on the basis of foreign standards, and the native normative base is not harmonized with them thoroughly, it would be logical to submit conclusions on the technical characteristics of the materials from laboratories or research centers attested in the countries of this legislation to design organizations. Moreover, the native normative and technical documentation must change as well, at least in terms of determination of the individual residual resource, or simply the assignment of the operational term for a hazardous production facility with a polystyrene layer in its base. Not only the rheological properties of the insulator but also the peculiar features of the structure in general shall be defined with regard to the dynamic loads from discharge and pour operations, blade agitators, the seismicity etc. in the coordinates associated with the permissible operational period of the whole facility.

Space Weather Effects on Technological Systems at the Northern Areas

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Introduction

Variations of solar wind parameters change electromagnetic fields at the ground level. Geomagnetic storm is a typical example of geomagnetic disturbance. Slow varying electric field during magnetic storm leads to exiting of geomagnetically induced currents (GIC) in any earthing conducting system, such as power lines, signal cables, buried pipelines and so on.

During global magnetic storms a disturbance covers the whole planet, magnetic field variations and induced electric fields can develop throughout both hemispheres practically simultaneously. Besides global storms, magnetospheric substorms (though smaller in scale and intensity) are also significant for development of GIC. The generated currents reach their highest values in the auroral and subauroral regions, under strong storm-related ionospheric currents or jets. Time variations of jets are the physical GIC source. In the report possible effects of GIC on technological systems are discussed.

Geomagnetically Induced Currents

The impact of geomagnetically induced currents and fields depends on the level of disturbance, conducting system parameters, its location and orientation, as well as on local ground conductivity. Variations of storm-related ionospheric jets are directed mainly along geomagnetic latitude and for the lines of East-West direction effect can be more strong. An inductive geoelectric field can reach the value of 1- 40 V/km. and related currents can reach magnitude of hundreds of A.

Electric power lines

In electric power lines these nearly DC currents run along lines to the earth through transformers and can be cause of saturation, relays malfunction and damage of transformers (Boteler, 2001).

Railway automatics

At a railway road GIC can affects on signaling system and leads to blinking of signaling lights (Eroshenko et al., 2010).

Pipelines

Variations of GIC in pipelines lead to changes of pipe-to-soil potential (PSP) and can affect corrosion conditions and interrupt regular operation of the cathodic protection system [*Smart, 1982; Viljanen, 1989*]. Fluctuation in pipe-to-soil potential difference, produced by geomagnetic disturbance, change the electromagnetic conditions on the pipe and it is temporarily not protected. In a time GIC-related corrosion can lead to appearance of a pit in the pipe wall. Most significantly this effect can developed at the border between zones with different resistivity as coast line or spots of permafrost, where soil have a wide range electrical resistivity values (1000 – 100,000 Ω-m for frozen and 40 – 1900 Ω-m for unfrozen soil).

GIC recordings

The problem of GIC-risk mitigation for different technological systems is active investigated in many countries. Polar Geophysical Institute takes part in Scientific Consortium of EURISGIC project. EURISGIC (European Risk from Geomagnetically Induced Currents) is supported by EU/FP7 program (grant no260330) and joined research groups from Finland, Sweden, UK, USA, Hungary and Russia. Current information of induced currents at power substations on N-W of Russia is presented on eurisgic.com site.

Concluding remarks

GIC excitation during geomagnetic disturbances is a bright demonstration of space weather effects on ground-based systems all around the planet.

It seems reasonable estimate the impact of geomagnetic disturbances on technological systems in Russia, at first at the North of country, where environment and climate conditions change dramatically along different conducting circuit. Except theoretical estimations and possible numerical simulations some experiments at existed systems are obviously needed. The work can include permanent recordings of GIC in power lines, PSP measurements at pipelines and permanent measurements of geomagnetic field variations.

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Preliminary Investigation on Permafrost Distribution in the Upper Reaches of Heihe River Basin in Western China

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Introduction

Permafrost and seasonally frozen ground have a dramatic influence on surface and subsurface hydrological processes, ecosystems, carbon cycle, and infrastructures in cold regions. The study of permafrost distribution and its temporal and spatial changes is of great importance for systematically understanding regional climate and environmental changes, water resources assessment, construction and resource development. During the summer of 2011, field investigation on distribution of permafrost had been conducted over the Heihe River basin. The Heihe River basin is located in the eastern part of Qilian Mountains with a cold and semi-arid climate. In this study, we present some preliminary results on distribution of permafrost and seasonally frozen ground over the study area (Fig. 1).

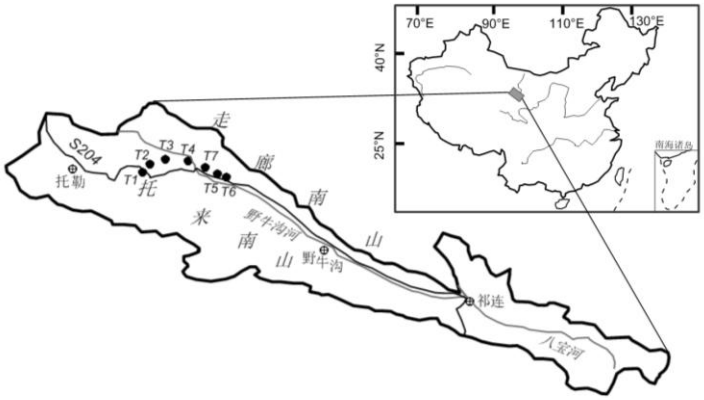

Fig. 1. Geographical location of drilling sites over the upper reaches of Heihe River basin in western China.

Field work and data sources

Seven boreholes were drilled with depths ranging from 20 to 100 m, completed by the late July and early August, 2011 (Fig.2). The seven boreholes span from 3600 m a.s.l. to 4132 m a.s.l. with spatial distance of about 50 km. Permafrost temperatures were measured about once a month after borehole drilling was completed. Permafrost temperatures were measured using a thermistor string with accuracy of 0.05°C in the laboratory calibration. Regional climate data were obtained from 12 meteorological stations with data mostly from 1960s to 2008.

Results

Lower Boundary of Permafrost: Based on data and information from borehole measurements after three months of drilling completion, soil temperatures at 10 m depth range from 2°C at 3600 m a.s.l. to -1.5°C at 4132 m a.s.l. (Fig. 3 and 4). Using these temperature profiles, it is preliminarily determined that the lower boundary of permafrost is between 3650 and 3700 m a.s.l. This result is consistent with the previous findings in this area [*Cheng 1987*]. However, further ground temperature measurements are needed to confirm these results.

Fig. 2. Drilling at site T4 during the summer of 2011.

Active Layer Thickness: Based on observations from drilling samples and subsequent temperature measurements, it is estimated that active layer thickness varies from 1.6 m at site T1 with elevation of 4132 m a.s.l. to greater than 4.0 m at site T7 of 3700 m a.s.l. (Fig. 1). Active layer thickness was also measured over the Ebo ridges using mechanical probes. The measurements were conducted at the beginning of October, 2011 and it is believed that the maximum thaw depth has been reached. The measurement technique is the same as the IPA CALM site measurements. Although the elevation at the Ebo ridge site is lower, the average active layer thickness is about 0.97 m with a range from 0.68 to 1.20 m. The thinner active layer over the Ebo ridge is perhaps due to (i) north-facing slope, (ii) thick peat layer (ranging from 0.3 to 0.5 m), (iii) little or no snow cover in winter months. Further studies are needed to better understand the dynamics of the active layer and upper permafrost.

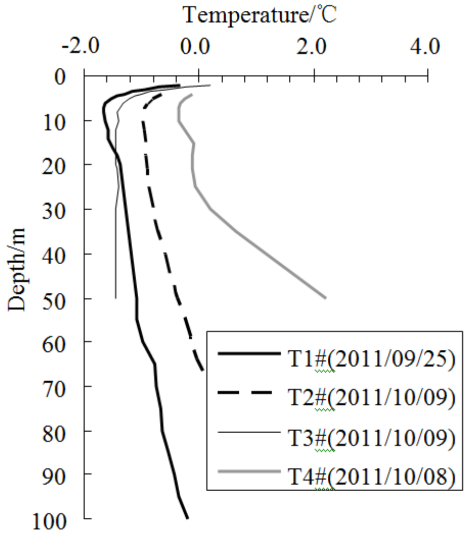

Fig. 3. Ground temperature profiles about two to three months after the completion of drilling at sites T1, T2, T3, and T4

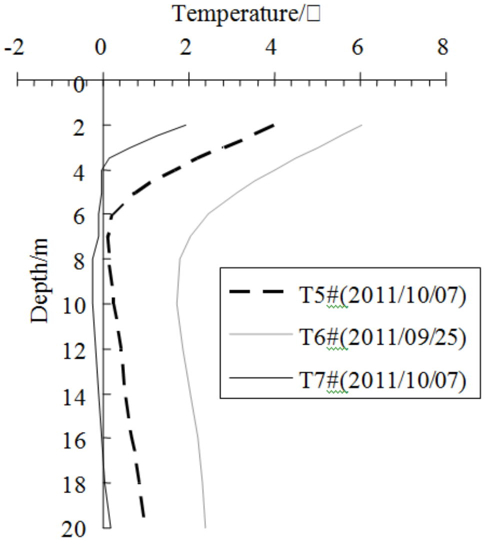

Fig. 4. Ground temperature profiles about two to three months after the completion of drilling at sites T5, T6, and T7. The lower boundary is roughly between site 5 and site 7.

Permafrost Thickness: Based on permafrost temperature profiles and drilling samples, permafrost thickness is estimated along the transaction from 3650 m a.s.l. to 4132 m a.s.l. (Fig. 1). Using the temperature gradient, it is estimated that permafrost thickness is about 113 m at site T1. At site T2, permafrost thickness is about 65 m determined from the temperature profiles directly (Fig. 3). While at T3 site, permafrost temperature at 50 m is -1.5°C and the permafrost temperature gradient from 20 to 50 m is very small, almost isothermal (Fig. 3). It is very difficult to estimate permafrost thickness at this site with current data and information and further study is needed. As moving toward lower elevation, permafrost thickness becomes thinner, about 27 m and 13 m respectively at site T4 and site T7.

Mapping of Frozen Ground: Using data and information from borehole drilling, temperature measurements, and mechanical probing of active layer depth, it is found that the lower boundary of permafrost over the upper reaches of Heihe River basin is at about 3650 m a.s.l. Certainly, the lower boundary changes with many local factors, such as slope aspects, vegetation type, peat layer thickness, soil types, soil moisture conditions, etc. Future work will need to focus on these factors affecting permafrost distribution over the study area. To the first order estimation, we use the value of 3650 m a.s.l. as the lower boundary to distinguish permafrost regions over the entire Heihe River basin. It is estimated that the total area of permafrost region is about 14,100 km^2, approximately 10.3% of the entire basin. The rest of Heihe River basin belongs to seasonally frozen ground regions (Fig. 5).

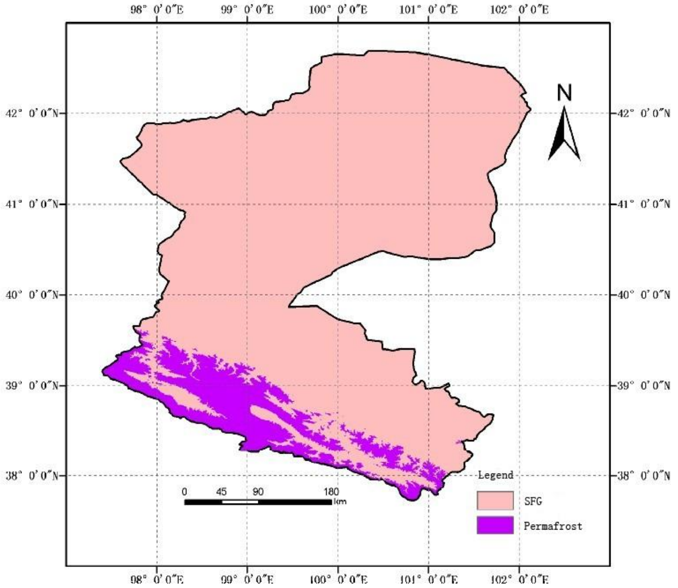

Fig. 5. Map of frozen ground distribution in Heihe River basin in western China.

Conclusions

Based field investigation, the lower limit of permafrost distribution in the upper reaches of Heihe River basin is at about 3650 m a.s.l., As moving from low to higher elevations, mean annual ground temperatures vary from around 0°C to -1.5°C; permafrost thickness ranges from a few meters to about 113 m; and active layer thickness decreases from greater than 4.0 m to 1.6 m at higher elevations. Approximately 14,100 km^2 or 10.3% of Heihe River basin belong to permafrost regions. Further study is definitely needed to investigate effect of local factors on permafrost and seasonally frozen ground.

Acknowledgements

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Coupled Thermo-Geophysical Inversion for Permafrost Monitoring

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Motivation

Significant permafrost degradation in the Arctic region has been predicted as a result of climate change, causing a risk of thaw settlements and mechanical failures of buildings and constructions in affected areas. Conventional approaches in permafrost monitoring, including thermal measurements, core analyses and borehole geophysical logs, have serious drawbacks because of their discrete character and high cost. In order to accurately simulate and forecast the thermal regime of the active layer and permafrost, this work aims at combining traditional thermal measurements with diverse geophysical data (mainly DC geoelectrical measurements) in a coupled inversion scheme using only air temperature data and time lapse geophysical measurements to set up and calibrate a heat transport model. The main benefits are reduced cost of geotechnical surveys, improved interpretation of soil properties, improved mapping of the vertical and horizontal extent of permafrost as well as enhanced model skill in predictions of future permafrost changes.

Approach

The generalized workflow is exemplified by use of geoelectrical data for heat model calibration (figure 1). A heat transport model (HTM) is developed calculating the temperature profile of the soil. The phase distribution between water and ice is found from the soil unfrozen water content and an equivalent 1D-multilayer geoelectrical profile is constructed using Archie´s law. The apparent resistivity is calculated based on the multilayer model and compared to measured electrical soundings. Finally, the parameters for the heat transport model are calibrated to fit the combined dataset of temperatures and apparent resistivities using a weighted iterative least squares approach. In practice, any kind of geophysical data can be used as long as a petrophysical relationship between any simulated state of the HTM and the relevant geophysical property of ground can be established.

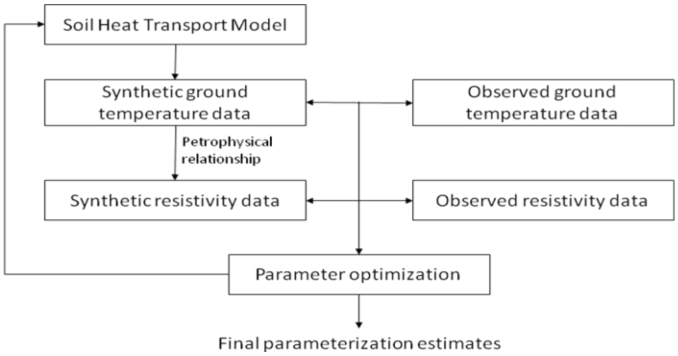

Fig. 1: Illustration of coupled inversion based on thermal measurements and electrical resistivity data.

Heat transport model

The HTM is used to describe the spatio-temporal evolution of subsurface temperature. The one-dimensional heat transport equation is [*Lunardini 1981*]:

$$c_e(x)\cdot\frac{\partial T}{\partial t}=-\frac{\partial}{\partial x}\left(-k_e(x)\cdot\frac{\partial T}{\partial x}\right)+S_s(x) \qquad (1)$$

where c_e is effective heat capacity (J/m^3/K ??), T is temperature (K), t is time (s), $k_e(x)$ is effective thermal conductivity ($W/m/K$) and S_s represents sources or sinks of heat (W/m^3). The phase change occurring at the transition between water and ice is regarded as an energy sink and is expressed as:

$$S_s(x)=-L\cdot\left(\frac{\rho_{ice}}{\rho_{water}}\right)\cdot\rho_{rock}\cdot\frac{\partial\theta_{ice}}{\partial t} \qquad (2)$$

where L is latent heat of fusion (J/kg_{ice}), ρ_{ice} is specific ice density (kg/m^3), ρ_{water} is specific water density (kg/m^3) and θ_{ice} is ice mass fraction based on dry weight of solids (kg/kg_{rock}).

Input parameters for the HTM are the specific heat capacities, specific thermal conductivities and specific densities of water, ice and rock, latent heat constant, water saturation, porosity and correlation coefficients a and b for unfrozen water content defined as [*Hoyer et al., 1975*]:

$$\theta_{water}(T)=a\cdot(273.15-T)^b \qquad (3)$$

for $T<T_{liq}$ (T_{liq} is temperature at which all the water is in the liquid form). The correlation coefficients are determined experimentally on the basis of dry weight of the material valid for saturated soils, relating them to the distinctive soil types. For the effective parameter estimation, the model domain is assumed to consist of a homogenous soil mixture of soil particles, water and ice and the effective parameters are derived as function of their respective volumetric fractions. Specific heat capacities of respective components are functions of temperature but vary a little in the range from 253.15 to 273.15 K [*Osterkamp 1987*] and are thus assumed constant. The resulting effective heat capacity is a product of volume fractional weighting of the specific heat capacities of the respective materials. Latent heat of fusion is incorporated in an apparent effective heat capacity and its temperature- and salinity-dependence is neglected. Density of water is set constant (1000 kg/ m^3) and density of ice is assumed to be equal to that of water. This assumption was proved satisfactory for both heat transport and apparent resistivity modeling.

The upper model boundary is prescribed by measured daily average soil surface temperatures from the investigation site (Ilulissat, West Greenland). The bottom boundary temperature is set to be constant in time. Consequently, to ensure stable conditions, the modeled domain needs to be deep enough (>20m). For each solving step taken by partial differential equation-solver (using MatLab built-in *pdepe*-function) the phase distribution is found, the effective parameters are re-evaluated and used for calculating the temperature in time and space.

Geophysical resistivity model

The geophysical part of the modeling framework consists of a one-dimensional geoelectrical model with a large number of layers of equal thickness. For each layer-representative temperature, calculated based on eq. 1, the fractions of water, ice and rock are found. Input parameters for the resistivity model are specific densities and specific resistivities of water, ice and rock, water saturation, porosity, and correlation coefficients for the unfrozen water content. The effective bulk soil resistivity is established through rock-specific petrophysical relationships, based on a modified Archie´s law [*Hoyer et al., 1975*]

$$\rho_{pf} = \tau \cdot \Phi^{-m} \cdot \left(\frac{f_{water}}{\Phi} \right)^{1-n} \cdot \rho_{water} \cdot e^{-\left(\frac{T_\theta}{44.6} \right)} \qquad (4)$$

where ρ_{pf} is effective resistivity of the partially frozen soil, Φ is porosity (m^3/m^3), f_{water} is the volume fraction of liquid water in a sample (m^3/m^3), ρ_{water} is resistivity of the pore water (Ωm) and τ (tortuosity factor), n (saturation exponent of the soil related to pore geometry), m (porosity exponent, an intrinsic property of the soil related to the geometry of the electrically-conductive water network imposed by the pore walls or surfaces of solid insulating materials) are constants. T_θ is the temperature in degrees below 0°C, and the exponential term accounts for the resistivity of unfrozen water at lower temperatures.

Forward apparent resistivity response modeling is performed by the CR1Dmod program [*Ingeman-Nielsen & Baumgartner 2006*] and the result is compared to the geoelectrical measurements acquired on the investigation site.

Coupled thermo-geophysical inversion

The most significant changes in physical parameters occur during the phase change of water between the liquid and the solid form [*Scott et al., 1990*]. This phenomenon allows for finding a link between thermal and geophysical properties of the ground and enables the HTM-calibration.

Fixed parameters are used for the thermal properties of water and ice. The inversion is based on iterative least squares formulation. The cost function is the sum of squared deviations between measured and forward calculated apparent resistivities. This cost function is minimized by fitting the thermal properties of the HTM from which the resistivity profile was calculated rather than the input parameters for the resistivity model.

After single parameter calibration for each of the chosen calibration parameters, the most uncertain parameters with respect to the confidence intervals are re-calibrated in a paired calibration. Not more than two parameters can be fitted at the same time, otherwise the confidence limits get high. Thus fitting more parameters with thermo-geophysical inversion requires more time lapse data and possibly a better resistivity model to get more reliable results.

Parameters and sensitivity analysis

Sensitivity analysis of each of the input variables is conducted comparing its Composite Scaled Sensitivity (*css*) as a root mean square of the sensitivity among all depths and time steps. *css* is proportional to the absolute sensitivity in the dataset to the given input parameter. The sensitivity analysis is made for the HTM and the resistivity model separately to choose the focus for the calibration of the model. Both models showed the highest sensitivity to porosity and water saturation.

Preliminary results and further model development

In this initial study it was confirmed that time lapse geoelectrical signal contain information that may be used in the calibration of the soil HTM. Despite the number of simplifying assumptions it was found that a set of parameters existed for the HTM that reasonably described the heat transport between the atmosphere and the soil profile. If boundary temperatures and the specific electrical properties of the soil material are known, a reasonable calibration of the soil heat transport parameters may be obtained. A better calibration would be achieved from multi parameter calibration for which more time lapse series are needed. These are planned to be acquired by installation of semi-automatic geoelectrical acquisition system that would make possible to cover an entire active layer freezing/thawing period.

Further laboratory measurements are carried out in order to establish rock-specific petrophysical relationships linking thermal and physical properties. The empirical parameters will be used as constraints in the model optimization or as fixed parameters where necessary.

In the future, the model should be extended to 2 and possibly 3 spatial dimensions to give an overview of the permafrost table variations in larger context. Setting up the multilayer model for handling also electromagnetic measurements would allow for building a regional scale monitoring program for permafrost.

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Permafrost degradation under abrupt warming in the central Mongolia Plateau

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Instructions

Recently permafrost degradation has occurred in most areas of the Arctic and the mountainous regions in Europe and central Asia under climatic warming [*Cheng and Wu, 2007; Isaksen et al., 2007; Osterkamp, 2007; Wu and Zhang, 2008; Zhao et al., 2010*]. The permafrost degradation could exert profound impacts on local hydrology, infrastructures, ecosystems in cold regions. In Mongolia, climatic warming has occurred to a great extent and caused great influence on the traditional pastoralism over the past decades. Permafrost regions occupy about 63% of Mongolian total territory, predominantly distributed in the mountainous regions. The monitoring of permafrost during past decades is mostly focused on the central Mongolian Plateau including Hovsgol, Hangai, and Hentei mountains. The observation data indicate that the permafrost temperature in most of Mongolia is close to 0°C [*Sharkhuu, 2003; Sharkhuu et al., 2007*]. The main objective of this study is to identify the abrupt climatic warming in permafrost regions during the past decades and concurrent permafrost degradation in the central Mongolian Plateau.

Data and study methods

We obtained the monthly mean air temperature data of eight standard weather stations located in permafrost regions of the central Mongolian Plateau from the Institute of Meteorology and Hydrology of Mongolia (over the period of 1961-2006) and the Global Surface Summary of Day dataset from National Climatic Data Center (http://www.ncdc.noaa.gov/oa/gsod.html) (over the period of 2007-2009) (Figure 1). The active layer thickness data and mean annual ground temperature data were obtained from the long-term Circumpolar Active Layer Monitoring Network (CALM) (http://www.udel.edu/Geography/calm/) and Global Terrestrial Network for Permafrost (GTN-P) (http://www.gtnp.org/index_e.html). The detailed information of those boreholes and the observation methods of those data have been introduced in above-mentioned websites of the CALM and GTN-P program and many literatures [*Sharkhuu 2003; Sharkhuu et al., 2007*]. The most recent data of mean annual ground temperature are provided by the Institute of Geography, Mongolian Academy of Sciences. The locations of those borehole sites for permafrost observation are showed in Figure 1. In this study, the trend magnitudes of climatic warming and permafrost changes are estimated using ordinary least squares regression and deriving the slope of the linear fitting. Moreover, the trend of climatic warming and the period of abrupt warming in summer were determined using a Mann-Kendall non-parametric trend test. The sequential values for forward U and backward U' were calculated on the basis of rank-based method to identify the change points in trends with time. Modarres and Sarhadi [*2009*] described the Mann-Kendall trend test methodology in detail for analyzing the rainfall changes of Iran. Recently the Mann-Kendall method has been used extensively for trend detection in hydrological and meteorological data.

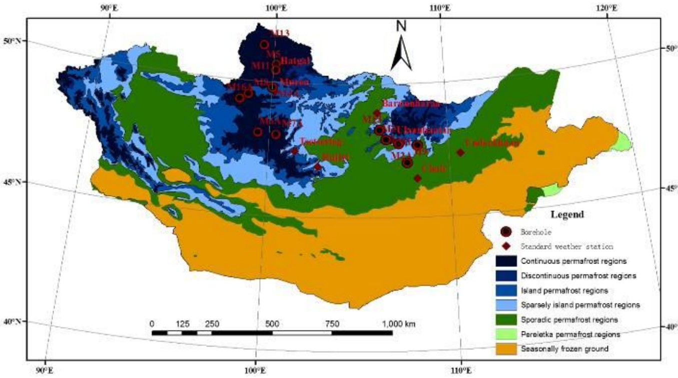

Figure 1 The location of selected standard weather stations and borehole observation sites and the permafrost distribution in Mongolia

Results and discussion

The climate in Mongolia has warmed more substantially than that in most of other regions of the world. Based on the records from 48 meteorological stations which are distributed evenly over the territory of Mongolia, the mean annual air temperature has increased by 2.14 °C during the last 70 years [*Dagvadorj et al., 2009*]. The mean trend for the increase of mean annual air temperature amounts to 0.042 °C/yr ($p<0.001$) which is a little higher than that of the whole country (0.038 °C/yr) during the period of 1961-2006 [*Dagvadorj et al., 2009*]. Drastic increase since 1994 in the mean annual air temperature was also significant in this analysis.

The sequential Mann-Kendall test was also used to graphically illustrate the forward trend (U(t)) and the backward trend (U'(t)) of mean annual air temperature for the eight standard weather stations during the period 1961-2009. The test reveals that the time series for mean annual air temperatures showed a steadily increasing trend since 1988 and that the pronounced change in mean annual air temperature has occurred in 1994. This result coincides with the above linear trend analysis result. As for the air temperature in summer, the mean trend at the eight standard weather stations is up to 0.049 °C/yr ($p<0.001$) which is much more than that of the whole country (0.036 °C/yr) during the period of 1961-2006 [*Dagvadorj et al., 2009*]. The Mann-Kendall trend test result indicates that the dramatic increase in summer air temperature has occurred in 1997, which is consistent with the changes of the linear trend analysis result. The winter air temperature at the selected eight stations also displays a significantly increasing tendency at a rate of 0.039 °C/yr ($p<0.05$), which is less than the increasing rate of the whole country [0.045 °C/yr over the period of 1961-2006, *Dagvadorj et al., 2009*]. Dissimilar to the general warming characteristics in Mongolia, the warming in summer in the permafrost regions of central Mongolian Plateau is more pronounced than that in winter. It can be inferred that the drastic rise in the summer air temperature would have a great influence on the changes of active layer thickness.

The MAGT shows an increase at all sites. The mean annual rate of increase in MAGT amounts to 0.022 °C/yr at those sites since the 1970s. We found that the temperature of permafrost with relatively low MAGT has risen more than those whose MAGT is close to 0 °C. This trend is similar to the increasing rate of MAGT of permafrost on the Qinghai-Tibet Plateau in the past 40 years [*Cheng & Wu 2007*], which likely results from the absorption of latent heat for phase change in high-MAGT permafrost regions. Among the sixteen boreholes, there are eight boreholes whose MAGT was measured continuously during the last decade. The results of linear fitting analysis indicate that the MAGT at seven boreholes has increased at a rate of 0.020 °C/yr on average ($p<0.05$) except that M1 shows almost no changes during the last decade. Compared with the mean annual increasing rate of MAGT along the Qinghai-Tibet Highway (0.043 °C/yr) during the last decade, the increasing rate is much less in the central Mongolian Plateau [*Wu & Zhang 2008*].

Most of the sites in the central Mongolian Plateau display an increase in ALT since the 1970s. The mean increasing rate of ALT is about 4.3 cm/yr over this period. Generally, the ALT in the permafrost with low MAGT shows less change than that with relatively higher MAGT. Among the sixteen boreholes, there are seven boreholes whose continuous observation data of MAGT are available during the last decade. Based on the linear fitting analysis, we found that the ALT at M1 site shows a drastic increase from 1996 to 2007 with a mean increasing rate of 45 cm/yr ($p<0.01$). As for the other six sites, the ALT has increased at a mean increasing rate of 7.3 cm/yr ($p<0.05$), which is very approximate to the change of ALT on the Qinghai-Tibet Plateau (7.6 cm/yr) over the same period.

Conclusion and recommendations

We have identified prominent climatic warming in permafrost regions of the central Mongolian Plateau. The sequential Mann-Kendall test indicates that abrupt warming for mean annual air temperature occurred in 1994 and for summer air temperature occurred in 1997. Corresponding to the intensive warming in permafrost regions of the central Mongolian Plateau, the MAGT of permafrost and ALT has significantly increased during the last forty years, especially in the last decade. The increasing rate of permafrost MAGT amounts to 0.022 °C/yr since 1970s and 0.020 °C/yr for the last decade. And the mean increasing rate of ALT amounts to 4.3 cm/yr since 1970s and 7.3 cm/yr for the last decade. Generally, the increasing rate of low MAGT is greater than whose MAGT is close to 0 °C. While the increasing rate of ALT in low-MAGT permafrost regions is less than whose MAGT is close to 0 °C. We infer that the permafrost degradation was predominantly due to drastic increase in mean annual air temperature, especially the intensive warming in summer air temperature during the last decade.

As climatic warming and permafrost changes have not been fully investigated in the central Mongolian Plateau before, this paper summarized the recent changes in climate and thermal regime of permafrost in this region. Systematic and continuous monitoring of permafrost is of great necessity for understanding the mechanism of response of permafrost to climatic changes. However, there are relatively few continuous observations of the thermal state of permafrost in Mongolia especially in the west mountainous regions. Therefore, it is suggested that we should conducted accurate and continuous observations to the thermal regime of permafrost in Mongolia, in order to enhance our understanding to mechanism concerned permafrost dynamics responding to ongoing climatic changes.

Acknowledgements

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Sedimentological Analysis of Relict Slope Deposits of Serra da Estrela, Portugal

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Introduction

Serra da Estrela is the highest mountain in Portugal (1993 m) and part of the Iberian Central Cordillera. Most of the western plateau area was glaciated in the Late Pleistocene and its morphology is dominated by glacial landforms. Vieira [*2004*] produced a detailed geomorphological map of the mountain, identifying stratified, head and debris-flow deposits. Based on the geomorphological analysis of the relationships between glacial and periglacial evidence, a first relative chronology was presented. A detailed and systematical sedimontological analysis has not been conducted before and absolute ages are lacking.

The aim of this work is to present a comparative review of the sedimentological characteristics of three relict slope deposit sites with special reference to lithofacies, fabrics and micromorphology. Our objective is to contribute to the better understanding of the morphogenetical significance of the different types of slope deposits focusing on clarifying the role of cold environment processes.

Sites and Methods

São Gabriel site is located at 680 m altitude. Two sections were studied: Facies B has been interpreted as the result of a flow deposit and Facies C as a solifluction deposit [*Vieira 2004*]. Souto do Concelho is located at 700 m altitude and two sedimentary units were studied: a lower unit interpreted as a flow deposit and a middle unit as a solifluction deposit. Penhas da Saúde is located at 1530 m altitude: unit 1 suggests the influence of a flow processes and unit 2 of solifluction.

Vertically aligned and oriented samples were collected. Micromorphology was studied from thin-sections following a terminology adapted from Stoops et al. [*2010*]. Lithofacies was analysed in the field: sedimentary units, characteristics of layers, structure, presence and type of beding, grain-size and clast morphology. Fabrics was characterized by measuring the dip angle of 50 clasts and then plotted on rose diagrams (2D) and polar diagrams or equal-area stereonets (3D).

Results and Conclusion

Fabrics at São Gabriel (Facies B) revealed several dipping directions: parallel, perpendicular and transverse orientations to the slope direction and a low dipping angle (10º). Macroscopical features relate to a water flow deposit. Microfacies show simple packing voids, related distribution is Chitonic–gefuric and massive and banded structure. Microfeatures are normal graded bedding of stream-laid sediments and a silty matrix forming bridges and irregular coatings between and around grains. Interpretation suggests runoff.

Souto do Concelho (Unit 1) fabrics show an equal amount of clasts parallel and perpendicular to the slope direction and moderate dip angles (30-40º). Characteristics suggest 2 types of slope deposits: rockfall talus or lobe fronts from solifluction deposits [*Bertran et al., 1997*]. Microfacies show complex packing voids, granular and massive structure and related distribution is chitonic to porphyric (matrix-supported). Microfeatures are moderately to well-developed: circular arrangement of grains and rounded vesicles which are associated with internal modification, core redox nodules which indicate disturbance and transport and vertical grains associated to frost heave [*Van Vliet-Lanoë in Stoops et al., 2010*]. Characteristics relate to solifluction sediments.

Penhas da Saúde (Unit 1) fabrics show a preferred orientation parallel to the slope direction as found in solifluction deposits, but also detected on debris flows [*Bertran et al., 1997*]. Dip angle is moderately high (20-30º). Microfacies illustrate a porphyric related distribution, massive structure and vesicle voids. Microfeatures are poor to moderately developed arrangement of grains, grain coating and rounded vesicle and moderately to well-developed soft sediment deformation structure. Interpretation indicates debris-flow [*Menzies & Zaniewski 2003*].

The fabric analysis wasn't a good discriminator, resulting in an unclear origin of the Souto do Concelho and Penhas da Saúde deposits. Micromorphology showed to be a useful technique to aid in the analysis of these sediments. The combination of the analysis of

the macro- and microscopic structures showed identical diagnosis for the São Gabriel slope, but the micromorphology analysis suggests diverse sedimentological processes in the Souto do Concelho and Penhas da Saúde deposits.

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Understanding Hydrological Characteristics of Surficial Drainage Networks: From plots to satellite data

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Introduction

Permafrost plays a key role in creating and maintaining networks of surficial drainage networks known as water tracks by constraining water to the near surface. These features make up the majority of the water transportation system in the foothills of the Brooks Range in the Alaskan Arctic. Hydrological and thermal modeling of water tracks is dependent on understanding the upper boundary conditions which in snow-free months are quantified by measurements of temperature, relative humidity, wind speed and evaporation/transpiration.

Water tracks influence these factors because they show changes in vegetation including the type and percent cover of low erect shrubs, graminoids and mosses from the surrounding area. There is also often an increase in soil moisture content and a deepening of the organic layer. Figure 1 illustrates that water tracks can be diverse in size and show capture a range of ecological, hydrological and geomorphic properties Understanding the effects on evapotranspiration in particular is fundamental for scaling the influence of water tracks to the basin level.

Figure 1. Water tracks north of the Upper Kuparuk Basin. Note curvilinear shape and variations in size.

This work used an upscaling approach from plots to Landsat data to focus on factors which effect evapotranspiration and its relationship to land surface temperature (LST) between water tracks and adjacent areas. One method for calculating evapotranspiration uses a two-source energy balance (TSEB) model where the main input data is LST and leaf area index (LAI) [*Anderson & Kustas 2008*]. Derivation of evapotranspiration rates using this method is dependent on both spatial and temporal resolutions of the input data.

Methods

During the first ten days of July 2010 a field campaign was undertaken where 2 m^2 plots were quantified using visible and near infrared imagery in addition to vegetation percent cover, soil morphology and depth to the active layer. Plots were aligned over transects which bisected water tracks. LAI was calculated using the alternative indirect method (cover photography) and also using an algorithm established for tussock tundra in the region [*Rocha & Shaver 2009*] for both normalized difference vegetation index (NDVI) and two band enhanced vegetation index (EVI2). Fortuitously, World-View 2 imager was acquired on July 10 which has a spatial resolution of 2.5 m and a spectral resolution from 400 to 1040 nm using 8 bands. Additionally during this period Landsat ETM data was acquired on June 30 (SLC-off over study area), and July 9 and 25. LAI was calculated for the satellite based imagery using the established algorithm and contrasted to the plot level data.

The other main input of the TSEB model is LST. Plot level measurements were collected using a FLIR thermal camera and mosaicked. This was compared against LST derived from the thermal band of the Landsat images. The LST products were also contrasted to measured ground surface temperatures (GST) from meteorological stations in the Imnavait and Upper Kuparuk basins since differences are known to exist [*Hachem et al., 2012*].

Multiple runs of the TSEB model were used to examine the temporal changes and the effects of different values of LAI which varied depending on the method of calculation and the spatial resolution of the data.

Discussion

Computing accurate estimates of LAI using satellite derived NDVI or EVI2 is a critical input for estimations of evapotranspiration using the TSEB model. Satellite imagery with spatial resolutions greater than 5 m can more accurately characterize vegetation patterns especially where surficial drainage networks are prevalent and the patterns complex. Many confounding factors exist which are highlighted by the spatial comparisons between the plot and satellite products. In the plot level data variations in the angle of vegetation can cause pixel saturation, shaded areas can have high NDVI values and moss spectral values vary by type and moisture content. In addition, mosses present an additional challenge as they lack stomata control during the transpiration process.

Analysis of the soil morphology and vegetation data also strongly indicated that there are many variations both between and within water tracks. Capturing these differences is dependent on the scale and scope of both the study area and the methodology used for examination. Quantifying evapotranspiration rates and distribution is valuable for capturing an important component of the hydrological cycle which impacts the thermal regime. In areas where water track are underlain by permafrost this is fundamental for both regionalized short and long term modeling efforts and analysis of physical systems for engineering applications.

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Permafrost and Related Forms in the Diamante Caldera (Central Andes, Argentina)

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The Diamante caldera is a volcanic depression located in the Central Andes, at 34º S on the Chilean-Argentine border, with two prominent reliefs: the Maipo Volcano (5323 m) to the west and the Laguna Diamante (around 7 x 3 km) to the east. The origin of this caldera is attributed to a large evacuation of ignimbrites, ~ 0.45 Ma ago [*Stern et al., 1984*], that caused the collapse of the area. The construction of the Maipo volcano in this caldera took place much later, after a long period of no volcanic activity [*Sruoga et al., 2005*]. The Diamante Caldera, widely glaciated during the Last Glaciation, still preserves some glaciers in favourable orientations, the most prominent covering the summit of the Maipo Volcano and mainly flowing to the south. Three small glaciers, with a south aspect, are located in the northwestern part of the caldera, while a glacier ice remnant lies in the northeast zone, with the front at 4550 m a.s.l. Former glacial activity left a till cover irregularly distributed on the caldera; most of the till can be found to the northwest of the Laguna, and no signs of terminal moraine forms could be identified, although the main glacier, moving from west to east in its upper part, and turning later to the south-southwest, probably reached much lower altitudes than those shown by present till cover. Numerous morainic arcs record an irregular retreating for the glacier front. Glaciofluvial deposits, now partially exposed as a terrace, lie under younger deposits, south of the Laguna. Postglacial surfaces, degraded by alluvial processes suggest a strong dynamic for the zone.

Temperatures registered in the study area were used to calculate daily, monthly and annual mean temperatures. The climograph shows a low average minimum (-11.7 ºC) and an absolute minimum of -20.24 ºC at 3301 m a.s.l. Mean daily maximum and minimum temperatures were contrasted with 0 ºC: a monthly mean temperature below 0 ºC indicates that part of the ground cannot unfreeze completely and that this situation lasts until the following spring time. However, at present, the positive annual mean temperature do not allow the existence of permafrost at 3300 m a.s.l. Minimum means, for the considered years, are always below 0 ºC which makes us expect important processes for winter periglacial microforms.

Field campaigns were carried out in the years 2004 and 2011. The inferior limit of mountain permafrost was detected by ice in a shelter, with south exposition at 3870 m a.s.l. approximately, in different years. Historic registers from 1951 - 1952 indicated a height below 3850 m a.s.l. as lower permafrost limit [*Corte 1953*]. In the same valley however, and considering the noses of cryoforms with creeping permafrost, cryogenic activity is observed at a height of 3750 m a.s.l. approximately. At other sites of the area cryoforms reach down to even 3600 m with signs of inactivity.

A geomorphological map was made for the analysis of the periglacial features in the area (rockglaciers, different forms of solifluction and patterned ground). It was produced on an ASTER image (15 m / pixel) using aerial photographs from 1963-64, at an approximate scale of 1:100 000, and the software of Adobe Illustrator. The map shows a great variety of forms (Fig.1), many of them still active at present [*Trombotto Liaudat & Alonso 2011*]. After glacier retreat, strong reliefs, in combination with the high altitudes and big amounts of nival waters, gave rise to an important periglacial landscape. Slopes present a great variety of mesoforms: bedrock is partially covered by talus slopes and debris cones in the upper parts, while landslides, alluvial fans and debris flow deposits are found in more distal positions.

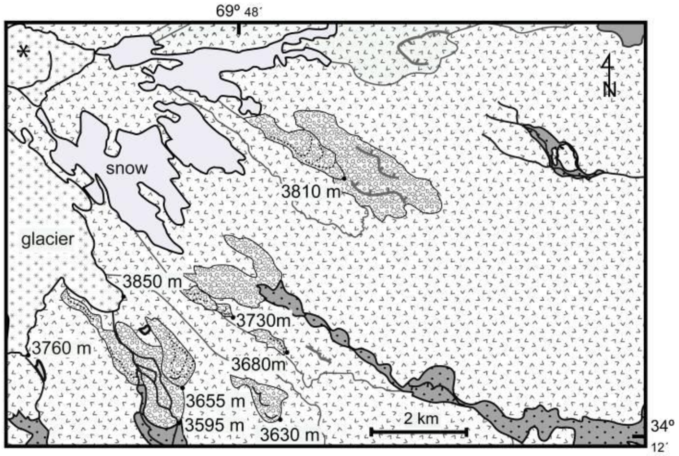

Figure 1. Partial view of the geomorphological map of the Laguna del Diamante. Glacigenic and cryogenic Rockglaciers, in this area, belong to two phases at least. Glaciers flow mainly to the south-east from the volcano summit (*, in the upper left corner). Notice alluvial deposits partially covering the lava flows on the volcano flanks. Altitudes refer to the fronts of glaciers and rockglaciers.

Rockglaciers, the most characteristic expression of mountain permafrost, were developed in different phases, as clearly shown on the Maipo slopes, but also to the east of the Laguna. Both genetic types, glacigenic and cryogenic, have been recognized in the Caldera and in the surrounding zones registered in the geomorphological map.

Perennial and seasonal snow patches are discontinuously associated with cryoplanation surfaces. Patterned ground with several sizes ranging from 30 cm at 3300 m a.s.l. until 1 m diameter at 3850 m a.s.l are present in the region [*Corte 1953*]. The latter are already in a periglacial environment with permafrost. Small periglacial features, previously studied by Corte in 1953, as stone bands, stone nets and extrusion microforms developed between 3300 m and 3800 m a.s.l.

Indicators of palaeopermafrost (structures caused by segregational ice or Taber ice) in a geological profile were identified at 3400-3500 m a.s.l. approximately on the foot of the southern slope of the volcano Maipo. They indicate an altitudinal depression of at least 300 m for paleopermafrost and the last important cryomere [*Trombotto 2007*].

The very well preserved remnants of a mud flow deposit, north of the Laguna, express the intensity of cryodynamics in this region until present days.

Although unconsolidated slope sediments have been partially reworked by the river system, and transferred to lower areas, torrential and gravitational processes in steep zones are very active, indicating that the Diamante Caldera is still in a paraglacial period, far from having reached an equilibrium with the present periglacial conditions.

Further campaigns will allow us to complete the geomorphological map and to obtain more accurate data on permafrost distribution and small related forms.

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Strength Properties of Thawing Soils

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Although the strength properties of thawing soils have been largely investigated, both in theory and in experiments, there remain poorly understood issues concerning specific controls of shear strength [*Bondarenko 1982, Shusherina et al. 1983*].

According to the available data, the measured mechanic properties of thawing soils are subject to several internal and external controls. The former include grain size, mineralogy, structure, and physical properties, and the latter are the conditions of thawing (that influence thawing rates) and of testing (close or open test systems, presence or absence of pore pressure, loading mode). The specific contributions of each factor have not been constrained so far.

The testing procedure ran as single-plane shear for thawing soils, a method which yields the minimum values of the parameters [*Tsrapov 2007*].

Shear was applied to the thaw boundary of soil samples, in unconsolidated-undrained triaxial tests. The tests were run in triplicate at each vertical load from a lever loading device. The horizontal shear stress was applied quickly (30-60 s), at the time when the soil samples reached the thaw limit, 2-3 mm below the specified shear plane. The testing apparatus is sketched in Fig. 1.

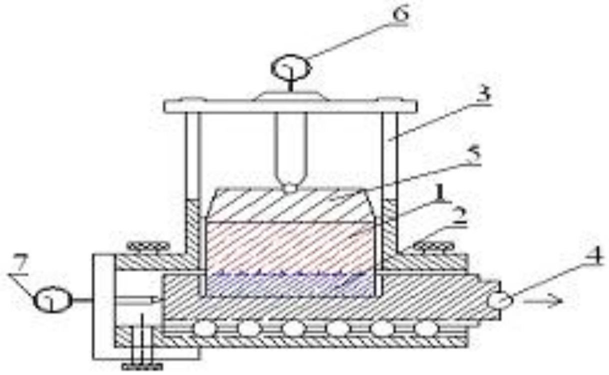

Fig. 1. Shear strength testing apparatus. 1 – upper container with unfrozen soil; 2 – lower container with frozen soil; 3 – normal stress transfer; 4 – shear stress transfer; 5 – warm stamp; 6 – clock-type settling indicator; 7 – clock-type indicator of shear strain.

The applied loading caused re-distribution of water content and density of soils within the thaw depth, more prominent in clay than in sand. Water content increased more strongly next to the thawing front and produced a zone of excess moisture in which both the soil skeleton and the pore water received normal and shear loading. As zone begins to form, pore pressure arise in it approaching the normal pressure value.

Three strength-dependent characteristic layers were distinguished about the thawing boundary (Fig. 2a): consolidated unfrozen soil, with consolidation degree about 1 (layer 1); partly consolidated soil near the thawing boundary (layer 2); almost unconsolidated soil at the thawing boundary (layer 3).

Simultaneously, pore pressure (U_w) was measured depthward. See a typical curve of depth-dependent U_w in Fig. 2 b. The pore pressure was the highest in layer 3, at the thawing boundary while its strength was the lowest, though pore pressure caused shear resistance. As the pore pressure dissipated rapidly due to high filtration of thaw moisture, the shear strength decreased. On the other hand, the strength increased by gravity-driven compaction of unfrozen soil particles.

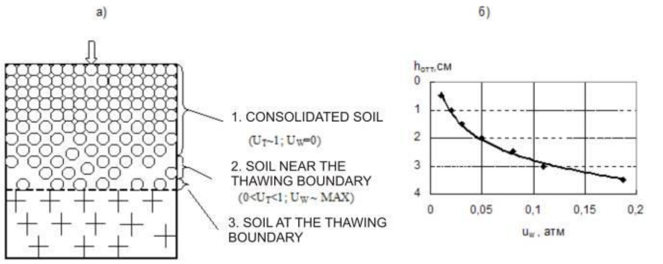

Fig. 2. Characteristic layers of thawing soil (a): consolidated unfrozen soil (1); partly consolidated soil near the thawing boundary (2); almost unconsolidated soil at the thawing boundary (3). Pore pressure U_w as a function of depth (b).

In Fig. 3 the shear strength of thawing clay is plotted against total and effective stresses, with regard to pore pressure and porosity.

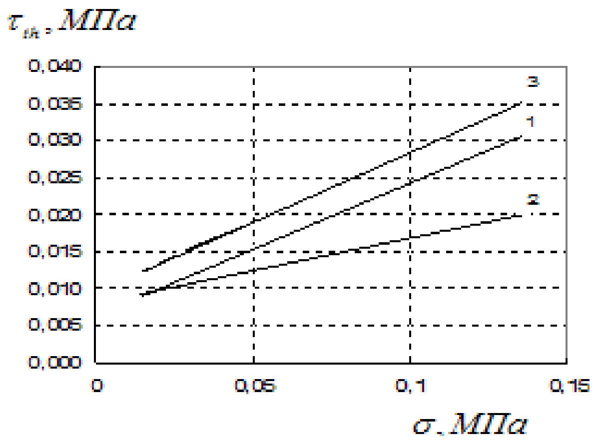

Fig. 3. Shear strength of thawing soil as a function of: total stress σ (curve 1); effective stress σ_s , with regard to pore pressure u_w and porosity *n* (curve 2); effective stress σ_s , with regard to pore pressure only (curve 3).

Pore pressure included into the model of water-saturated thawing clay jointly with porosity causes a mixed effect on the resulting shear strength estimates, by increasing cohesion and decreasing friction. The pore pressure alone, without porosity, leads to higher cohesion but exerts no influence on friction.

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Quaternary Deposits at the Dzhelon-Sise Upland (the Yano-Indigirskaya Lowland)

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The Dzhelon-Sise Upland is situated in the middle reaches of the Berelekh River. It is a neo-tectonic elevation with height marks of up to 100 m [*Ovander & Rybakova 1985*]. It is surrounded by a lake-alluvial plain with numerous alas basins and Yedoma remnants with surface marks at heights from 5 to 50 m.

Satellite images clearly demonstrate round basins ranging from 0.4 to 1.4 km in dimensions at the near-watershed section at the surface of the elevation. Some of them contain small lakes but most basins are drained with streams forming an erosional network at both walls of the elevation. These basins are highly similar to the alas basins in their morphology but they are significantly smaller in dimensions. Thermokarst origin of the basins suggests the presence of the ice-rich deposits at the Dzhelon-Sise Upland that belong to an ice complex never mentioned in books as far as the authors could find out. Field stu-dies with the purpose of determining the structure and origin of basins and deposits containing them were conducted in August

2011 at the northern section of the elevation from the side of the Ary-Mas River (Fig.1).

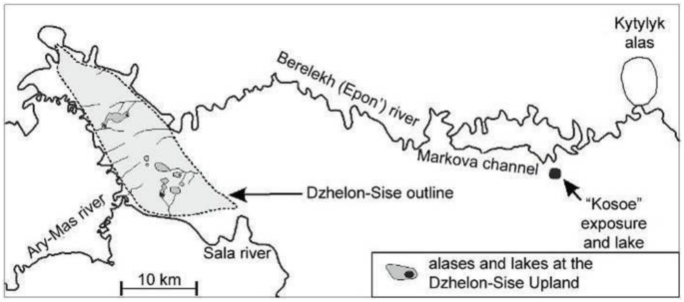

Figure 1. The schematic map of the Dzhelon-Sise Upland area.

A shore outcrop underwashed by the Ary-Mas River exposes sand and gravel deposits with boulders that are dated by the Paleogene-Neogene age [*Ovander & Rybakova 1985*]. There are virtually no other outcrops at the higher parts of the elevation. The largest of the basins examined is situated at the elevation watershed; from the elevation, on its either side, there stretches a chain of basins decreasing in dimensions. In the adjacent basin eastward there is a small lake that underwashed its eastern shore. But at present the outcrop largely flooded and overgrew with shrubbery. Three more basins partly merged with each other are situated westward from the watershed basin. General inclination of basin bottoms along the elevation slope is distinctively expressed, and their dimensions decrease as their distance from the watershed grows.

The most lowland basin contains a lake with the dimensions of 450-500 m. There is a small stream flowing out of it towards the Ary-Mas River; the height of the riverhead is 35-40 m. The depth of the lake is not determined. The lake occupies a considerable area of the flat bottom of the basin. The bottom is slightly inclined towards the Ary-Mas River. At the north-eastern part of the basin its bottom gradually transitions into the bottom of the adjacent basin situated higher. The measured relative depth of the basin is 25-30 m. Microrelief of virtually all the walls of the basin consists of silt pinnacles exposed to a varying degree. Basin shores that are most intensely underwashed by the lake are the south-western and southern shores. At their upper parts in the walls of slit pinnacles there are fragments of a section that can be seen, and ice veins between them are exposed on the surface. The relative height of a basin wall is lessened here down to 11-12 m due to the development of a thermoerosional valley situated slightly to the south. Thus, we can say that the deposits with wedge ices that contain a lake basin represent a relief-forming ice complex and the type of the basins is thermokarst; the basins form alases at present.

Deposits composing the ice complex are depicted in silt pinnacles at approximately 10-m height above the lake level. They are represented by dusty brown clayey silts with a small amount of vegetative detritus. Sedimentary lamination is not visible. The cryogenic structure at the level described is of massive or microschlieren variety, sometimes it is lenticular. Syngenetic ice veins intersected at this level are approximately 1.5 m wide, with a vertical banding, but elementary veins are not distinguished. There was revealed an epigenetic ice vein (approximately 5 m wide) in one of the silt pinnacles at the middle part of a ground column.

Flat-bottomed valleys of small streams on the slopes of the elevation in the Berelekh and the Ary-Mas Rivers dig into the ice complex formation. At present modern thermal erosion develops almost everywhere in them. It is usually expressed in the intense digging of streams into flat bottoms at the depth of several meters as well as in forming of steep and precipitous walls and waterfalls in the upper reaches of thermoerosional ravines. Such ravines are knee-shaped in projection, especially in higher narrower valley sections. Ravine beds reveal light-gray wedge ices with the width of more than 1 m, the width of some of the elementary veins is 5-8 mm. The cutting depth at the upper reaches of one of the streams flowing southwestward into the Ary-Mas River is 4.2 m, and the cutting exposes a section of the deposits filling the valley. Ravine wall reveals two intersected horizons of allochthonous vegetative detritus of 0.5-0.6-m thickness that are separated by brownish-gray clayey silts with sand and gravel lenses in foundation. Vegetative detritus contains fragments of shrubbery branches of up to 2-m thickness; wedge-shaped projections of originally ground veins of up to 0.5-m height are registered in the foundation. This suggests that the main valleys of watercourses draining the elevation were formed during the Holocene period. Later they were filled by the alluvial-prolluvial-deluvial deposits with wedge ices and now they are intersected by thermoerosinal ravines.

The specimens of wedge ice and of surface waters were collected during the studies for determining their isotope composition. Isotope composition of oxygen and hydrogen was determined in the laboratory of Alfred Wegener Institute for Polar and Marine Research (Potsdam, Germany; analyst – H. Meyer). Seven specimens from syngenetic wedge ices of the ice complex on the Dzhelon-Sise Upland that were taken at 9-10-m height above the lake level helped to obtain the average values of $\delta^{18}O$= -33.39‰ (the range of changes is from -34.39 to -31.46‰) and the average value of δD= -251.96 (the range of changes is from -269.70 to -197.30‰). Five specimens from syngenetic wedge ices that were collected in the upper reaches of thermoerosional ravines helped to obtain the average values of $\delta^{18}O$= -28.19‰ (the range of changes is from -30.40 to -26.03‰) and the average value of δD= -214.30 (the range of changes is from -230.60 to -198.3‰). For comparison: the water from the lake in the alas basin at the Dzhelon-Sise Upland has $\delta^{18}O$= -20.20‰ and δD= -157.0‰, and the water from the Berelekh River has $\delta^{18}O$= -18.50‰ and δD= -147.4‰.

Deposits and syngenetic ice veins of the ice complex were also tested in the "Kosoe" exposure depicted by the authors at 55 km eastward from the Dzhelon-Sise Upland. It is a shore exposure of a thermokarst lake in the area of the Markova channel in the lower reaches of the Berelekh River. The height of the exposure is approximately 25 m above the lake level; ice veins tested are situated at the height of approximately 19 m. The following isotope characteristics were obtained for them according to five specimens: $\delta^{18}O$= -33.13‰ and δD= -260.1‰. 31 specimen helped to obtain the following isotope characteristics for the ice vein from alas deposits as such in the area of Kytalyk station (the lower reaches of the Berelekh River, 12 km north-eastward from the "Kosoe" exposure): $\delta^{18}O$= -27.01‰ and δD= -206.1‰.

The analysis of the obtained analytic data on the isotope composition of wedge ices with regard to their attribution to certain types of quaternary deposits and their bedding conditions demonstrates that these data considerably vary for deposits of the Late Pleistocene and the Holocene periods. At the same time, syngenetic ice veins from the ice complex at the Dzhelon-Sise Upalnd and in the "Kosoe" exposure have rather a similar isotope composition. Ice veins from ravine deposits at the slopes of the Dzhelon-Sise Upland and facies from alas deposits as such it the area of Kytalyk station are quite similar by their isotope composition as well. This suggests that deposits of the ice complex at the Dzhelon-Sise Upland were formed within the period of the Late Neo-Pleistocene. Then, during the Holocene, they were dissected due to the development of lake thermokarst traces of which are found at the elevation today, and due to erosion processes at the slopes. Morphology of the alas basins suggests that thermokarst lakes appeared at the near-watershed section of the elevation and later were shifted down the slope, as the massif elevated. Due to that, chains of the interrelated alas basins were formed. Large basins could not be formed due to the erosion processes in ravines at the beginning of the Holocene.

It would be interesting to study the issue of genesis of the ice complex deposits at the Dzhelon-Sise Upland. Were the ice complex deposits formed in lowlands and then uplifted in the process of a neotectonic elevation of the Dzhelon-Sise massif or were they accumulated at the massif already elevated? In first case, the deposits of the ice complex have the same genesis as in the area surrounding the elevation, while, in second case, they must apparently be of an aeolian origin with further partial slope re-deposition. There are no facts yet that could definitely resolve this issue. From our point of view, accumulation of 20-30-m thick deposits at a very limited elevated area is unlikely due to the development of slope and erosion processes. In case if the elevation of the massif was started already in the Holocene we would have remains of well-developed alas basins at the modern elevation surface. This is why the Dzhelon-Sise Upland probably elevates since the end of the Late Neo-Pleistocene. In this case, elevating speed can be approximately assessed as 5-6 mm per year (elevating was supposedly started approximately 15 000 yr BP). Resolving of this issue will be possible after obtaining radiocarbon datings of the ice complex deposits and the deposits of stream valleys on the slopes as well as after mineralogic and granulometric analysis of deposits.

Acknowledgements

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The Gas Hazard of the Cryolithozone in Yamalskiy Region (the Yamal Peninsula and the Kara Sea Shelf)

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Natural gas, oil and condensate fields unique in reserves (the Bovanenkovo, the Kharasavey, the Rusanovskoe fields etc.) are concentrated in the area of Yamalskiy Region, including the Yamal Peninsula and the adjoining Kara Sea shelf.

The problems occurred at the initial development stages already. They were associated both with extremely complex geocryological conditions of the area and the gas content of the cryolithozone grounds. Multiple gas shows were registered in the process of exploration, geotechnical and production drilling in the Yamalskiy Region area.

Gas emissions from the cryolithozone interval represent a serious problem in the process of well drilling and well construction. Intrapermafrost gas shows are registered in the form of degassing of the circulating fluid, bubbling and emission of the drill fluid as well as in the form of open gas blowing. They frequently lead to accidents, including fires in wells. The recent field and laboratory studies as well as computer simulation of the cryolithozone evolution in the region showed that most of gas shows are associated with the decomposition of relic gas-hydrates confined to permafrost. These are gas-hydrate accumulations formed earlier in the hydrate stability paleozones that were repeatedly formed in the Yamalskiy Region section during the recent 80 thousand years.

The formation history and the structure of the cryolithozone within the area of research have the determining meaning for the formation of relic gas hydrates and their preservation up to now.

The cryolithozone of the Yamal oil and gas region is studied unevenly. A review map reflecting the development and the thickness of cryolithozone and of permafrost in the Yamal Region area (the Yamal Peninsula and the Kara Sea shelf) of 1:2,000,000 scale was prepared on the basis of the mapping materials analysis (cryolithozone maps for the Kara Sea shelf and thematic maps of the Yamal Peninsula, drilling materials and literature generalization [*Melnikov & Spesivtsev 1995; the Yamal Peninsula 1975; Structure and properties... 2007*]).

The map contains the information on the thickness of the cryolithozone (the position of the zero isotherm), the thickness of permafrost (bearing ice) as well as on the temperature and the structure of permafrost.

Permafrost is developed continuously on the most part of the Yamal oil and gas region's dry land. The maximum thicknesses of the permafrost and of the cryolithozone are confined to the axial part of the peninsula and vary from 300 to 450 m.

The permafrost thickness regularly falls with transition to lower geomorphological levels, and cooled grounds appear in the lower part of the section.The permafrost thickness falls till 0-50 m within the lowest levels – large river floodplains, the laida and low islands in the Kara Sea.

The annual mean permafrost temperature varies from minus 6 - minus 8 °C at the highest geomorphological levels to 0 – minus 1 °C at the lowest ones.

Cooled ground prevails at the Kara Sea shelf, according to the data available. The shallow part of the shelf (isobath 10-20 m) surrounding the Yamal Peninsula is characterized by the maximum thicknesses (50-150 m) and the development of permafrost containing ice. Permafrost of the island and rare island distribution with the thickness of up to 50 m can exist till the 100-120 m isobath.

There are no actual data confirming the existence of permafrost in the deeper part of the shelf (isobaths 200-400) due to the absence of drilling data. The estimated thickness of cooled grounds can make up 25-50 m. The cooled ground temperature makes up from 0 to minus 1 ºC, according to the measurements executed [*Melnikov & Spesivtsev 1995*].

The position and the thickness of the zones of methane hydrate stability and methane hydrate metastability were estimated within the identified geocryological areas on the basis of the prepared map reflecting the development and the thickness of cryolithozone and of permafrost in the Yamal oil and gas region's area and on the basis of the drilling data.

The calculations employed: the equilibrium curve of PT conditions of methane hydrates existence in different geological and geochemical conditions; the data on the annual mean ground temperature, the position of the zero isotherm, the temperature gradient below the cryolithozone bottom and on the permafrost thickness.

A review map of the gas hazard of the cryolithozone in the Yamal oil and gas region was prepared on the basis of calculation results.

The ubiquitous development of permafrost in the upper part of the section of the Yamal Peninsula and the existence of permafrost islands on the shelf provide for the wide development of the gas hydrate metastability zone within the Yamal oil and gas region.

The gas hydrate metastability zone is the zone of possible existence of relic gas hydrates due to the self-conservation effect [*Ershov et al. 1991*]. It is limited by the permafrost development and thickness. The gas hydrate metastability zone plays an important role in the hydrate saturation of grounds in the cryolithozone of the Yamal oil and gas region and also determines its gas hazard.

The gas hydrates stability zone within the Yamal oil and gas region is developed to a lower degree. As the calculations showed, the gas hydrates stability zone can form on the dry land with the cryolithozone thickness equaling above 250 m, or in deep-water subaquatic conditions on the shelf.

Therefore, natural gas hydrates in the Yamal oil and gas region can occur both in the stable and the metastable states. Relic gas hydrates that are the most aggressive to temperature, baric and chemical technogenic impacts inevitable in the process of field development and that are therefore the most gas hazardous are developed practically everywhere.

The gas hazard of the cryolithozone is defined by the possible response of the hydrate-bearing stratum to the disclosure of hydrate-saturated horizons. From this standpoint, the areas are the most gas-hazardous if their thick continuous gas hydrate metastability zone is underlain by cooled salted grounds aggressive to gas-hydrates.

The problem of the gas hazard in the cryolithozone was discussed in more detail based on the example of the Bovanenkovo oil and gas condensate field.

The outline map of gas shows distribution, types and characteristics in the cryolithozone intervals of the Bovanenkovo oil and gas condensate field was prepared based on the generalization of the data from permafrost appraisal, exploration and monitoring well drilling. The extensive factual material allowed us to analyze the dependence of the cryolithozone gas hazard on the geological and tectonic structure of the Bovanenkovo oil and gas condensate field's territory (confinedness to fault zones etc.), the petrographic-geochemical particularities of grounds etc. It also allowed us to predict the behavior of the hydrate-saturated permafrost of the Bovanenkovo oil and gas condensate field for the whole period of field operation.

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Permafrost degradation and climate-related thermokarst dynamics in populated Central Yakutia, Eastern Siberia

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Introduction and background

The monitoring of permafrost landscapes is a cornerstone for the quantifications of future environmental changes and their impacts on periglacial areas. Thawing permafrost has been caused massive landscape changes, enhanced release of organic carbon from frozen deposits, and impacts on human existence. Degradation of ice-rich permafrost results in characteristic thermokarst landforms that are widespread in Central Yakutia. The Holocene thermokarst evolution is dominantly a climate-driven process. Permafrost thawing due to increased air temperatures in the early Holocene resulted in surface subsidence and the subsequent formation of thermokarst lakes and depressions (alases). In addition, the landscape in Central Yakutia is subject to strong short-term modifications by intensified land use and extreme weather events [*Brouchkov et al., 2004; Fedorov & Kontantinov, 2009*].

However, it is not sufficiently clear, how and when thermokarst depressions in Central Yakutia were formed or how they have evolved since the late Pleistocene-Holocene transition and secondly, which climatical, morphological or hydrological parameters are currently influencing thermokarst depression and lake dynamics. In particular, the anthropogenic aspect is of special interest as human existence in this populated region is strongly connected to the use of thermokarst depressions and lakes for agriculture, fishing and as water resource [*e.g., Desyatkin, 1998*] (Fig.1).

Remote sensing provides the most prospective tool for monitoring thermokarst processes on large scales. However, the successful interpretation of remote sensing data requires substantial field knowledge to understand small-scale variations that might be connected to conditions of cryolithology, relief, vegetation, hydrology, and land use [*Ulrich et al., 2009*]. In order to close this lack of knowledge a new Russian-German Research project will start in summer 2012. The overarching aim of the project “Short and long-term permafrost dynamics due to human impacts (land use) and climate changes in Central Yakutia, Russia” is to contribute to the understanding of permafrost degradation processes, their influencing factors and environmental impacts on different time-scales (years to 1000’s of years) in the sub-arctic regions of Central Yakutia. To reach this goal, remote sensing and GIS techniques will be combined with detailed geomorphological and cryolithological analyses at different thermokarst key sites (Maya-Mooro-Beke-Yukechi; Tyungyulyu; Myuryu; Neleger). The Lena-Aldan region east and north-east of Yakutsk is of special interest, as this area is highly affected by thermokarst. Furthermore, the region has been investigated over the last few decades by several Russian groups of the Permafrost Institute Yakutsk and also as part of joint Russian-German projects, which provides an excellent basis for more comprehensive further studies.

Research objectives and perspectives

Three basic hypotheses underpinning the project are as follows:

1. Short-term events on time-scale of years to 10’s of years within the last decades can be identified by change detection methods using time series of airborne and satellite remote sensing data (Fig. 1). Particularly, changes are quantifiable by mapping, delineating and geomorphometric analyses of lake and depression areas as well as by detection of specific surface signatures e.g., vegetation, surface moisture (hydrology), salinity using multi-spectral remote sensing data. This in combination with existing and new field measurements of environmental parameters (i.e., temperature, precipitation, active layer depth, surface subsidence) will results in regional quantifications of land cover changes within disturbed and natural developed thermokarst depressions.
2. Sedimentological, cryolithological, and paleoecological records in relation to the geomorphology of different thermokarst depression components (i.e., terraces, inter-depression areas, and lakes) at diverse sites provide paleoenvironmental archives for long-term landscape evolution on time-scale of hundreds to thousands of years. Their detailed analyses will results in new insights of spatial and temporal variability of thermokarst relief and evolution and of permafrost dynamics at specific sites in connection to natural climate variations and regional permafrost history during the Holocene.
3. By combination of temporal and spatial high-resolution remote-sensing data with detailed field analyses, the field data information will be extrapolate to regional scales. This will lead to the development of DEM based schematic models of past and future landscape evolution of the Lena-Aldan-Amga region and the discrimination of areas being at different risk due to permafrost degradation hazard analysis.

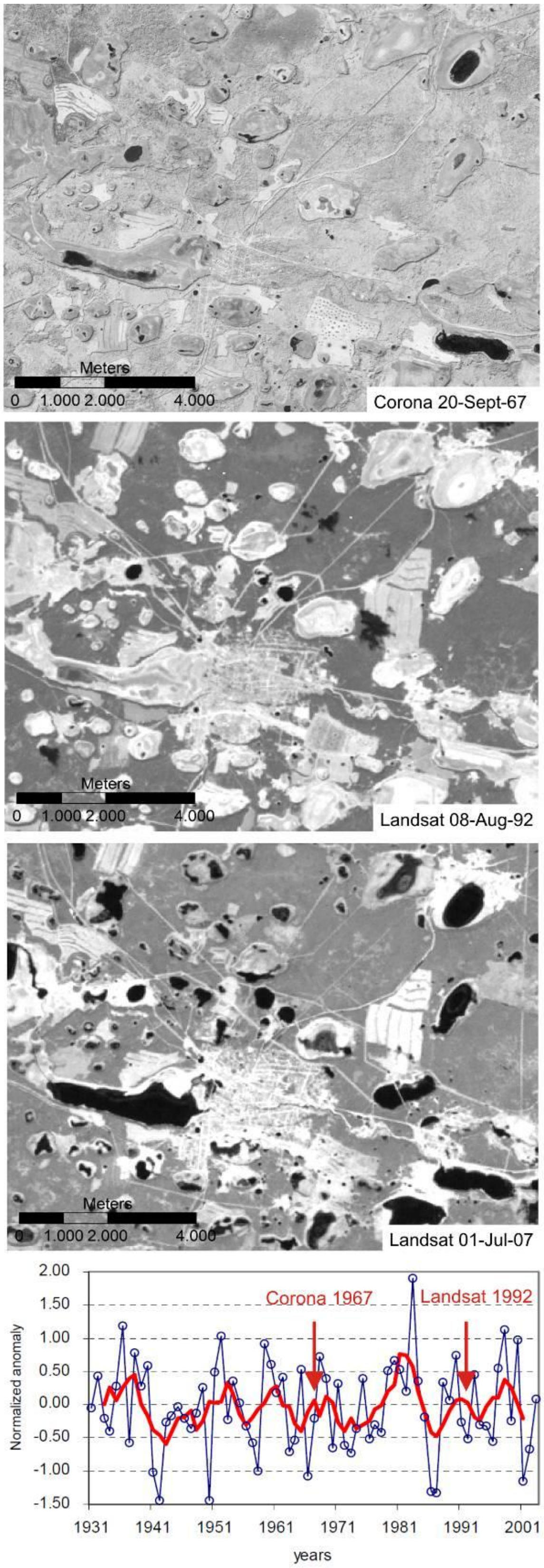

Figure 1. Development of a thermokarst dominated landscape with lake area change, and settlement growth on the example of the alas Maya and its surroundings between 1967 and 2007 by Corona and Landsat images. By comparison, the lower diagram by Fedorov (2006) illustrates dynamics of cryoecological stress in landscapes of Central Yakutia in the time between 1931 and 2001.

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Assessment of the Hazard of Water Erosion Processes During the Development of Hydrocarbon Deposits in the Yamal Peninsula

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The Arctic region is extremely rich in various natural resources, which leads to the active involvement of these resources into the sphere of public interest. At the same time the development of the area should be accomplished in the ways that minimize negative impacts on the environment.

One of the priority regions of the Arctic development is the Yamal Peninsula. Back in 2002, the Board of Gazprom OJSC defined it as a region of the strategic interest for the company. In the future the industrial development of hydrocarbon deposits of the Yamal Peninsula will allow to provide about half of the annual gas production of Gazprom OJSC.

However, in the process of the development of the Yamal Peninsula production fields Gazprom OJSC is faced with the necessity to solve a large complex of the hardest problems and tasks. Among them a special place is occupied by environmental problems.

Thus, difficult climatic and natural conditions with long hard winters and short cool summers considerably complicate the production and transportation of hydrocarbons in the region. At the same time the vulnerability of Yamal natural systems to anthropogenic stress in the process of development contributes to the transformation of vegetative ground cover to the point of its complete destruction. This leads to a change in the hydrological regime of water bodies due to changes in the conditions of surface discharge formation. This also causes the increase of the area of flood plains and the activation of dangerous exogenous processes such as thermokarst, thermal erosion, cryogenic slipouts, cryogenic frost heave, frost cracking, and solifluction. They present a great threat to engineering structures of the gas production complex.

According to current estimates, thermal erosion is the most dangerous exogenous process, which is the process of permafrost destruction by water erosion due to simultaneous thermal and mechanical effects of water flows. As a rule, thermal erosion is developed on the slopes of fluvial and marine terraces in the form of linear formations – landslide scars, rain channels, erosions, and gullies. These forms of the manifestation of the process correspond to different stages of the development of thermal erosion – from the planar stage to that of a gully. Thermal erosion hazard lies in the fact that temporary erosive flows are formed during snowmelts and rainfall in the conditions of linear violations of vegetative ground cover on the slopes with the gradient of 3 ÷ 6° or more. The flows are also formed on discontinuities of slopes and on coastal edges of rivers and lakes. Such flows can promptly destroy permafrost by a thermal erosion cutting and threaten engineering structures and communications.

To solve these and other emerging problems in 2009-2011 Gazprom VNIIGAZ LLC organized environmental and technological expeditions with the participation of the leading specialists of relevant scientific research institutes of the Russian Federation.

During the expeditions comprehensive geo-ecological studies of the modern state of the environment and the assessment of the state of water-erosional network on the territory of the Bovanenkovskaya group of fields and the crossing area of Pipeline Bovanenkovo-Uhta through the Baydaratskaya Bay were carried out.

Thus, due to the unique natural conditions on the Yamal Peninsula, its development is impossible without the use of environmentally safe technologies minimizing the anthropogenic impact on the environment and ensuring its preservation.

Aspects of the Thermal Regime on the Periglacial Belt of Southern Carpathians (Romania)

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Introduction

Periglacial phenomena in Romania developed at various times and under a considerable range of environmental conditions during the Pleistocene and Early Holocene. The legacy of periglaciation across Romania is a rich variety of landforms, deposits and sedimentary structures, especially in the alpine domain where the periglacial landforms represented the main detailed elements of the geomorphologic landscape. In this temporal context, it is clear to make a difference between the relict elements and present-day periglacial processes. On the other hand, it is self-understood that in the lowland area the periglacial elements have a relict character, in contrast to the highland area, in essence alpine domain, in which some of periglacial elements have the climax status [*Urdea et al., 2008*]. It is unanimous recognize the fact that the periglacial processes are one of the most significant geomorphological processes involved in the recent transformation of the high-mountain relief of Europe, inclusive Carpathians Chain [*Rączkowska 2009*].

For a very well documented thermal regime in the periglacial belt on the Southern Carpathians, especially about frost and freezing and thawing cycles, with morphogenetic effects, in fact periglacial processes, such as weathering, frost heaving and frost creeping our team stared a monitoring program in this direction and, in consequence our paper have in intention to show some results.

Study area

General characteristics

The Southern Carpathians, or Transylvanian Alps, are the most massive and highest part of the Romanian Carpathians, having 11 peaks above 2500 m and a maximum elevation of 2544 m in Moldoveanu Peak (Făgăraş Mountains). Ten percent of the area lies above 2000 m and 17% above 1700 m, in fact, in the actual periglacial belt. In the high area of the Southern Carpathians the geomorphological landscape is dominated by glacial landforms, while the periglacial elements (rockglaciers, talus cones and scree slopes, block fields, rock streams, cryoplanation terraces, patterned ground, solifluctions, tors etc.) are widespread.

Climatic conditions

From the climatic point of view we must take into account the existence of an alpine periglacial climate lying above timberline in Southern Carpathians. The climatic conditions specific for the high zone of the Romanian Carpathians are cold, with the mean annual air temperature of 4.4°C at Cuntu (1450 m), 3° C at Cozia (1577 m), 0.4° C at Bâlea-Lake (2038 m), -0.5°C at Ţarcu (2180 m) and -2.4°C at Omu (2505 m), where the absolute minimum temperature is -38°C. The vertical thermal gradient in the high area of the Southern Carpathians is 0.57°C/100 m. The mean annual precipitation is due to the atmospheric circulation rather than altitude (1072.2 mm at Cuntu, 844,2 mm at Cozia, 1220.3 mm at Bâlea-Lake, 959.4 mm at Ţarcu and 969.8 mm at Omu). Because the spreading of some periglacial form is correlated with continentality [*Höllermann 1983*], we calculated the different continentality indexes. For example, Gorczynski and Gams continentality indexes show a clear differences between the meteorological station situated at high altitude, Bâlea, Ţarcu and Omu. The thickness of the snow layer can vary between 20 and 264 cm in the cold semester and is highly variable according to the wind action. The snow cover in the region lasts between 148-221 days of the year, while the interval without freeze is between 0-143 days/year. The isotherm of 3°C mean annual temperature - indicating the lower limit of periglacial environment according to French [*1996*] -, is situated around 1700 m a.s.l. By climatic-geoecological types of the periglacial belt in mid-latitude mountains point of view [*Höllermann 1985*], the Southern Carpathians are inscribed in a transitional area between the humid sub-type, specific for Alps Mountains, and arid sub-type of the moderate continental type, specific for Central Caucasus Mountains.

Sites description and methodology

Because the ground temperatures are more relevant for cold-climate weathering and permafrost formation than air temperature [*French 2007*] we have started to evaluate this climatic parameter in various active/relict periglacial landforms situated in the periglacial belt of the Transylvanian Alps (Table 1) (earth hummocks, solifluction lobes and terraces, rockglaciers, tors and rock walls). In Muntele Mic massif (located in the extremely North-Western part of the Southern Carpathians), we have measured the annual thermal regime of the earth-hummocks terrain (MM 1) and nearby grassy flat ground (MM 2), and respectively, the thermal regime of the rock walls of a periglacial tor, oriented to North (MM N), and South (MM S).

For the high part of the periglacial belt our attention was oriented for permafrost detection in rock glaciers and freeze/thaw cycles in rock walls which sorrounding the rockglacier, situated in two glacier cirques, Căldarea Pietroasă (PTR) and Văiuga (VAI), oriented to North, East and West, from Făgăraş Mountains (Table 1).

Each selected site was equipped in the summer of 2010 with the DS1923 tempeture/humidity thermistors (Maxim Integrated Products, Inc., USA), with 14400 seconds measurements interval and a resolution of ±0,0625°.

Thermal regime aspects

The recorded values of ground temperatures showed significant differences than air temperature regime. For the Muntele Mic site we have measured the temperature at 4 different depths (10, 20, 30 and 40 cm) and we have noticed important distinctions between earth hummocks and flat grassy thermal regimes (Table 2).

Table 1. Thermistors location

Thermistors	Lat.	Long.	Alt. (m a.s.l.)
PTR RG	45°35’	24°36’	2137
PTR N	45°35’	24°36’	2227
PTR E	45°35’	24°35’	2218
PTR W	45°35’	24°36’	2196
VAI RG	45°36’	24°37’	2295
VAI N	45°36’	24°37’	2325
VAI E	45°36’	24°37’	2332
VAI W	45°36’	24°37’	2329
MM 1	45°22’	22°28’	1759
MM 2	45°22’	22°28’	1777
MM TOR N	45°23’	22°28’	1635
MM TOR S	45°23’	22°28’	1635

Table 2. Ground thermal regime (°C) of the earth hummock (MM1) and grassy flat ground (MM2) from Muntele Mic

Depths	10 cm		20 cm		30 cm		40 cm	
Site	*MM1*	MM2	*MM1*	MM2	MM1	MM2	*MM1*	MM2
MAGT	5.4	5.2	6.2	5.2	6.8	5.3	7.6	5.1
Days with T≤ 0°C	144	86	118	0	110	0	0	0
First day with T≤ 0°C	27.11	3.01	3.01	-	26.01	-	-	-
Last day with T≤ 0°C	26.04	2.04	28.04	-	11.05	-	-	-

Regarding the granitic tor from Muntele Mic we discovered considerable high differences between the northern aspect wall and southern aspect wall. Thus, the mean annual temperature of the wall was 4.6°C to the north and 6.6°C to the south, while the number of days with freeze-thaw cycles vary significant (Table 3)

Table 3. Number of days with freeze-thaw cycles – Muntele Mic periglacial tor

months	MM TOR N	MM TOR S
Nov.	3	5
Dec.	6	9
Jan.	11	13
Feb.	8	14
Mar.	7	10
Apr.	6	4
May	3	1
TOTAL	44	56

The ground surface temperature (GST) of two rock glaciers (Pietroasa and Văiuga) from Făgăraş Mountains was continuously monitored for 1 year in order to detect permafrost. The mean anual GST and the temperature regime in the BTS window were used to evaluate the probability/possibility of permafrost occurence [*Ribolini & Fabre 2006*] (Table 4). The GST results combined with ERT surveys show the presence of permafrost in Căldarea Pietroasă RG.

Table 4. GST parameters for Căldarea Pietroasă and Văiuga rock glaciers

Name	MAGST (°C)	BTS window (°C)	Maximum BTS (°C)	Average BTS (°C)	Minimum BTS (°C)
PTR RG	0.0	01.03–31.04	-3.2	-4.4	-5.3
VAI RG	1.6	01.03–31.04	-0.0	-0.2	-0.5

In the case of a glacial cirque (Căldarea Pietroasă) we measured the temperature regime of the walls with different aspect during 2010-2011 winter. The situation presented in fig. 1 show that the lowest temperature are on the north walls, where the mean annual temperature is -0.7°C, while on the west wall is 1°C, respectively 2.1°C on the east. The number of freeze-thaw cycle days vary between 33 (west aspect wall) 26 (east aspect wall) and 23 (north aspect wall).

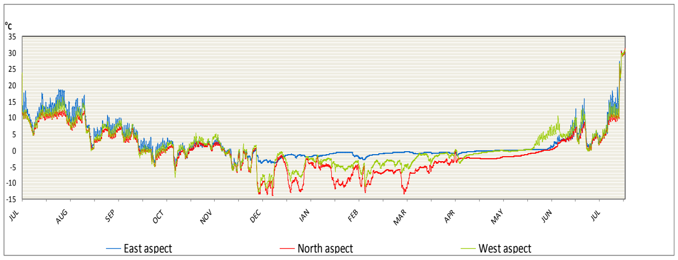

Fig.1. Căldarea Pietroasă – thermal regime of glacial cirque walls

A similar situation was recorded in the Văiuga glacial cirque where the lowest mean annual temperature is on the north wall (2.7°C), while on the wall with west aspect (3.8°C) the temperature is higher than on the east wall (3.3°C).

Since the anthropic pressure on alpine environments begin to grow in the last decades further work on accurate mapping of periglacial landforms, continuining measurements of periglacial processes dynamic and periglacial landforms internal structure using geophysical methods and a better knowledge of particular climatic conditions for a wide range of periglacial processes are required tasks in the future.

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The Impact of Permafrost on Particularities of the Soil Cover of the North Siberian Lowland

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Introduction

Permafrost significantly defines the morphological profile as well as physical and chemical properties of soils. The permafrost impact on the soil development is so diverse that it allows us to consider it a soil formation subfactor. The soil cryogenesis process should be understood as a combination of processes of physical, chemical and biological transformations occurring due to the impact of negative temperatures and phase transitions across 0°C, i.e. in the process of their freezing, staying in the frozen state and thawing [*Makeev 1981*]. The soil cryogenesis is fully manifested in the cryolithozone. The soil cryogenesis is most clearly manifested in soils with a high degree of hydromorphism, because the moisture in these soils is the material the freezing of which causes a wide development of cryogenic soil formation of the mineral part of the soil and the soil formation products. Moreover, the ice accumulated in the soil stratum requires additional expenditures for thawing. This eventually reduces the thermal resources of the vegetation period abruptly.

The studies of the soils of the forest-tundra ecotone were carried out at the Ary-Mas model site located at the Taymyr Peninsula within the North Siberian Lowland, in the southern tundra subzone. Ary-Mas is the northmost forest massif in the world. The permafrost thickness varies from 100 to 800 m within the North Siberian Lowland and makes up 400-600 m in the area of the Khatanga River. The area is characterized by the low ground temperature (from -5 to -16°C) and quite high ice content of the deposits (40-60%) [*Geocryology…, 1989*].

Research methodology

A profile (2550 m long) was made at the Ary-Mas site, from the watershed to the 3rd above-floodplain terrace of the Novaya River (left tributary of the Khatanga River). Six test areas were developed along the profile, differing by various vegetative associations and the nature of the relief. 1-4 sections (17 in total) were developed at each site in the most typical conditions.

The detailed descriptions of the vegetation and the soil cover were produced along the profile and at each site. Morphometric characteristics of all larches were also described if their heads fell on the profile line or they grew at the test sites. The seasonally thawed layer was measured in different ecotopes (light larch forest, larch open stand and tundra) for identification of the permafrost impact on soils. 3800 measurements of the depth of the seasonally thawed layer and 339 measurements around numbered larches (113 trees in total) were made along the profile. The depth of the seasonally thawed layer was also measured at test sites and within the 5 m radius from each soil section. Loggers (6 in total) were placed at the depth of 10 cm in different ecotopes for 10 days (between 9 and 18 July 2011). They measured the temperature every 4 hours.

Results

All the studied soils of the Ary-Mas site are referred to the gley soil division according to the "Classification of Russia's Soils" [*2004*] and to cryosols according to the international soils classification WRB [*World Reference Base..., 2007*]. Since the studied soils are thin (the active layer depth is from 11 to 64 cm, an ice-rich transient horizon is identified), they can be referred to cryogenic ones. Slow transformation of the organic substance, formation of peat horizons and accumulation of flow humus are also characteristic of the cryogenic soil formation in general and of the studied soils in particular.

The minor seasonal thawing depth and poor drainage of the area precondition general gleization in the Ary-Mas soils, and formation of temporary perched ground water in some cases, that is associated with the presence of an aquiclude and the release of the moisture from the frozen state. Cryogenic processes assist in the humus accumulation in the suprapermafrost soil stratum. N.A. Karavaeva and V.O. Targulyan [*1978*] called this phenomenon humus suprapermafrost retinization. This process is not expressed morphologically at the area of research and is identified analytically only: humus is accumulated in suprapermafrost horizons in the amount of 1.0-4.3%. Despite the development of heave processes, soil profiles are homogeneous and no cryoturbations are noted.

The lowest average values of the seasonally thawed layer depth for the whole area are observed in forest ecotopes. For example, the average value of the seasonally thawed layer in the open larch forest is 30.5 cm, with the lowest values of the seasonally thawed layer found right around larches (20.2 cm). Here, the lowest soil temperatures are observed at the depth 10 cm, varying from 3.7° to 5.7°C. In these conditions the root systems can develop only in the horizontal plane (broadwise) and require greater areas. This intensifies the root competition, preconditioning the instability and the general weak survival rate of trees. Therefore, permafrost is one of the main reasons for sparseness of the wood cover of northern forests and open stands. Coarse-humic, flow-humic and cryogenic-oxidized gley sols are formed in open larch forests.

The thawing depth around trees is wider in larch open forest than in larch open stand. The average value of the seasonally thawed layer around trees is 25.9 cm. In general, the average value of the seasonally thawed layer for this ecotope is 39 cm. As compared to the larch open forest, the soil temperatures here are by 1.5-2°C higher and make up 5.9°-7.3°C. Such distribution of the seasonally thawed layer depths and the temperature around larches in open stands is evidently associated with better thawing of the frozen horizon in more open (less forested) spaces. Coarse-humic gley soils are formed in larch open stands directly close to trunks.

More complex soil cover is typical of tundra ecotopes. Frost-mound soil complexes (mound cotton grass-suffruticous tundras with overgrown spot medallions) are most widely developed at the sites with tundra vegetation in case of the absence of wood species. Their formation is associated with the irregular change of the volume in the process of freezing of the clayey silt over-moistured ground in the absence of free moisture. The spots in the soil cover of the area under study occupy minor sites up to 20% of the territory. The diameter of spots (Fig. 1) can vary within rather a large range: from several tens of centimeters to first meters. The most typical values of the spot without vegetation at the Ary-Mas site were 30-50 cm in diameter, with the diameter of the whole spot equaling 1.0-1.5 m (including the borders).

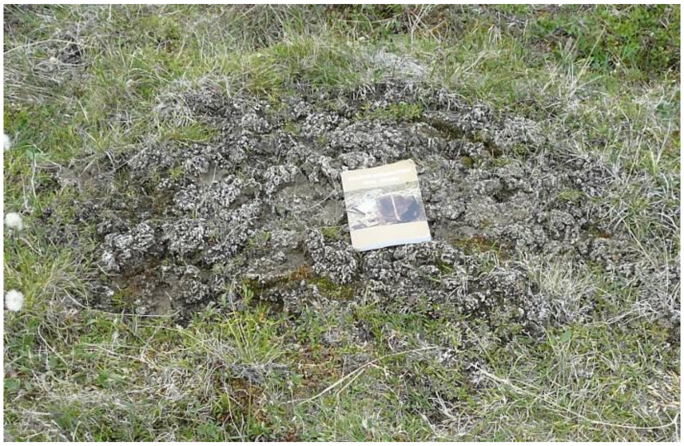

Figure 1. Overgrown spot medallion. Photo by A.A. Usacheva

Poorly developed soils of spots are formed on the spot in spotted-mound complexes. Gley humic and coarse-humic soils are developed on the borders, and peat humic gley soils are developed in the depressions around the mound. A relatively low thickness of the seasonally thawed layer and, respectively, of the soil profile in general (below 45 cm) is characteristic of the soils in the depressed parts of the complex. On the contrary, the greatest thickness of the seasonally thawed layer (above 50 cm) is noted at the uplifted elements of microrelief. The highest soil temperature values (8.3°-12.0°C) are noted here as well, with the maximum ones characteristic of the spot medallion peaks with almost no vegetative cover (12.0°C). This is more than by 3.5° higher than the temperature in the depressions between them. The differences in the values of the seasonally thawed layer depth and in soil temperatures are associated both with the permafrost bedding level and with the warming of the soil surface at the spot and in depressions.

Conclusions

The studies showed that the frost heave and the small-patterned frost cracking are most expressed on forestless sites with tundra vegetation, and slightly weaker expressed in open stands, which is associated with the significantly lower thickness of the snow cover, of the thawing depth and with the temperature of the active layer.

Spot soils are not formed in rarefied larch forests, and in the open stands they occupy significantly smaller areas (not more than 10%) than in tundras. Therefore, the cryogenically preconditioned contrast nature of the soil cover falls with the occurrence of wood species.

Acknowledgements

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Paleocryomorphic Soils of the Center of the East European Plain as Archives of Paleoecological Natural Events

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Abstract

The spatial variability of magnetic susceptibility in paleocryomorphic soils of the center of the East European Plain was studied in the work. It was established that magnetic susceptibility distribution in modern soils is closely associated with paleocryogenic structures located at the depth of 2 m and lower. Magnetic susceptibility topoisopleths allow to judge on the formation and the existence of various, especially strong magnetic iron oxides and conclude on soil formation conditions. The magnetic susceptibility survey allowed to identify a number of indicators that are hard to detect in the field.

Keywords: cryomorphic buried soil; magnetic susceptibility; paleocryogenic structures; variability

It is known [*Alifanov & Gugalinskaya 1993, 2000; Velichko et al. 1996*] that the soil cover in the center of the East European Plain has the traces of cryogenic deformations. They in turn precondition the significant spatial variability of soil properties. The understanding of the regularities of soil properties distribution in space is of great interest, both for the fundamental soil science and related sciences. We used one of the parameters defined without any preliminary sample treatment (chemical or physical), namely bulk magnetic susceptibility, for identification of regularities in the soil properties distribution. Magnetic susceptibility is a physical value characterizing the magnetizability of soil Fe-bearing components. The intensity of flowing of some elementary soil processes and the environmental conditions of the profile formation are defined in the process of paleogeographic reconstructions on the basis of the magnetic susceptibility value in different genetic horizons.

It is known that iron forms characterize very important genetic peculiarities of soils. Nonetheless, the methods of such forms identification, based on the different iron compounds solubility are not sufficiently accurate. This is because there arise some difficulties in identification of some iron forms so that the other ones are not touched. Magnetic susceptibility measurements allow to characterize different (first of all, strong) magnetic crystalline iron oxides even if their content is insignificant.

The studies were conducted in Tula Region, in the conditions typical of the Central Russian Upland, on clayey-illuvial typical and podsolized black soil. The spatial variability of magnetic susceptibility was studied in sections-outcrops with the length from 12 to 23 m and the depth down to 3 m.

The following soils were revealed in the sections: modern black soil underlaid by the Late Pleistocene covering loess-like clayey silt, cryomorphic buried soil horizons and a moraine. The following types of paleocryogenic structures were identified: pseudomorphs in wedge ice, large wedged ground structures (LWGS), nonsorted circles and solifluction deformations.

The following facts were identified as a result of three-year investigations: areas with high magnetic susceptibility values that also have increased thickness on topoisopleths are observed in humus horizons of modern soils located above the LWGS system. The positive correlation ($R^2=0.94$) was identified between the distribution of magnetic susceptibility values and the C org. profile distribution. High magnetic susceptibility values are preconditioned by the presence of paedogenic high-magnetic Fe oxides (of magnetite type). This testifies to alternation of wetting and drying processes here, corresponding to anaerobic and aerobic periods, and also to variable pH and to the participation of the organic substance in these oxides formation [*Vadyunina & Babanin 1972; Vodyanitskiy 2008*].

The abrupt increase of magnetic susceptibility values (up to the values typical of humus horizons of modern soils) at the depth of 250 cm (Fig. 1, the lower diagram) testifies to the presence of a unique geochemical (lithological?) barrier corresponding to the boundary between subhorizons (A1) and (A1B) of the buried soil humus horizon (Fig. 1, the upper diagram). We think that subhorizon (A1B) is actually an independent buried soil layer formed in the automorphic position in relatively warm climatic conditions, with good aeration, seasonal drying and domination of oxidizing conditions. Even more anomalous high magnetic susceptibility values ($1.44\text{-}3.03\times10^{-3}$ SI units) are revealed at the contact between (A1B) and the moraine. This is usually associated with the conditions favorable for the chemosynthesis of strong-magnetic ferrous minerals. The presence of such conditions is confirmed by multiple subhorizontal and subvertical ochreous interlayers that are 0.5-1.0 cm wide. The inclination of the moraine surface and the differences in its particle size distribution with overlaying deposits assist in the development of the lateral groundwater flow, preconditioning the contrast water-air regime here.

High magnetic susceptibility values in the moraine can be associated with the increase in the iron content in the composition of paramagnetic clayey minerals, while their long-term preservation is probably associated with deferred limonitization preconditioned by the increased concentrations of absorbed cations here.

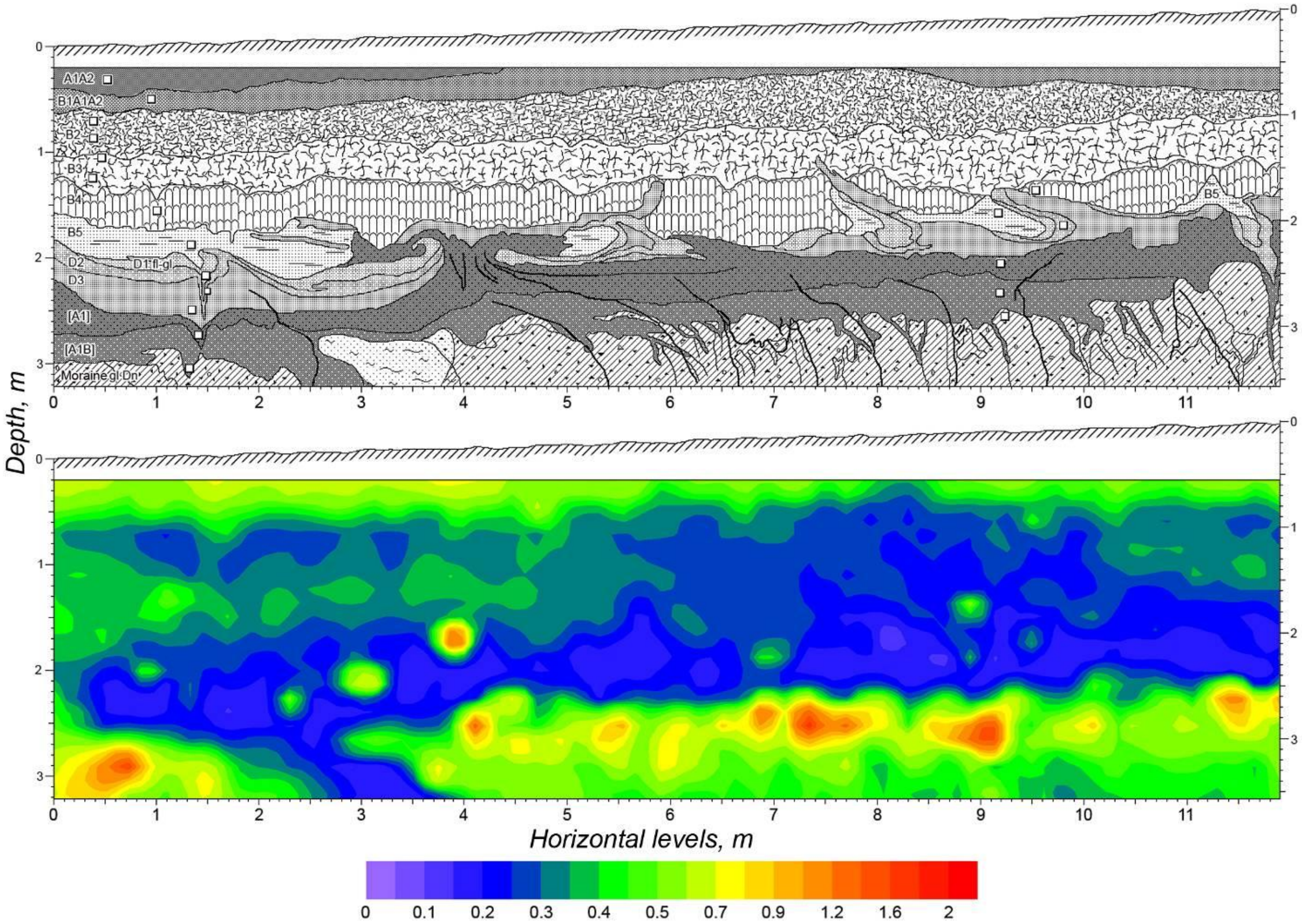

Figure 1. The diagram of section 1-2010 (at the top) and the topoisopleths of spatial distribution of magnetic susceptibility values ($\times 10^{-3}$ SI units) (at the bottom).
Tula Region, Venev area

Therefore, we managed to instrumentally reveal the indicators on the basis of magnetic susceptibility the detection of which was morphologically complicated. Specifically, we managed to identify a paleocryogenic block uplift and an interblock depression, the buried soil horizons in sections as well as to assume the direction of the prevailing moisture flow routes.

Acknowledgments

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A History of Permafrost in Siberia During the Last 450 ky, a Tool for Climate Change Prediction

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Permafrost degradation is one of the major threats of human-induced global warming. This process may release the ca. 1672 Giga-ton carbon pool that is stored in the permafrost into the atmosphere, enhancing the greenhouse effect [*Grosse & Romanovsky 2011*]. It will also endanger buildings and infrastructures built on permafrost, including Siberian oil and gas facilities, which are the major energy sources for Russia and its trade partners [*Anisimov & Reneva 2006*]. Thus, ability to predict the scale of permafrost degradation in the near future is of great importance.

In this study we use speleothems to track the evolution of permafrost during the last ~450 ky on a North-South transect. Atmospheric waters seeping into caves allow formation of vadose speleothems (stalagmites, stalactites and flowstones) only when the averaging annual surface temperature is >0°C. Periods of speleothem deposition therefore provide a tracer for presence or absence of permafrost. Twenty-eight speleothems were collected from three caves along a North-South transect in Eastern Siberia. The studied caves are distributed within the southern boundary of continuous permafrost zone (Ledyanaya Lenskaya, 60.3°N-116°E), through the discontinuous permafrost zone (Botovskaya, 55°N-105°E) and island permafrost (Okhotnichya, 52°N-105°E).

Hundred-and-one speleothem horizons from these caves were dated by highly accurate and precise U-Th analyses using a Nu-Instrument Multicollector-Inductively-Coupled-Plasma-Mass Spectrometer (MC-ICP-MS) at the University of Oxford. The youngest speleothem age in the Lenskaya Ledyanaya was ~425 ky, corresponding to the early interglacial Marine Isotope Stage (MIS) 11, while 14 other horizons in 6 additional speleothems from this cave were older than the U-Th dating limit (500 ky). In Botovskaya and Okhotnichya Caves the speleothem ages (27 and 58 respectively) from twenty one speleothems cluster into following time periods: >500, 435-370, 355-308, 212, 201-193, 128-118, and 10-0.5 ky, corresponding to the interglacial MIS-11, 9, 7, 5 and the Holocene.

Interglacial early MIS-11 was the youngest period of speleothem deposition in the northern part of the research area, contrasting with the more temperate region north-west of Lake Baikal where speleothems grew during the peak of each of the interglacials. These results suggest that early MIS-11 in the Eastern Siberia was much warmer than today, causing permafrost degradation at the boundary of present-day continuous permafrost north of 60°N. The exceptional warmth of the early MIS-11 is supported by the paleotemperature reconstruction based on the record of biogenic silica from Lake Baikal sediments [*Prokopenko et al. 2001*], showing temperatures 2-5°C higher than at present, whereas MIS-5.5 was only 1-4°C warmer than today [*Fotiev 2009*].

A record of Pacific Warm Pool Sea Surface Temperatures (SST) reflecting changes in mean global temperature suggests a global warming of 0.5-1°C during MIS-5.5, and of 1-1.5°C during the early MIS-11 [*Hansen et al. 2006*]. The magnitude of the permafrost degradation during these periods can be a basis for the prediction of Siberian continental climate in the future. Thus, an increase in global temperatures by 0.5-1°C, as during the MIS-5.5, will cause degradation of mainly discontinuous permafrost. However, global warming of 1-1.5°C will resemble a climate of early MIS-11, causing permafrost degradation at the southern fringes of the continuous permafrost zone north of 60°N.

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Permafrost Degradation and Carbon: The Importance of Ecosystem Recovery

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Introduction

Northern soils contain nearly twice as much carbon as the atmosphere. Permafrost degradation caused by a warming climate will destabilize this carbon store. Part of this carbon will enter the atmosphere as CO_2 or CH_4, contributing to a positive feedback on climate warming [*e.g. Schuur et al., 2008*]. Typical disturbances of permafrost soils by warming are pond formation, formation of thaw lakes and thaw erosion features, which may expose soil carbon to either anaerobic or aerobic decomposition.

However, recovery of ecosystems may create new carbon sinks on various time scales. These ecosystem recovery effects need to be incorporated in an appropriate way in evaluation of future carbon emission from permafrost soils under global warming conditions. Below three examples are addressed.

Carbon fluxes from permafrost degradation features

Study area

The examples below are based on the Indigirka Lowlands in Northeastern Siberia, which includes Kytalyk/Chokurdagh research station (70°50' N, 147°30' E). Kytalyk research station is located in the basin of a drained thaw lake, at the edge of the floodplain of the Berelegh river, a tributary to the Indigirka.

Thaw ponds

The microrelief at the research site is dominated by ice wedge polygons and low palsa-like features with dry peat soil and *Betula nana*-dominated vegetation, alternating with wet sedge meadows. The palsas are attacked by melting at their edges, which creates ponds with dead *B. nana* remains. Comparison of recent high resolution GeoEye images with Keyhole images shows a threefold increase of thaw ponds since 1977.

Fresh thaw ponds show a strong emission of both CO_2 and CH_4, resulting in a strong greenhouse gas (GHG) source (Figure 1). Other wet vegetation types are net sinks despite high CH_4 fluxes, e.g. Carex-dominated vegetation. This sink results from their strong net CO_2 uptake. The dry *B. nana* vegetation on the palsas is also a sink, with a negative CH_4 flux.

At first sight the formation of fresh ponds increases the net GHG flux. However, ponds appear to be colonized rapidly by dense *Carex-Eriophorum* stands, and may ultimately be colonized by *Sphagnum*. This results in a return of the carbon sink, probably within a time scale of years. Both the *Carex-Eriophorum* and *Sphagnum* dominated vegetations are net sinks (Figure 1). This succession still has to be confirmed by experimental research, but the observations strongly suggest a limit on the GHG source.

Thaw lakes.

Thaw lakes in the study area show locally signs of active expansion and are sources of CH4. The occurrence of many drained thaw lake basins (DLTB's) in the area suggest repeated formation and drainage of lakes throughout the Holocene. Modeling of thaw lake expansion [*Van Huissteden et al., 2011*] clearly demonstrates that with future global warming scenarios thaw lakes expansion will speed up, and new lakes may be formed in ice-rich permafrost.

However, this model also shows a clear limit on thaw lake expansion, caused by drainage of lakes when they are integrated in the drainage system. If permafrost degradation continues to sufficient depth and taliks interconnect, also drainage by groundwater flow will be enhanced. The DLTB in which Kytalyk research station is located, is a net GHG sink [*Van der Molen et al., 2007; Parmentier et al., 2011*]. Also DLTB's in Alaska show evidence of carbon storage in soils [*Hinkel et al., 2003*].

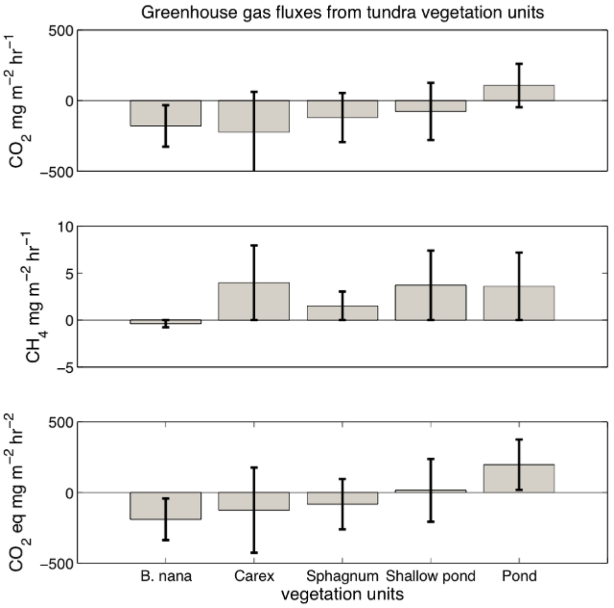

Figure 1. Greenhouse gas fluxes from tundra vegetation units associated with thaw ponds. B. nana: dry *Betula nana* dominated vegetation on palsas; Carex: *Carex-Eriophorum* dominated wetland, in sedge meadows and colonizing ponds; Sphagnum: *Sphagnum* hummocks; shallow pond: pond with submerged *Sphagnum*; Pond: fresh pond with dead *B. nana*.

Thaw erosion.

Mass wasting enhanced by permafrost degradation locally occurs in the area, in particular along river and thaw lake banks. Static chamber flux measurements show relatively small fluxes from freshly eroded, nearly unvegetated soils at these locations, averaging to a near-neutral GHG balance (-4.6 ± 128 mg CO_2 eq m^{-2} hr^{-1}, n=16). However, these sites also show vigorous vegetation growth with forbs and larger *Salix sp*. shrubs, as soon as soil movement stabilizes. This may be related to increased nutrient availability.

Hitherto, net ecosystem exchange and total CH_4 fluxes over this type of ecosystem have not been quantified; their limited extent and inhomogeneous terrain makes these areas unsuitable for eddy covariance application. However, by their nature as pioneering vegetations a large sink is likely.

Discussion and Conclusions

Although permafrost degradation features undoubtedly represent considerable greenhouse gas and carbon sources, their lifetime is limited. At timescales from several years (ponds, mass wasting) to decennia or hundreds of years (thaw lakes) these sources may be converted to sinks, as soon as vegetation is re-established. In particular pioneering vegetation related to more nutrient-rich conditions may result in a strong sink.

This effect of ecosystem recovery occurs on the same time scale as future global warming. It should be taken into account when carbon and GHG release from permafrost is quantified. Consequently, also the vegetation successions during ecosystem recovery should be studied in more detail, including their GHG and carbon balance. Hitherto, models that are able to quantify these effects are lacking.

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Permafrost Extension during the Last Permafrost Maximum (LPM) in the Northern Hemisphere

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Project outline

Understanding the sensitivity of permafrost extent to climate changes is crucial to cope with environmental and infrastructural problems and to unravel the dynamics of climate feedbacks in the near future. Evidence of permafrost extension and climatic conditions during the Last Permafrost Maximum (LPM), term to be preferred above LGM (Last Glacial Maximum), will be helpful to document a wide range of responses of permafrost to climate changes [*Kitover et al., 2012*]. A preliminary map with permafrost limits for the Eurasian continent has been presented as a poster during NICOP [*Vandenberghe et al., 2008*], but mapping of permafrost should be more specific while other continents and regions should be included, but limited to the northern hemisphere. Now, it is the aim to construct a map of the northern hemisphere permafrost extent during the LPM. This operation is to be carried out on the base of existing data by a group of experts dealing with the different regions concerned and is supported as a 'task force' (Action Group) by IPA. We report here on the progress of this project

Criteria used to identify the existence of former permafrost seem to be uniform over the different regions. They include mainly polygons of ice-wedge casts and sand wedges, pingo remnants and large cryoturbations. In addition to these traditional criteria, also modeling of subsoil temperatures can fulfil the role of a proxy at a specific point when such models would indicate former temperature values that proof undoubtedly the existence of permafrost at that specific place during LPM. Reconstructing former permafrost might seem simple, but problems of different nature arise and need a solution before mapping. A few complications deal with the potential differentiation of permafrost: differentiation between altitudinal and latitudinal permafrost is difficult in mountainous regions, while the boundary between continuous-discontinuous-sporadic permafrost is often vague and gradual. Insertion of relict permafrost, although an interesting topic, might induce other complications. Another issue is the potential link between climatic conditions and permafrost: it may be tempting, especially in view of (paleo-)climate modeling experiments [*Vandenberghe et al., 2012*], to 'derive' mean annual air temperatures from permafrost occurrence, despite other factors than a mean temperature determine the occurrence of permafrost.

This project of permafrost boundary mapping is 'work in progress'. In practice, we decided to give priority to determining the southern limit of all kinds of permafrost, including sporadic, discontinuous and continuous permafrost. We agreed also to make no distinction between altitudinal and latitudinal permafrost at all, but the contour lines of 1000 m, 2000 m and 4000 m elevation will be represented in the base map. Provisionally, we will attempt to delineate also the boundary between continuous and discontinuous permafrost in the lowlands (below 1000 m). This should be based on the principle of mapping discontinuous permafrost where permafrost indicators occur only in known favourable conditions (for instance, topography, soil lithology, vegetation, etc.) and continuous permafrost where such indicators occur also in unfavourable conditions.

It is the intention to publish the map of maximum permafrost extent during the LPM in a special journal issue, together with a number of papers that deal with permafrost (including climatic conditions, ecology, morphological processes, etc.) during that period in different regions of the northern hemisphere. Preliminary interests may be announced to the members of the Action Group.

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Geophysical Study of Lowland Permafrost in Komi-Nenets Area, North-West Russia

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Abstract

We present results of a 5-years (2007-2011) project aiming to new applications of electrical and electromagnetic (EM) ground and airborne techniques in permafrost studies. The study is based on geophysical measurements made at three lowland permafrost research areas and one mountain area, laboratory measurements of sediment samples and on geological and temperature borehole data from the research sites. The study areas are situated in the Northern Komi Republic and the Nenets Autonomous Area in Northwestern Russia (fig. 1a). The field EM and electrical resistivity (ERT) sounding data were inverted to 1D and 2D electrical conductivity models. Especially the electrical models from the lowland tundra area, based on the ERT data, show a very nice correspondence with the ground temperature. The electrical conductivity data collected for typical soils and sediments, both in frozen and in unfrozen state, is the basis for advanced use and interpretation of EM techniques and EM data, and for geophysical modeling of permafrost. The conductivity data give a possibility to calculate how, for example, a particular EM system would work at different kind of permafrost areas, i.e., what scale of structures and problems could be explored by it.

Introduction

Thawing permafrost, due to climate warming, is of major concern in the extensive lowland permafrost areas in the northern Komi Republic and the Nenets Autonomous Area in northwestern Russia. Ground temperatures monitored at several research sites in Komi and Nenets areas since 1970's show a clear warming trend [*Oberman and Mazhitova 2003, Oberman 2008*]. In addition to warming ground, permafrost has disappeared from large areas at the southern limit of the permafrost zone and the number and size of taliks increased during the 30-35 years monitoring period.

Drilling and monitoring wells provide accurate geological and temperature information, but only from a very single points. That's why different kind of cost effective and rapid remote sensing techniques have been used in mapping and monitoring permafrost areas [*Kääb 2008, Panda et al. 2010*]. Compared to satellite and aircraft remote sensing techniques, the advantage of geophysical electromagnetic and electrical techniques is that they provide relevant information also from the deeper subsurface layers. Depending on the geophysical method, models imaging the subsurface can reach depth scale of tens or hundreds meters.

We made electrical and electromagnetic (EM) soundings at four representative temperature monitoring research areas situated at the Bolshezemelskaya lowland tundra and the Polar Urals (fig. 1). The main objective of our project was to estimate the sensitivity of different geophysical electrical and EM techniques for imaging relevant permafrost structures in different geological, hydrogeological and morphological environments. To improve the geological and permafrost models of the research sites was an important objective also.

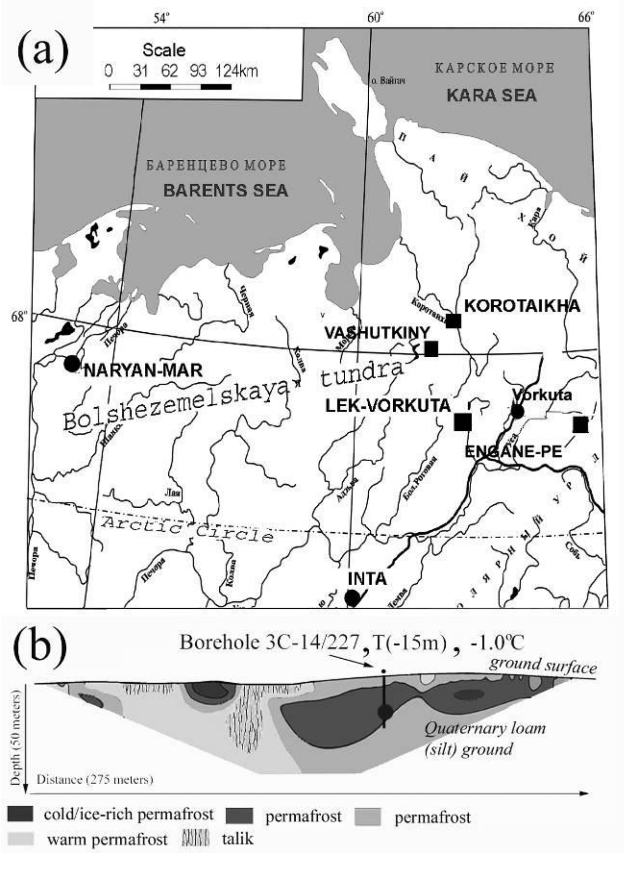

Fig. 1. (a) Map of Northern Komi Republic and Nenets Autonomous Region and location of the study sites Lek Vorkuta, Korotaikha, Vashutkiny and Engane-Pe. (b) Permafrost model section based on electrical conductivity (Lek Vorkuta station).

Features of the study areas

Geophysical measurements were made at four sites. The Lek Vorkuta site (fig. 1) is characterized by discontinuous and sporadic (extent of permafrost, accordingly, 50-90 and 10-50% of area), thin and “warm” permafrost, while the two other lowland sites, Korotaikha and Vashutkiny, show continuous, thicker and cooler permafrost. The permafrost temperatures at the depth of zero annual amplitude at the Lek-Vorkuta site were typically between -1°C and 0°C and between -1°C and -3°C at the Korotaikha and Vashutkiny sites. All the lowland tundra sites are characterized by a flat, gently undulating treeless landscape (shrub tundra) 40-170 m a.s.l.. Climatically the sites belong to circumpolar climate region the mean annual air temperature (MAAT) being ca. -6°C. The MAAT at the Vorkuta weather station over the period 1950–2009 was -5.9°C and the annual precipitation ca. 500mm. Thickness of the Quaternary sediments around the Korotaikha and Vashutkiny is more than 100 meters, but less around Lek-Vorkuta site. Sediments are characterized as clayey to sandy loams and are sometimes overlain by a thin peat layer or palsa mires. Bedrock at the lowland sites consists of sedimentary rocks. The fourth site, Engane-Pe at the Polar Urals, is characterized by thin glacial till cover over crystalline bedrock.

Geophysical studies

We started the project in 2007 with a series of geophysical measurements and geological studies at the Lek-Vorkuta station. The field work continued in 2009 at the Korotaikha station and 2010 at the Vashutkiny station (fig. 1). Year 2011 study site was Engane-Pe at the Ural Mountains. Resistivity sounding (also known as Electrical Resistivity Tomography, ERT) has been the basic technique for high-resolution characterization of the electrical conductivity of the sediments and structures as well as for studying the effect of relevant geological factors such as grain size, moisture, temperature, ice-content, etc., on the electrical conductivity. The ERT studies were made by a multi-electrode resistivity system using mostly 5 meters electrode spacing, which with 56 electrodes gives a depth penetration of ca. 50 meters. EM measurements have been made by a multi-frequency (8 frequencies from 0.44kHz to 51 kHz) horizontal-loop MaxMin Slingram system and by a transient EM-system (TEM). The MaxMin-soundings were made using 40m and 100m coil spacing and the TEM soundings with a transmitter (Tx) loop size of $20*20m^2$. Depth penetration of the EM techniques was also about 50 meters, but the MaxMin-soundings with 100m coil spacing had a deeper ca. 100 depth penetration. In situ temperature and conductivity data were collected from surface waters and loose sediments. Minor tests with a VLF-R system, TEM measurements with a larger $100*100\ m^2$ Tx-loop, soil laboratory studies (mineralogy, grain size, electrical resistivity and induced polarization), were also made.

Results and conclusions

Almost all geophysical profiles were measured over shallow (typically 20 – 30 meters) drilling sites owning geological and ground temperature reference data. The geophysical field results were inverted to 1D or 2D electrical conductivity models. At the lowland tundra area, where the loamy sediment cover was thick, we found mostly a good conformity between the electrical conductivity and the ground temperature. Because of the homogenous sediment material (mostly loam and sandy loam), the difference in electrical resistivity between the taliks and the frozen ground was typically clear and unambiguous. At the Engane-Pe mountain site, however, the results were not so unambiguous. There the crystalline bedrock is covered with thin glacial till layer and the conductivity models are strongly affected, not only by temperature, but also by the lithology.

The electrical conductivity data, including the near surface apparent resistivity and the model resistivity values, as well as the in-situ and laboratory results, were analyzed and classified as talik, warm permafrost, permafrost (two classes) and cold/ice-rich permafrost. The resistivity values for the unfrozen loamy sediments were typically close to 50 Ohmm, while the highest resistivity values for ice-rich permafrost were in the level of 5000 Ohmm. The classified electrical conductivity data were then transformed to permafrost models (fig. 1b).

The electrical conductivity data, covering the typical soils, sediments and sediment formations, both in a frozen and in an unfrozen state, together with the results achieved with the EM techniques, form a basis for modeling and for planning mapping and monitoring projects for larger areas in Komi and elsewhere at the same kind of lowland tundra areas.

The analysis of the electrical conductivity models together with borehole temperature, sediment and geotechnical data proved electrical and electromagnetic techniques useful tools both for mapping and monitoring of permafrost at the Komi-Nenets area.

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The Problems of Reconstruction of the Cryolithozone of Northern Eurasia During the Pleistocene Cold Maximum: Methods and Results

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Long-term and systematic studies are conducted in the Evolution Geography Laboratory of Institute of Geography of RAS for creation of reconstructions of the long-term cryolithozone of Northern Eurasia for different Pleistocene and Holocene chronic sections. Reconstructions for the epochs of maximum climate cooling in the Pleistocene Age are of special value. During this period the expansion of the long-term cryolithozone in Eurasia reached maximum values for the Quaternary Period (Valdai and Sartan epochs).

Methods of reconstruction of paleocryolithozone

The following data was used for this purpose: 1) paleocryogenic indicators; 2) paleoclimatic data; and 3) aerial and satellite photos. As is known, paleocryogenic indicators (pseudomorphs in wedge ice, ground veins, solifluction and involution traces, etc.) are the most important information for the deposits of certain chronic sections in the course of reconstruction of the paleocryolithozone. The paleoclimatic data (received with the help of other methods) allow to define many cryolithozone parameters (permafrost temperature, permafrost thickness, etc.). Aerial and satellite images are the main source for the study of the relict cryogenic morphosculpture (relict cryogenic microrelief).

Reconstruction results

The complex data analysis for the north of Eurasia allows to reflect the specifics of the cryolithozone in this huge region at the maximum of climate cooling at the end of the Pleistocene Age (approximately 20-15 thousand years ago). Huge expansion of the continuous long-term cryolithozone occurred to the west and to the south at that time, as compared to the present time. Its southern boundary went southward from 50º N, and the width reached about 3.5-4.0 thousand km together with the dried shelfs. A relatively narrow strip of discontinuous long-term cryolithozone was located to the south (in the east of Asia, approximately till 40º N).

The significant part of the very south of the modern temperate belt and the adjoining part of the subtropical belt were a part of a deep seasonal freezing zone.

Huge areas within Europe and Asia were occupied with landscapes having thick veins of ground ice and wedge-polygonal relief that is currently developed only in the north of Siberia. Ground glaciation of Eurasia during this period was the most important component of the natural environment of the Earth's largest continent.

Construction and Exploitation of Transportation Systems in Cold Regions

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Abstract

Research relevance
The novelty of the research topic is based upon the fact that transport and transport infrastructure creating the conditions for its functioning belong to one of the systemically important branches that ensures the territorial integrity of the country and its unity of the economic space.

Keywords: infrastructure; North region; resistance to cold; thermokarst.

Issues of Constructionand Operation of Transport Systems

Features of the infrastructure

Quite a few issues relating to transport infrastructure are especially sharply manifested in the regional context. In the developed central regions and cities about 25% of the total length of roads functions under the regime exceeding the optimal level of loading, while marginal residential regions (where a considerable part of the population lives) 28,000 populated areas lack year-round transport connection points with the main transport communications of the country. Emerging issues in development of the transport system in the regions stem from the lack of regulation and, in some cases, of proper institutional environment adequate for the new conditions, as well as from the lack of the necessary mechanisms ensuring abidance bylaws, norms and rules.

Methods and practical requirements for the transport infrastructure of northern regions

In recent years, not only the issues of transportation of goods between Russian senders and recipients, but also the issues of transit service became acute. Russia utilizes its transit potential extremely insufficiently. The Northern Sea Route is practically inactive. The Baikal-Amur Mainline is poorly loaded. The Trans-Siberian Railway does not operate to its full capacity, either. As before, the main traffic volumes between Asia and Europe are directed via a circuitous route through the Suez Canal. The northern regions having its own peculiarities bring forward special requirements for the development of transport infrastructure, which should be thoroughly studied. The structure of the transport system in Russia is complicated. It includes several sub-systems (rail, road, sea, river, air and pipelines), each of which consists of the following key elements: infrastructure, transportation and management. The transportation system includes transportation nodes and corridors, as well as industrial and public transport .

Northern specificity

The main problems of design, construction and operation of buildings in northern regions are associated with widespread permafrost. First of all, permafrost greatly complicates the design of pipelines. Due to a large depth of seasonal thawing layer (up to two meters or more), low bearing capacity of unfrozen grounds, instability of permafrost and intense cryogenic processes, virtually all pipelines have to be laid above the ground – on poles or overpasses.

A pipeline laid above the ground is exposed too much stronger fluctuations in temperature than during underground pipe lying. Specifically critical in this case are cold winter conditions, when heat loss from the surface of the pipes exceeds acceptable values, which subjects them to a real threat of congelation. For this reason, the pipes are insulated, heat tracers are attached to water pipes, transitional heating plants are built near water conduits and so on. All these measures, first of all, require considerable expenditure, and, secondly, do not ensure the complete fail-safety. Any stoppage in water supply in the winter period may result in an accident with grave consequences that is associated with defrosting of pipes and their consequent breakdown... Another outstanding feature of the operation of water and heating pipelines in northern regions is associated with the peculiarities of natural waters' hydro chemical composition (that are characteristic of the wetland landscape) and, in particular, with low pH values and high iron content. Steel pipes transporting such water are subject to intensive encrustation, which considerably shortens their period of service.

Construction in northern regions

Despite the harsh conditions of life, the northern regions do not lose their attractiveness as the largest natural deposits of oil, gold and diamonds. In the first half of the twentieth century, when the active industrial development of northern territories was just initiated, not only industrial buildings but also administrative and residential ones were built, which eventually led to emergence of rather large cities.

Today it is difficult to overestimate the economic importance of the North as a huge reserve of raw materials, this is why there are repeated debates regarding the issues of urban development and preservation of urban areas in northern regions. Construction of facilities and buildings in permafrost requires special technologies, thorough study of grounds and preservation procedures. Any violation of the construction technology or inappropriateness of the architectural plan to the harsh climatic conditions can lead to deformation and subsidence of the building. In addition, the situation is exacerbated due to predicted global warming. The ice is a solid foundation to build a house on, unless it begins to melt.

Construction in northern regions can only be successful when it is based on an integrated approach, starting from a thorough geological and soil studies and finishing with strict energy accountability. Proper design and compliance with all building codes during the construction of a building are not enough in conditions of the constant cold. Construction should be followed by careful technical inspection of buildings that is necessary to revealdefects, assess the suitability and operating capacity of all the facilities and to predict the performance values of a building. Thermal vision survey is an effective way to identify even the defective parts that are hidden and not visible at first sight. The method provides for a video survey conducted within a thermal range invisible to the human eye, which gives full information about the temperature distribution over the surface of an object and allows one to identify the leaks of air, the design and construction faults, breach of the sealant, etc.

Another issue that constructors face in northern regions is the problem of energy conservation. The efficiency of heat consumption depends on many factors, including planning solutions (correct glazing and thermal insulation) and the smooth operation of heating systems. Energy diagnostics of a facility helps to determine the actual values of resistance to heat transfer not only for the whole building, but also for its particular walls. The survey helps to identify deficiencies and to reduce power consumption by 30-40%, as well as to improve the quality of the entire heating system. Power certificate is issued as a confirmation of the successful inspection of a building. The document displays the characteristics helping in creation of the overall power balance.

Such promising measures as the introduction of new construction technologies and competent diagnostics of buildings will help to withstand severe northern nature and eventually solve the acute current problems of urban development in the northern regions of Russia.

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Morphometrical Analysis of Thermokarst-Lake Basins, Kolyma Lowland, NE Siberia

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Abstract

The aim of research is to identify regularities of thermokarst lakes evolution in the Holocene. The results of comparison of morphometrical characteristics of the thermokarst lakes have been presented. Several regularities of thermokarst lakes evolution in the Holocene of the Bolshaya Chukochya river lower stream are received.

Keywords: Kolyma Lowland; morphometrical analysis; remote sensing; thermokarst-lake basins.

Introduction

Thermokarst lakes are studied actively. They can be considered as an indicator of possible climate change [*Smith at al. 2005, Kravtsova & Bystrova 2009, Grigoryev at al. 2009 and others*]. Investigation of thermokarst lakes and forecasting their development is also necessary to assess the greenhouse gas emissions as a result of possible climate warming. Morphometric analysis of thermokarst-lake basins based on remote sensing data and GIS-studies helps to understand the regularities of the thermokarst processes evolution during the Holocene and enables prediction of the future development of thermokarst [*Hinkel at al. 2005, Morgenstern at al. 2011 and others*]. The aim of research is to identify regularities of thermokarst lakes evolution in the Holocene using the morphometrical analyses.

Study area and methods of research

Study area

Study area is located within the tundra zone of the Kolyma lowland on the right bank of the Bolchaya Chukochya river lower stream. The territory is characterized by thermokarst-lake basins (alases), the remnants of the Late Pleistocene surface (Yedoma) formed by Ice Complex and the river valleys. Area of the study region is 815 sq km, with the Yedoma occupying about half of the total area. The surface has the absolute heights of 30-50 m, gradually dropping from south to north.

Methods of research

To allocate the terraces of thermokarst lakes the CORONA images with a resolution of 5 m were used. The morphometric analysis was made for alases formed by one lake, so-called single alases [*Morgernstern at al. 2011*]. This type of thermokarst-lake basins occupies 205 sq km; it's about 50% of the total alases area. For each single alas the following main indicators were accounted: the area of alas, the area of the lake within the alas, the direction of the lake development and the number of terraces.

The four levels of thermokarst lakes terraces by the absolute heights were allocated: the first - from 11 to 20 m, the second - from 21 to 30 m, the third - from 31 to 40 meters, the fourth - more than 41 meters. To determine the absolute heights the DEM based on 1:200000 scale topographic map were used.

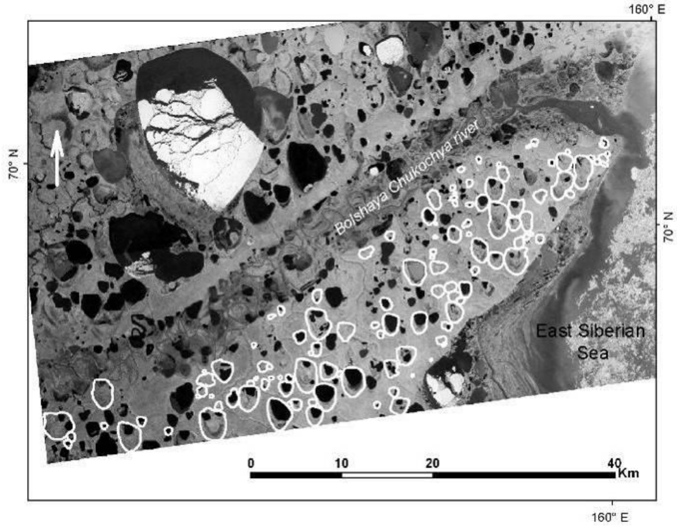

Fig. 1. Map of study area. White line shows the single alases.

Results

Within the study area 119 single alases were allocated. The main morphometrical characteristics are shown in the table 1.

The main conclusions are:

The higher the value of the absolute height of the surface is, the greater than is the area of each single alas, and the smaller is the area of the lake inside.

The larger the difference between the absolute heights of the upper level terrace and the lake local erosion basis is, the greater than is the total number of terraces. The deepest alases with the most complex terracing are to be found on upper level.

The most common direction of the lake development (shown by terracing pattern) is strictly from south to north which is in contrary (has no correlation) with wind directions or the surface slopes and can be explained by the sun exposition.

The total number of lake terraces within the alases of same height level is not a constant figure, which evidently shows that no global factor effects the lake terracing but rather the local changes of erosion basis.

Table 1. Comparison of some morphometrical characteristics of alases.

Level of the upper thermokarst lake terrace	Total alas number	Average number of lakes terraces	Main orientation of lake development	Percentage of lakes area, %	Alases area, sq km
41-50 m	12	7	N	11	2,1
31-40 m	68	5,6	N	19	1,9
21-30 m	25	5	N	29	1,5
11-20	13	4,5	N	21	0,6

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Assessing the Permafrost Presence and Rock Glacier Activity in Mountain Environments. An Example from Southern Carpathians, Romania

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Rock glaciers (RGs) are one of the most widespread periglacial landforms in the Southern Carpathians [*Urdea 1998*]. A model for the prediction of permafrost occurrence in rock glaciers and their activity statuses was established in this area across the highest six massifs: Făgăraş, Retezat, Parâng, Iezer, Ţarcu and Godeanu where 97 RG above timberline (between 1700 m and 2300 m a.s.l.) were considered. Reported to all RG, 20 of them were investigated in the field with different thermal methods (BTS - bottom temperature of snow, GST - continuous ground surface temperature monitoring and SWT - spring water temperature during late summer) and geophysical methods (DC resistivity, GPR), in the attempt to identify permafrost presence. Also, the percentage of vegetation cover on RG surface as a permafrost indicator [*Ikeda & Matsuoka 2002*] was determined for all of the 97 rock glaciers using ortophotomaps.

The model was based on a simple formula which took into consideration values of some of the main factors involved in permafrost presence, such as: mean altitude, the amount of solar radiation during snow-free interval, mean annual air temperature (MAAT), GST and the length of the snow-free interval, all computed in Geographic Information Systems. The mean altitudes and solar radiation values were obtained using the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM), with 30 m cell size. MAAT was obtained by extrapolating the data from the meteorological stations, taking into consideration a lapse rate of 0.65°C/100 m characteristic for Romanian Carpathians [*Cheval et al., 2011*]. GST was calculated using daily Moderate Resolution Imaging Spectroradiometer (MODIS) images covering the 1st May – 1st January time interval which includes the snow-free interval. The modeled values of air and ground temperatures, solar radiation and porosity of debris were crosschecked and validated by *in situ* measurements on several RGs. The formula used for the algorithm development was:

$$\boldsymbol{PI} = [(A_r - A_{ref}) + (T_{ref} - T_r) + 0.8(S_r - S_{ref}) + \\ +0.6(SFI_{ref} - SFI_r)] \times P_f, \text{ where:}$$

PI= permafrost index; A_r= mean altitude calculated for each RG; A_{ref} = reference RG altitude (the critical value for permafrost existence); S_r= mean solar radiation received by each RG; Sref = reference value of solar radiation; T_r = mean ground temperature of each RG; Tref = reference ground temperature; SFI_r = snow-free interval; SFI_{ref} = reference snow-free interval, P_f = weighting factor derived from texture (0.85 for pebbly RGs or 1.15 for bouldery RGs). All the values were normalized by standard deviation.

The reference values were established based on the field measurements performed on the 20 RG and represent the critical values required for the permafrost existence.

Depending on the debris texture, the RGs were roughly grouped in two classes (pebbly and bouldery) which have been used as weighting factors for the PI. Finally, based on the resulting scoring, RGs were classified in the three types: active, inactive and relict. Probably active RGs (5) were found as developing just in two massifs (Retezat and Parâng), with a preference for the granitic bedrock. Probably inactive RGs (54) which prevails are developing in five massifs (excluding Godeanu massif where permafrost seems to be absent) with a maximum frequency in Retezat (29) and Parâng (12).The widespread occurence of relict RGs (38) together with the disproportioned ratio between active and inactive RGs, indicates that permafrost is in disequilibrium with the current climate conditions and probably in recession in the Southern Carpathians, as could be assessed for the most ice-cored RGs. An important stress is exerted by the summer temperatures which raised with 1.2 - 1.6 °C in the last 50 years for the alpine and subalpine levels of the Romanian Carpathians [*Croitoru et al., 2011; Vespremeanu-Stroe et al., 2012*].

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Inter-Annual Water Storage Variations In The Lena Watershed, Siberia, Derived From GRACE And Complementary Satellite Data

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Motivation

The Gravity Recovery and Climate Experiment (GRACE) satellite mission has proven as valuable tool to observe hydrological mass variations, e.g., in the Amazon basin or Okavango Delta, groundwater depletion in Northwest India, inland glacier mass losses and El Nino Southern Oscillation (ENSO) related water storage variations. The long time span of one decade of GRACE observations now also allows the detection of smaller inter-annual mass variations. In our study, we address the permafrost-regime in Siberia, Russia. Hydrological processes in permafrost regions are very sensitive to climate change. Siberia is affected in particular, as it experiences a stronger warming trend than the global average. We analyze different satellite data to quantify water mass changes in central Siberia.

Total Mass Variations from GRACe

GRACE monthly solutions from the Deutsches GeoForschungsZentrum (GFZ) and the University of Texas Austin, Center are used for the time period from January 2003 to June 2011. Spatial smoothing is carried out by a Gaussian filter with a radius of 340 km. A pixel-wise trend estimation is conducted by the fit of constant and linear terms, annual, 2.5-yearly, 3.7-yearly and 161-daily periodicities. Mass variation for central Siberia are exemplarily presented for the region of Yakutsk in Figure 1. The mass variation shows a strong seasonal and a non-linear inter-annual signal. During the time period from January 2003 to January 2007 a significant increase in the height of the equivalent water column (EWC) can be observed. However, since 2007 the mass trend seems to be reversed. Hence, no significant trend can be noticed for the whole observation period. The mass variations observed by GRACE can mainly be attributed to changes in hydrology. The effect of glacial isostatic adjustment can be ruled out for the region of central Siberia and the remaining signal from the reduction of the atmospheric mass is very small [*Vey et al., 2011*].

Mass Variations from Lake level Change (Altimetry)

Water mass variations in the permafrost can be caused by (1) changes in the surface water storage related to variations in the lake level, lake size and lake number or (2) to changes in the subsurface water storage related to variations in the soil moisture and the deep groundwater. In this study we concentrate on the lake level variations. Central Siberia is covered by thousands of small lakes. As consequence of a strong wetting trend in this region lake levels are rising. In order to quantify the mass variations related to changes in the lake water storage we analyze altimetry data from the Jason-2 and Envisat satellite over the time period from 2003 to 2010 [*Crétaux et al., 2011*]. Lake levels are estimated for lakes with an surface ranging from 15 to 150 km². The selected lakes should cover the region uniformly. The lake level variations are found to depend on the region. The combination of lakes with similar inter-annual lake level variations results in the definition of three regions. We estimate the lake level variations separately for each region by calculating the weighted mean of the observed lake levels in one region depending on lake size and assuming that all lakes in the region follow the behavior of the directly observed lakes. For the lake surface extent we use data derived from multi-spectral satellite observations (passive and active microwaves, visible and near-infrared imagery) provided by Papa et al., [*2010*]. This data set covers the period from 2003-2004 with an spatial resolution of 0.25° x 0.25° and a monthly temporal resolution.

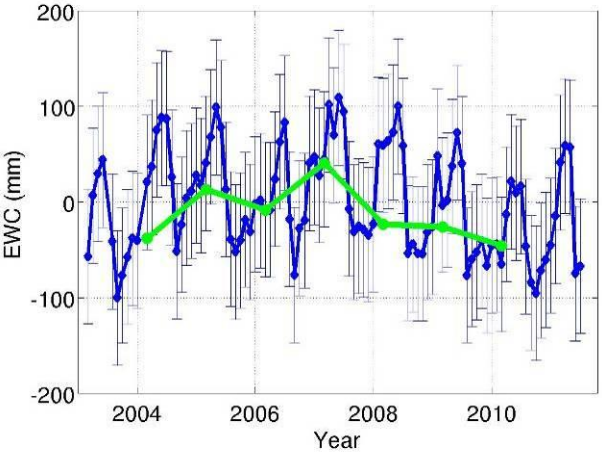

Figure 1: Variations in equivalent water column (EWC) from GRACE (monthly solution and annual mean). The increase in water mass for the period 2003-2007 reverses into a decrease from 2007 onward.

Conclusions

We compared the total mass variation derived from GRACE and the mass variations related to changes in the lake level. The lake level changes can explain between 15% to 40% of the water storage changes observed by GRACE. Other potential reasons for water storage variations could be related to changes in lake surface extension, soil moisture changes, increase in sub-permafrost ground-water storage and talik formation. The planned SWOT-altimetry mission would be an ideal tool to monitor the water storage changes in the little Siberian lakes.

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Detailed Geomorphological Survey of the UNIS Ice-wedge Monitoring Site Area (Adventdalen, Svalbard)

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Introduction

This study focuses on the tundra polygon area at the southern part of the Adventdalen valley floor that is being monitored for different types of geomorphic processes since several years by the teams of Hanne Christiansen and Norikazu Matsuoka. The study site is located at 78º10’42.8’’ N, 16º16’24.9’’ E. Ice wedge contraction cracking, frost heave, mud-boil dynamics, permafrost thermal state and active layer depth as well as their environmental controls are being studied by these authors.

In the framework of the project ANAPOLIS - Analysis of polygonal terrains on Earth as Mars Analogues, we aim at characterizing and classifying the spatial patterns of the tundra polygons in Adventdalen and at understanding the environmental causes for the different patterns. Our approach includes using high resolution aerial imagery, as well as a detailed ground-based geomorphic survey. The UNIS tundra polygon monitoring site was chosen as a key site for our survey and to evaluate the potential of the multisource geomorphic mapping. This presentation shows the results of the mapping and discusses the implications of the findings for the tundra polygon patterns of Adventdalen.

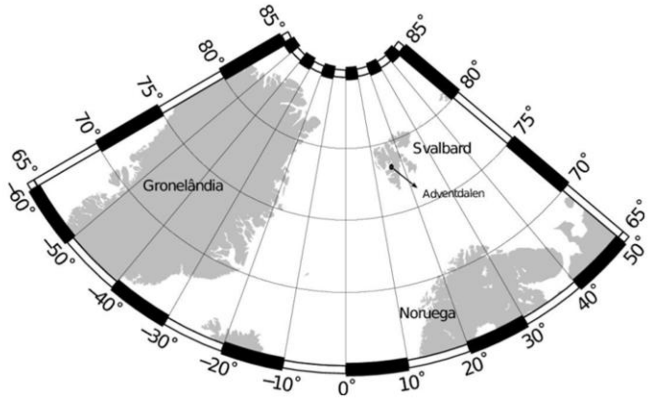

Figure 1. Location of Adentdalen, Svalbard.

Methodology

The detailed geomorphological map of the UNIS Adventdalen tundra polygon monitoring site was prepared using the following techniques:

- High resolution aerial photography from the Norwegian Polar Institute flight of 2009, with a ground resolution of about 20 cm. The scenes were obtained in 4 spectral bands: visible (RGB) and near infra-red. The orthorectification was performed using selected ground control points inside the study area with coordinates obtained from a DGPS survey.
- Very high resolution aerial photography (visible – RGB) obtained with an Unmaned Aerial Vehicle by Kolibri in 2009, with a spatial resolution of ca. 6 cm. Orthorectification was conducted similarly to above.
- Field geomorphic surveying using DGPS with identification and georeferencing of geomorphic units at the submetric scale.
- Topographical surveing using DGPS in order to identify morphological variations at a decimeter vertical scale.

The final map was produced in a GIS environment by analysing the ground truthing obtained in the field with the DGPS together with aerial photo interpretation made at the two scales.

First results and discussion

The elaboration of the detailed scale geomorphic map by joining systematical field surveying with high and very high resolution imagery, including near infra-red wave-length, allowed for a precise identification of many submeter features that were before difficult to identify. This is especially true since the Adventdalen terrace is mostly flat and shows no proeminent topographical features. But more interesting than the features that have been identified are their spatial patterns and relationship between them.

The terrace is part of a gently sloping alluvial fan marked by small fluvial channel incisions. Some channels show pebbly lag surfaces which interbed with a silty clayey material probably of a mix surface wash and eolian origin (loess). The fine material dominates in the surface and becomes thicker towards the river margin in the more distal part of the fan, where frost wedges dominate the surface. In the coarser and proximal part of the fan, closer to the road the surface is dominated mainly by mud-boils.

Our detailed approach allowed for the detection of a number of subfeature types inside the main geomorphic units, with the following preliminary classification: alluvium, bars, gullies, debris flow levees, coarse mudboils, fine mudboils, cracked mudboils, peat plateau, inter-peat plateau depression, peat hummocks, peat surface, peat holes, polygons, vegetation cracks, vegetation stripes, wet depressions. The significance of this features is being analysed and soil samples have been collected from each of them.

Acknowledgements

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Dissociation of Gas Hydrates Into Supercooled Water and Gas, From Nuclear Magnetic Resonance Data

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Abstract

A pulsed nuclear magnetic resonance (NMR) study has revealed dissociation of CFC-12 (Freon-12) hydrate into gas and supercooled water.

Keywords: dissociation; gas hydrate; nuclear magnetic resonance (NMR); supercooled water.

Introduction

Gas hydrates have been believed, for a long time, to dissociate only into gas and ice at temperatures $T < 273$ K [*Sloan & Koh 2008*]. However, Melnikov et al. [*2009, 2010, 2011*] observed dissociation of gas hydrates into gas and supercooled water in experiments. This effect is of large scientific and practical importance and requires comprehensive investigation. First of all, visual observations have to be supported by instrumental data, for instance, pulse nuclear magnetic resonance (NMR) measurements.

Experiment

The pulse nuclear magnetic resonance NMR method allows estimating the content of liquid water in a sample, which may also contain gas hydrate and ice [*Chizhik 2009*], and thus reveal gas hydrate dissociation into gas and supercooled water.

The instrumental work was performed on a specially designed system consisting basically of a Bruker *Minispec - mq* pulsed NMR relaxometer operating at the resonance frequency 19.65 MHz for hydrogen nuclei, equipped with a unit for changing and maintaining temperatures (the thermostabilization accuracy ±0.1 K). An additional compression unit in the relaxometer created and maintained the required gas pressure, to ±0.1 kPa over the sample. The low-field ^{1}H NMR experiments were run with CFC-12 (chlorofluorocarbon CCl_2F_2, or Freon-12) chosen for its ability to form hydrates at low pressures and for being void of hydrogen nuclei, which simplifies the analytical procedure.

We analyzed samples consisting of more than 90 wt. % CFC-12 hydrate that contacted with liquid water. To promote hydrate formation, ice was used in 100 to 200 μm grains and the samples were subjected to cyclic temperature changes [*Vlasov et al. 2011*].

In the beginning of the experiment, the prepared samples stayed at invariable pressure and temperature within the stability of CFC-12 hydrate (point A in Fig. 1). At these conditions, the content of liquid water was measured for more than six minutes.

Then the pressure was lowered stepwise (within 2.0 Pa at a step) and the ^{1}H NMR measurements continued until an increase in the amount of liquid water was steadily recorded, which meant that the sample surpassed the ‘liquid water-hydrate-gas’ equilibrium line (point B in Fig. 1).

Note that the dynamics of liquid water content was studied in that specific ^{1}H NMR relaxometry experiment following the 90° pulse method or with the Carr–Purcell–Meiboom–Gill (CPMG) pulse sequence [*Vashman & Pronin 1979*].

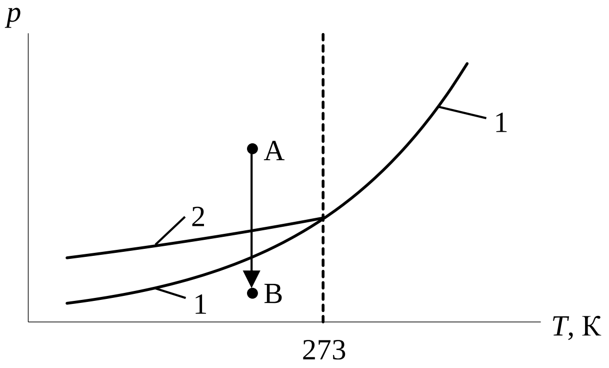

Fig. 1. Conditions of experiment. 1 – ‘liquid water-hydrate-gas’ phase equilibrium line; 2 – ‘ice-hydrate-gas’ phase equilibrium line’.

Results

The experimental points where CFC-12 hydrate dissociates into supercooled water and gas are shown in Fig. 2, along with free-running ‘ice-hydrate-gas’ and ‘liquid water-hydrate-gas’ phase equilibrium lines. The phase diagram was plotted in the following way:a sample with CFC-12 hydrate was subject to pressure change at a constant temperature to reach the hydrate thermodynamic instability, i.e., below the ‘liquid water-hydrate-gas’ equilibrium at $T > 273$ K or the ‘ice-hydrate-gas’ equilibrium at $T < 273$ K. Then the pressure was increased in the course of dissociation, and the system passed to the state which never changed after. The respective invariable p and T parameters were assumed to be the phase equilibrium point, and a set of those points made the phase diagram.

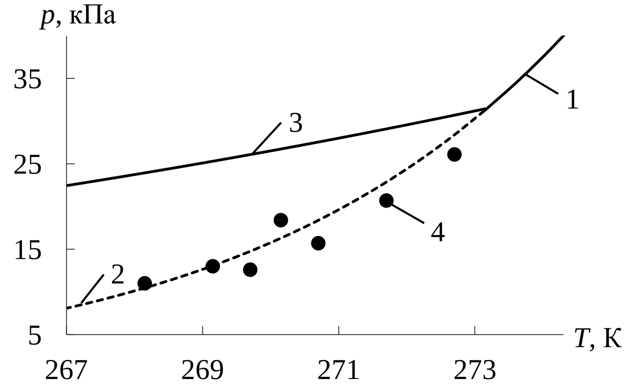

Fig. 2. p, T diagram of the system 'water–gaseous CFC-12'. 1 – free-running 'liquid water-hydrate-gas' phase equilibrium line; 2 – extrapolation of 'liquid water-hydrate-gas' line into $T < 273$ K domain; 3 – free-running 'ice-hydrate-gas' phase equilibrium line; 4 – dissociation into gas and supercooled water measured by ^{1}H NMR.

It is clear from Fig. 2 that the experimental ^{1}H NMR dissociation points almost lie on the 'liquid water-hydrate-gas' line extrapolated into $T < 273$ K.

It is very important that CFC-12 did not dissociate into ice and gas between A and B (Fig. 1), otherwise no subsequent dissociation into supercooled water and gas would have been possible. This fact has implications for the mechanism of gas hydrate dissociation in the domain of minor supercooling of water. Namely, gas hydrate can dissociate into ice and gas in this domain uniquely when it immediately contacts ice and into supercooled water and gas when it does not.

Conclusions

The reported NMR analysis has provided solid evidence for gas hydrate dissociation at $T < 273$ not only into gas and ice but also into gas and supercooled water. Further experimental and theoretical work is needed to elucidate a number of related issues. Specifically, the conditions required for dissociation either into gas and supercooled water or into gas and ice have to be constrained. Another objective is to constrain the p-T region where gas hydrates are expected to dissociate into gas and supercooled water, etc. The NMR method successfully applied in this study may be a useful tool in the future relevant research.

Acknowledgements

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Challenges in Evaluating Mining Impacts in the Periglacial Environment of the South American Andes

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Introduction

The South American Andes have abundant mineral resources, which attracts mining. Many deposits are located in remote locations and at high elevations characteristics of dry, periglacial environments. Periglacial landforms such as rock glaciers, protalus ramparts, gelifluction slopes, pattern ground and ice wedges dominate over glaciers and, glaciaretes [*Corte 1988*].

As in many high mountain environment, the distribution of permafrost and its landforms is heterogeneous and sporadic, being dependent on elevation, slope angle, slope aspect, vegetation (or the lack thereof) and micro topography that affects the distribution of snow accumulation and creates cold air sinks. It is not uncommon to find features such as active rock glaciers at elevations lower than the lower probable permafrost altitude limit. These are examples of periglacial landforms that are i) a legacy from past colder climates and ii) prove of mass movements through ice deformation in this environment. Rock glaciers, which often form close to the lower elevation limit of permafrost, have the capacity of creeping considerable distances over millennia which sometimes results in their presence in terrain lacking permafrost.

As a result of the heterogeneity of surficial conditions, which affect thermal ground characteristics, especially aspect and snow accumulation, the distribution of ground ice is highly variable and is greater in valley bottoms where the slopes are flatter and colluvial or fluvial sediments allow the aggregation of ground ice.

The South American Andes currently are facing a unique combination of geophysical conditions that challenge the evaluation of environmental impacts resulting from mining activities. First, permafrost related terminology finds local variations that sometimes contradict definitions coined in the northern hemisphere and that may confuse the decision making. Second, the heterogeneity of mountain periglacial conditions, in contrast to the Arctic, makes the evaluation of impacts a probabilistic issue where a regular approach usually overestimates the interaction between permafrost and the projects affected area. Third, the international debate on the hydrological importance of the periglacial environment and ground ice commonly found in landforms such as active rock glaciers, affects the evaluation of environmental impacts. This is especially the case in the light of the new regulations that some South American countries have passed, with the objective of protecting water resources within the periglacial environment (e.g., Argentine National Glacier Act Law 26.639).

Environmental regulations

Government regulator sinvarious countries in South America have passed regulations or guidelines which are oriented towards the protection of the periglacial and glacial environments. However, these new regulations do not define why the periglacial environment needs to be preserved and which characteristics require protection. The temporal dynamics of the periglacial environment considering the duration of certain projects, the spatial heterogeneity of mountain permafrost and its ice content challenge regulatory agencies to define the purpose of the regulations. Hence, questions with respect to the validity of such laws and guidelines have emerged. For example, if there is a project which occurs largely in dry permafrost, which is part of the periglacial environment, is there the need to preserve the thermal state only for the sake of temperature? Or is it the protection of the ground ice the focus of these regulations? If so, does any and every amount of ground ice require protection or would it be better to further the understanding of the mountain permafrost hydrology and protect the features that contribute to and affect the hydrology of mountain basins on a measurable and significant level? Hence, is there a critical and site specific ground ice content that warrants protection? These are just a few questions that come to mind when reading the new regulations pertaining the Andean periglacial environment. In essence, and as with every case of unknown environments, the key conditions that must be met is the understanding of its physical characteristics and related processes in order to have regulations which are properly targeted to effectively achieved their protecting role.

Terminology and geomorphic classification

The evaluation of the impacts related to any kind of project requires the establishment of a conceptual and terminological framework that defines the landforms and processes that warrant consideration in the respective evaluation. This conceptual framework ought to be understood and agreed upon by the different entities that partake in the evaluation and approval process (proponent of the project, stakeholders and the respective authorities and governing agencies). If these various groups involved do not share a common definition scheme, the overall objective of the impact evaluation is undermined since the focus of attention tends to move to the redefinition and understanding of landforms and geo-processes rather than an objective assessment of the project's activities and related impacts. Further, it is difficult for the general public to understand potential impacts from certain projects if even the parties directly involved do not share a unified definition for certain terms. Such uncertainties may be used to manipulate interest groups. Although the International Permafrost

Association and UNESCO have agreed in an official permafrost and glacier related terminology, projects located in South America experience difficulties due to local variations of the internationally accepted definitions. Currently the main issues arise from differences in the definition and understanding of (a) the periglacial environment and the distinction between glacial and periglacial, (b) the definition of permafrost and (c) the definition of rock glaciers and the distinction between uncovered (white) glaciers and rock glaciers.

The *periglacial environment* is conventionally defined as those environments in which frost action and/or permafrost related processes dominate (French, 2000; French & Thorn, 2006).However, in South America, the existence of permafrost is a condition sine qua non to define an environment as periglacial, whereas this is not the case in the northern hemisphere. On the other hand, the *glacial environment* is defined as areas covered by glaciers or other perennial surface snow and ice masses today, i.e., environments that are *glacierized* (not *glaciated*) [*Cogley 2011*]. Furthermore, the definition of *glaciers* also varies. In Chile, government guidelines define glaciers under Lliboutry [*1956*].They consider a glacier to be «every perennial ice mass, formed by snow accumulation, independently from its shape, size and dynamics”. This definition does not recognize the existence of forms such as glacierets and snow / ice patches.

Data limitation

The pronounced heterogeneity of periglacial conditions of mountain environments, usually results in (a) a poor understanding of local conditions and how they affect the project and (b) a potential overestimation of the interaction between periglacial landforms and the areas affected by a particular project. Projects that are under budget and time constrictions usually don’t recognize the necessity to invest resources to conduct detailed studies on the periglacial environment. Hence, conclusions are usually drawn from a limited amount of potentially non-conclusive observations. The combination of limited observations and inappropriate extrapolations can result in an overestimation of impacts by the stakeholders and regulatory agencies on the one hand, and potential impact underestimation by the project proponents.

Periglacial hydrology

An additional source of discrepancies and confusion is the understanding of the hydrology of the mountain periglacial environment. Within the periglacial hydrology, it is crucial to appropriatelyasses the hydrological role of permafrost and the active layer. Because of their high ice contents rock glaciers are particularly scrutinized irrespective of their glaciogenic or cryogenic origin. Various studies have addressed the hydrological role of permafrost underlain terrain and rock glaciers in mountain areas [*e.g.,Corte, 1976; Krainer&Mostler, 2002*]. The heterogeneity of the conditions, in combination with the several different types of observations needed to quantitatively asses its hydrology and the subsequent costs, have resulted in studies which address the issue qualitatively [*Arenson & Jakob 2010*]. One of the most important challenges with respect to determining the water contribution of the periglacial environment is its field measurement program. It is not uncommon to observe an overestimation of the water contribution from rock glaciers, which is directly assumed to come from the melting of ground ice within this landform. This mainly results from the difficulty of separating the hydrographs in their different components of flow, where snow melt and shallow ground water originating from areas upslope, are erroneously combined with the specific amount of water derived from ground ice melting [*e.g.,Marangunic, 1976*].

Conclusions

The evaluation of construction related impacts in the arid South American Andes is challenging. The main issues concern:

(a) definitions, terminology and theoretical framework,

(b) heterogeneity of mountain periglacial environment and permafrost conditions; and

(c) the hydrological role of permafrost and related landforms such as rock glaciers.

These issues need to be resolved to ascertain scientifically-based environmental impact assessment in such environments, which help project proponents and stakeholders alike. This requires additional scientific studies that address potential impacts from construction activities in such environments and a joint international effort and initiatives for consensus-building on the topics of terminology, heterogeneity of mountain conditions and the hydrological role of permafrost landforms and the periglacial zone.

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Multiscale Bayesian Fusion Approach using Geophysical and Remote Sensing Data for Characterizing Arctic Tundra Hydrogeochemical Properties

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Recent findings suggest that warming climate has a significant impact on the Arctic ecosystems, which could in turn cause feedback to the climate system. A new Department of Energy project, called the Next-Generation Ecosystem Experiments (NGEE Arctic; http://ngee.ornl.gov/), has been initiated to address how permafrost thaw and degradation– and the associated changes in landscape evolution, hydrology, soil biogeochemistry and plant community dynamics– affect this feedback. Developing a predictive understanding of this feedback system requires characterization of various subsurface properties, such as active layer thickness (ALT), soil moisture, temperature and geochemical parameters. Such characterization is challenging due to the need to sample over large spatial areas in high resolution, and the spatial heterogeneity influenced by microtopography, soil texture and vegetation [*Zona et al., 2011*]. This work presents a multiscale data fusion method to estimate subsurface hydrogeochemical properties and state distributions, using datasets that sample different properties over various measurement support scales, such as point measurements, surface geophysical data and remote sensing data. The proposed method, based on a hierarchical Bayesian model, allows us to integrate multiscale, multi-type datasets consistently to quantify uncertainty associated with the estimates. We demonstrate our approach using co-located datasets collected at the Barrow Environmental Observatory, Barrow, Alaska.

Methodology

Data Collection Strategy

To improve predictive capabilities and process understanding, NGEE Arctic includes intensive subsurface-surface characterization efforts that involve various types of point, geophysical and remote-sensing data. At the Barrow site our datasets include (a) airborne high-resolution LiDAR data; (b) surface-based ground penetrating radar (GPR), electrical resistivity tomography, spectral induced polarization, and electromagnetic data; and (c) point-based soil temperature, moisture, geochemistry, texture and ALT measurements along and in the vicinity of several ~500m transects across the polygonal ground. Each dataset offers both advantages and limitations; together, the datasets offer the possibility of providing high-resolution information over large spatial extents. The point-based measurements are invasive and typically sparse, yet they provide direct information about the subsurface properties and states. They are also used to establish the correlations among subsurface properties, geophysical attributes and surface features for calibrating geophysical and remote sensing data. The high-resolution surface geophysical datasets are non-invasive and spatially extensive; integration of these datasets increases the spatial coverage and potentially reveals the fine-scale property variability and spatial correlation structure. The remote-sensing data can further increase the spatial coverage and improve the estimation over a large area through the subsurface-surface correlations. Integration of these disparate datasets requires an understanding of relationships among different hydrogeochemical-geophysical-physical variables and a framework that can honor all datasets and their interdependencies.

Bayesian hierarchical model

The Bayesian hierarchical model consists of three main statistical models; (1) data model: $p(\text{data}|\text{process}, \boldsymbol{\beta})$, (2) process model: $p(\text{process}|\boldsymbol{\alpha})$ and (3) prior model: $p(\boldsymbol{\alpha},\boldsymbol{\beta})$, where $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ are the model parameters [*Wikle et al., 2001*]. The process model describes the spatial-temporal patterns of the subsurface properties, conditioned on $\boldsymbol{\alpha}$. Although it is usually not feasible to develop a complete physical model to create such patterns (e.g., depositional processes, polygonal-ground evolution), we can often approximate the patterns using simple functions such as polynomial and cosine functions. The data model connects the patterns created by the process model and the actual data for given $\boldsymbol{\beta}$ and measurement errors. The data can be a direct measurement or a function of the subsurface properties; for example, spatial averaging for low-resolution datasets. The overall model – a series of conditional models – is flexible and expandable to include complex physical processes or observations. For example, the process model can include multiscale physical processes by having additional hierarchical structures [*Ferreira et al., 2007*]. Once all the conditional models are developed, we can estimate the joint posterior distribution of the parameters and process $p(\text{process}, \boldsymbol{\alpha},\boldsymbol{\beta}|\text{data})$, using Bayesian estimation algorithms such as the Markov-chain Monte-Carlo (MCMC) method.

Demonstration

ALT Estimation

Here we show one example of our data integration; ALT estimation based on the point probe, surface GPR and LiDAR elevation data. For the GPR data, the arrival time of the signal reflected at the bottom of active layer was converted to ALT using the velocity estimated by the common-midpoint surveys.

First, we developed a process model for ALT (m):

$$\mathrm{ALT} = f(dh, w) + \varepsilon_a, \qquad (1)$$

where f is a function, dh is the microtopography (i.e., deviation of elevation from the trend), w is the indicator for the presence of surface water, and ε_a is the residual random component representing additional spatial variability. Although the LiDAR data provides the elevation, we included it as an explanatory variable, since the topography is a dominant control over the subsurface properties [*Zona et al., 2011*], and also the elevation is quite accurate and spatially exhaustive in the domain of interest. The same argument can be applied for the surface water. We define the data model for each point data z_p as:

$$z_p = \mathrm{ALT} + \varepsilon_p, \qquad (2)$$

where ε_p is the measurement error. The data model for each GPR data point z_g is:

$$z_g = g(\mathrm{ALT}) + \varepsilon_g, \qquad (3)$$

where ε_g is the measurement error, and g is a function connecting the actual ALT to the one from the surface GPR. Based on the exploratory data analysis, we assumed a 2nd-order polynomial for $f(dh,w)$: $f(dh,w)=[dh^2\ dh\ 1\ w]\bullet[\alpha_2\ \alpha_1\ \alpha_0\ \alpha_w]^T$, and a linear model for $g(\mathrm{ALT})$: $g(\mathrm{ALT})=0.94\mathrm{ALT}+0.04$. We also assumed that ε_a is a multivariate Gaussian distribution with exponentially decaying spatial correlation (correlation length 11.0m, standard deviation (STD) 0.19m and nugget fraction 0.56). Table 1 shows the other fixed parameters. Using MCMC-Gibbs sampling, we computed the posterior distribution of $\boldsymbol{\alpha}=\{\alpha_2\ \alpha_1\ \alpha_0\ \alpha_w\}$ and ALT at the prediction locations; $p(\{\mathrm{ALT}\},\boldsymbol{\alpha}$□$\{z_p\},\{z_g\})$ (the curly bracket denotes ALT and data at multiple locations). Although the current model is fairly simple, we can extend it by adding more explanatory variables (e.g., surface vegetation), considering spatially variable $\boldsymbol{\alpha}$ and jointly estimating the currently fixed parameters.

Table 1. Assumed distributions and parameters.

	Value	Unit
Distribution of $\{\varepsilon_p, \varepsilon_q\}$	Independent normal	
STD of $\{\varepsilon_p, \varepsilon_q\}$	{0.01, 0.07}	{m, m}
Prior distribution of $\boldsymbol{\alpha}$	Independent normal	
Prior mean of $\boldsymbol{\alpha}$	{0.88,-0.25,0.26,0.10}	$\{\mathrm{m}^{-1}$, , m, m}
Prior STD of $\boldsymbol{\alpha}$	{0.10,0.10,0.10,0.10}	$\{\mathrm{m}^{-1}$, , m, m}

Figure 1(a) shows the ALT data from the point probe and the surface GPR. Along this 100m transect, we had point data every 3m and GPR data every 0.2 to 0.4m. The surface GPR not only provides fairly accurate ALT but also captures the fine-scale heterogeneity missed by the point data. The multiple peaks of the ALT profile correspond to trough locations on the surface in the moderately high-centered polygons. In Figure 1(b), the estimated ALT and uncertainty bounds from our estimation method are compared with the point data. Although the estimate is a simple function of microtopography and surface ponding, it shows good agreement to the point data. Figure 1(c) shows the estimated ALT in the 2-D domain including the point and GPR data, based on the estimated $\boldsymbol{\alpha}$ and LiDAR elevation data. It suggests that, by collecting sparse point and geophysical ALT data, this method can estimate ALT over a large area based on topography. We can see the polygonal-ground feature by large ALT at the troughs.

Summary and Future Work

In this paper, we described a multiscale hierarchical Bayesian method for integrating multiscale, multi-type datasets. As the first example, we illustrated how the method can be used with the GPR and LiDAR data to estimate ALT over a large area. Although the current example model is still simple, the results suggested that effective combination of point, geophysical and remote-sensing data can provide high-resolution information about important subsurface properties needed to parameterize both 2D/3D landscape and reactive transport models. As future work, we will improve the ALT estimation and extend the methodology to estimate other subsurface properties including ground ice using various combinations of datasets.

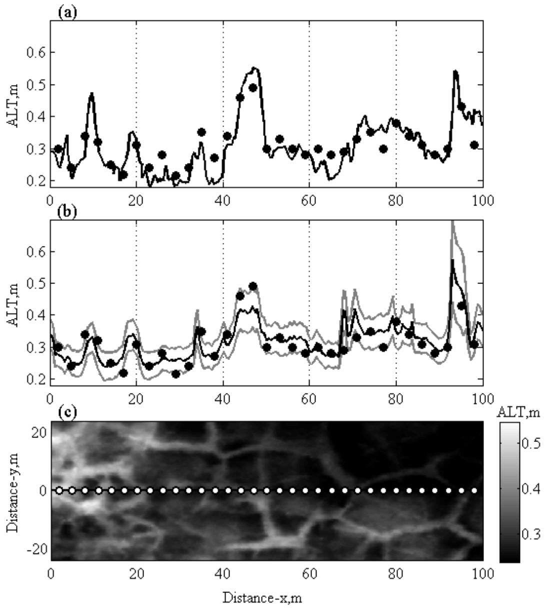

Figure 1. (a) ALT from the point probe (dots) and from the surface GPR (bold line), (b) Estimated ALT (black line), 99% confidence interval (gray lines) and point data (dots), and (c) Estimated ALT in the 2-D domain. The white dots in (b) are the point data locations, and the GPR line.

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Soil Microbiota of Contrasting Alaskan Permafrost Environments

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Introduction

Permafrost soils are a unique habitat for microbial life. Surprisingly, this frozen, water limited environment contains a large diversity of microbial life, often active and acclimated in freezing conditions. The extent to which microorganisms are active in frozen soils, and differences in community composition among different permafrost soils, are important elements for determining greenhouse gas fluxes from the decomposition of permafrost carbon. Permafrost soils contain large stores of organic carbon, and the ultimate fate of that carbon depends upon many physical, chemical, and microbiological factors [*Graham et al., 2011*]. In this study, we asked whether the continually frozen condition of permafrost influences the composition of the microbial community independent of changes in resource availability (carbon and nitrogen). We compared the influence of permafrost with the influence of landscape type by comparing two strongly contrasting landscapes: a high organic matter permafrost peatland near Hess Creek, AK and a low organic matter, loess dominated permafrost soil near Coldfoot, AK. We hypothesized that being in a continually frozen state in permafrost would affect the composition, diversity, and activity of the microbial community independently of the strong influence of organic matter content on microbial communities.

Methods

Site locations

Our high-organic matter lowland permafrost site was located at Hess Creek near the Yukon River (65º40’12.84” N, 149º04’36.24”W). The low organic matter site was located near Coldfoot, AK, just north of the arctic circle (67º12’04.6”N, 150º16’20.1”W), a site with continuous loess permafrost and low organic matter content. Both locations have permafrost at approximately 60cm depth. Soils were sampled in spring of 2007 and immediately processed in a -20oC cold room where the soil cores were scraped of surface contamination and cut into active layer and permafrost sections. Solid and liquid phase carbon and nitrogen concentrations were influenced less by depth (active layer vs. permafrost) than they were by landscape location (Hess Creek vs. Coldfoot) (Table 1).

Table 1. Physical Properties of Active Layer (AL) and Permafrost depths (from Waldrop et al., 2010)

	Hess Creek		Coldfoot	
	AL	Permafrost	AL	Permafrost
Carbon (%)	40	40	3	2
Nitrogen (%)	1.8	1.4	0.2	0.1
Dissolved Organic Carbon (mg/L)	17.6	17.3	9.1	3.2
Total Dissolved Nitrogen (mg/L)	0.5	1.5	0.3	0.2

Communities

We sequenced bacterial 16S rRNA genes in DNA extracted from the samples before and after incubation at 5°C to determine the bacterial community composition. This resulted in a total of nearly 1,000,000 16S rRNA gene amplicons (approximately 15K per sample) using Roche 454 Titanium pyrotag sequencing and identification of 14,000 distinct operational taxonomic units (OTUs, 97% sequence similarity) from 104 Greengenes (DeSantiset al 2006) defined phyla, including those with uncultured representatives.Microbial diversity was examined by comparing rarefaction curves of 16S rRNA OTU reads among our samples. Ordinations of microbial community 16S rRNA gene data were conducted using principal coordinates analysis of weighted UniFrac distance matrices (see Mackelprang et al, 2011).

Results

Microbial diversity

The high organic matter soil (Hess Creek) had much higher bacterial diversity than the low organic matter soil (Coldfoot) site (shannon diversity at Hess Creek = 4.98; Coldfoot = 4.45). Microbial diversity may often be limited by the amount of energy resource. However, microbial diversity was lower in permafrost soils compared to active layer soils, even though the carbon and nitrogen contents of permafrost and active layer soils were similar within sites. Thus diversity is reduced in permafrost soils likely through the stress exerted on the microbial community through continuous frozen conditions, and not by reductions in bioavailable C in permafrost.

Microbial community composition

At the phylum level, there was little difference in the most abundant bacterial taxa between sites or between permafrost and the active layer community. The most abundant phyla in all soils consisted of Actinobacteria, Chloroflexi, and Proteobacteria, composing between 60 and 80% of the total community. Although we did not examine archaea in this study, in a connected study we found that archaea were more abundant in permafrost compared to active layer soils.

At the class level, the most common OTUs in both locations and soils (permafrost and active layer), were Anaerolineae, Rubrobacteridae, and Deltaproteobacteria. Much of the variability in community composition occurred with the less abundant organisms. When community composition data were compared using Unifrac Principal Coordinates Analysis and ANOVA, overall community composition differed both by location and by depth (permafrost vs. active layer) (Fig 1). Interestingly, there was as much difference in community composition between active layer and permafrost soils as there was between microbial communities taken from the active layers of very different landscape types (Hess Creek vs. Coldfoot). Moreover, there was greater variation in the composition of the microbial community between permafrost types than there was between microbial communities in different active layers. These results highlight the strong influence of permanently frozen conditions on the composition of the microbial community, which functions independently of the typical structuring influences on microbial communities such as carbon and nitrogen.

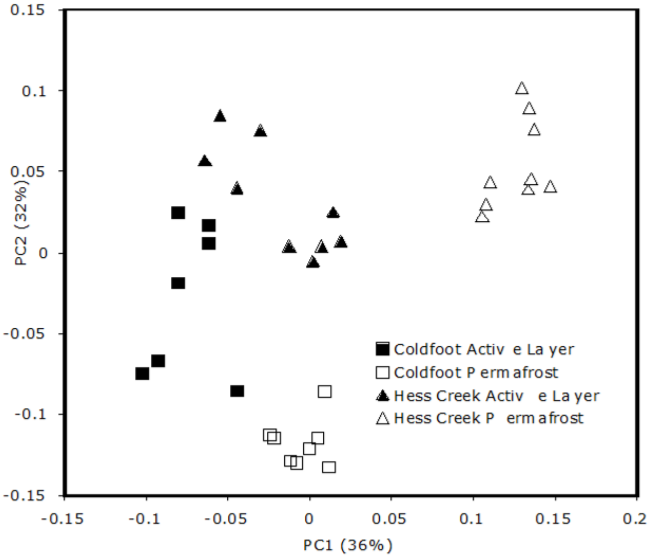

Figure 1. Microbial community composition based upon ordination of 16S rRNA OTUs. Community composition differed between by depth (active layer vs permafrost) and location (Hess Creek vs. Coldfoot)

Through incubation studies, we know that microbial communities in frozen soils are active and respiring. However, we have observed that microbial communities are respiring faster in frozen permafrost than they are in frozen active layer soils, indicating that permafrost microbial communities are acclimated to frozen conditions. Our incubation studies have also shown that methanogens are much more prevalent and much more active in permafrost from organic lowlands than permafrost from loess sediments such as Coldfoot. Understanding the mechanisms that lead to these important differences influencing greenhouse gas production is an area of future research.

In conclusion, our research shows that microbial communities inhabiting permafrost environments are impacted by long term frozen conditions independent of changes in resource availability. Microbial communities in permafrost are less diverse than microorganisms in active layer soils and the composition of the microbial community is just as impacted by the frozen condition as they are by differences in soil carbon and nitrogen concentrations.

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Biological soil crusts of Hayes Island, Franz Josef Land, Russia: High cover, biomass and NDVI

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Biological soil crusts (BSCs) are "…an intimate association between soil particles and cyanobacteria, algae, microfungi, lichens and bryophytes…which live within, or immediately on top of, the upper millimeters of soil" [*Belnap & Lange 2003*]. They are common in sparsely vegetated landscapes where they help to stabilize and protect soils from erosion. BSCs have been most thoroughly studied in the arid deserts and semi-deserts of the world, but they are also common in sparsely vegetated Arctic landscapes, especially the "polar deserts" [*Bliss & Gold 1999*] and on dry and barren microhabitats such as frost boils in more continuously vegetated tundra areas [*Kade et al. 2005*]. They fix nitrogen and improve site conditions for higher-plant seedling establishment, and have a marked effect on the soil thermal and hydrological properties and reduce the susceptibility of High Arctic soils to surface needle-ice cryoturbation [*Bliss & Gold 1999*]. In the more arid parts of the High Arctic, such as northern Canada where they have been studied most intensively, BSCs are a "common but locally restricted feature", occurring primarily in association with well-irrigated microhabitats downslope of persistent snowbanks and in drainages [*Bliss & Gold 1999*]. Here, we report extensive cover of BSCs at an extreme High Arctic location near the Krenkel Hydrometeorological Climate Station on Hayes Island, Franz Josef Land (FJL) (80.5˚N, 57.9˚E), Russia. We describe the methods of biomass determination, site characteristics and preliminary assessment of BSC cover, biomass and the Normalized Difference Vegetation Index (NDVI). The observations were made during a joint U.S.-Russia expedition to Hayes Island, 7-13 Aug 2010 [*Walker et al. 2012*]. The chief goals of the expedition were to 1) collect ground observations from the extreme northernmost bioclimate subzone (Subzone A = polar desert of Russian authors) to help interpret satellite-derived spectral data that are being used to trace the recent trends of vegetation change in the Arctic, and 2) to establish Russia's northernmost permafrost- and active-layer-monitoring site. Most of Hayes Island is covered with sedimentary deposits consisting of unconsolidated sands, derived from alluvial and marine sediments at lower elevations and sandstone bedrock and eluvium in the low hills. The island has a maritime High Arctic climate caused by the moderating influence of the Barents Sea. The mean annual temperature is -12˚C and the range of mean monthly air temperatures is from - 27˚C in February to 1˚C in July. Only July has a mean temperature above freezing. The absolute recorded extremes are -42˚C and 12˚C. Cloudiness, summer fog and frequent storms are typical. Mean annual precipitation is 282 mm, with the maximum precipitation occurring during November to February. From the air, most zonal sites on mesic gently sloping hills between drainages appear black, a consequence of the abundant black and dark-colored BSCs that cover the soils. On most surfaces vascular plant cover is very sparse. *Papaver polare* is the dominant vascular plant. Other common cushion and mat forbs include *Stellaria edwardsii, S. crassipes, Cochlearia groenlandica, Draba subcapitata, D. micropetala, Saxifraga cernua, S. cespitosa, S. oppositifolia, Cerastium arcticum, C. regelii.* Graminioids (*Phippsia algida, Alopecurus borealis* and *Poa abbreviata*) cover less than 1%. Site 1 (zonal sandy loam site) was located on a gentle west-facing slope at an elevation of 30 m with relatively abundant vascular plant cover. Mean active layer depth was 34±2.1 cm on 11 Aug. The soil was on average 61% sand and 7% clay (USDA methods). The soil pH was 6.0 to 6.5. Volumetric soil moisture was 38±3%, and soil conditions were saturated with small pools of water on the surface during sampling. Small patterned-ground features formed by seasonal frost cracking (non-sorted polygons 10-15 cm in diameter) were common. The cracks between polygons provided protected habitats for small mosses, lichens and forbs. Site 2 (somewhat drier sandy site) was located on a flat marine terrace at about 10 m elevation. The depth of thaw averaged 33±2.7 cm on Aug 12. The surface geomorphology was composed of large flat-centered ice-wedge polygons 20-25 m in diameter and small nonsorted polygons 10-20 cm in diameter. Compared to Site 1, Site 2 was better drained and had conspicuously less moss cover and more BSC cover. The soil was on average 81% sand and 3% clay. Volumetric soil moisture was 33±3%. Soil pH at this site ranged from 5.2 to 5.6. The vegetation, soil, and spectral properties of the land surface were described using methods presented in Walker et al. (2012). Only plant cover, biomass and NDVI are reported here. At each site, plant cover was measured along five 50-m transects using a Buckner optical point-sampling device, which has a telescope with cross hairs that sights vertically down on the plant canopy (100 points / transect, 500 points total at each site). Biomass was sampled using a 20x50-cm clip-harvest frame in the center of five 5x5-m relevés at each site. In previous expeditions to the Yamal Peninsula, we did not determine the biomass of BSCs because they normally are a small component of he biomass and because of the difficultly of separating the BSCs from the substrate. At Hayes Island, the BSCs are extraordinarily abundant and thick, and relatively easy to separate because of the sandy soils. The vegetation and top 2 cm of soil were removed intact from each 20x50 cm biomass sample using a serrated bread knife. The slices of soil with attached vegetation and BSCs were divided in half and placed intact into two gallon-size Ziploc bags. Replicate samples of crusts were sent to the Komarov Botanical Institute in St. Petersburg for determination of the primary readily identifiable components. The aboveground vascular plants, mosses and lichens were removed by fingers or clipped with scissors from the soil slices and sorted according to plant functional types (mosses, lichens, graminoids, forbs) and live and dead components. Small representative “cookies” containing the BSC biomass were cut from the remaining intact slices of soil with a 5-cm diameter (19.6 cm^2 area) lid from a 300 ml Edge® shaving-lotion can. Five cookies were cut from each 20x50-cm plot if possible. Excess mineral soil was removed from the bottom of each cookie, leaving a thickness of about 0.5 cm. We then quickly agitated the cookie sample in a Waring blender to detach the organic material from the sand. We then added water to separate the heavy sand from the lighter crust material, decanted the water and lighter organic fraction, removed the water by filtering, and then ashed the organic to determine its mass (described in more detail in on-line Appendix S6 of Walker et al., 2012). Extrapolation to 1 m^2 was determined by multiplying the mean biomass of the cookies times the number of cookies per m^2. NDVI is derived from the red (R) and near-infrared (NIR) channels of spectral data [NDVI=(NIR–R)/(NIR+R)]. Higher NDVI values are indicative of high vegetation chlorophyll content or high photosynthetic potential. Ground-based measurements of NDVI were obtained using a handheld PS-2 portable spectrometer (Analytical Spectral Devices, Inc., Boulder CO). Measurements were made at 1-m intervals along each 50-m transect. Because of very wet conditions, only three transects were sampled at Site 1 and two at Site 2. NDVI was also sampled at five biomass sample sites at Site 1 and four at Site 2. NDVI was also calculated from a Landsat ETM±(scene LE202001200. 1212SGS00, 07/31/2001) and AVHRR multispectral satellite data that covered the study sites [*Walker et al. 2012*]. The primary identified lichen components of the BSCs were *Protopannaria pezizoides, Lecidea ramulosa, Baeomyces rufus, Lepraria gelida, Ochrolechia inaequatula, Ochrolechia frigida, Pertusaria* cf. *coriacea*, Common small bryophytes included in the BSCs were *Polytrichastrum alpinum, Orthothecium chryseon, Bryum rutilans* and *Anthelia juratzkana*. Other unidentified components included lichen prothalli and algal crusts. Measured cover of BSCs at Site 1 (sandy loam zonal site) was 48±6% (n=5 transects, 100 points each). Of these 38% were black crusts, 3% white crusts, and 5% other. Cover of other cover components on Site 1 included 18% bare soil, 17% moss, 9% fruticose and foliose lichens, 7% forbs, and 2% graminoids. Measured cover of BSCs at Site 2 (sandy site) was 59±12% (n=5 transects, 100 points each). Of these 48% were black crusts, 2% white crusts, and 10% other. Cover of other cover components on Site 2 included 16% bare soil, 9% moss, 12% fruticose and foliose lichens, 7% forbs, and 1% graminoids. BSC biomass for Site 1 was estimated at 95±29 g m^{-2}. This was about half the non-BSC aboveground biomass: total biomass of live and dead moss, non-BSC lichens, forbs and graminoids) on the zonal site was 208±110 g m^{-2}. BSC biomass for Site 2 was at 220±37 g m^{-2}. This was about six times the non-crust biomass (36±23 g m^{-2}) on the sandy site. If the BSCs are included in the calculations of total aboveground biomass, the total biomass values of the two sites are comparable. At Site 1, the total biomass (including live and dead BSCs, mosses, lichens, forbs, and graminoids) is 303±117 g m^{-2}. At Site 2 total biomass is 256±46 g m^{-2}. These biomass values are considerably higher than values recorded at the northernmost (bioclimate subzone A) site at Isachsen along the North America Arctic Transect (NAAT), where total biomass values averaged 171 g m^{-2}, but BSCs were not included [*Walker et al. 2012*]. Mean NDVI using the handheld spectrometer was 0.445±0.033 at Site 1 and 0.479±0.015 at Site 2; the Landsat ETM NDVI values were 0.163±.032 for Site 1 and 0.137±0.022 for Site 2; and a single AVHRR pixel that covered both sites had an NDVI value of 0.088. The handheld NDVI values were extraordinarily high for such an extreme northerly site. The high cover and biomass of BSCs clearly contributed to the high handheld NDVI values, but the very wet conditions during measurement also undoubtedly affected the measurements. It is not possible to evaluate the effect of the wetness on the Hayes Island NDVI values without measuring the sites in dry conditions, but a study of BSCs at an Israeli desert location [*Karnieli et al. 2001 cited in Belnap and Lange 2003*] reported an NDVI of 0.32 for wet crusts, triple that of dry desert BSCs at the same location. The comparable mean handheld NDVI value at Isachsen, a much drier, more continental zonal site along the NAAT, was only 0.27 [*Walker et al. 2012*], but BSCs were also much less common there. This first study of BSCs from subzone A adds to earlier studies of BSCs in the High Arctic [*Bliss & Gold 1999, Yoshitake et al. 2010*]. Black BSCs are the dominant portion of total biological cover and biomass. The BSCs also contribute to the relatively high NDVI of this extreme maritime location. BSC cover, biomass, and NDVI need to be considered in assessing the trends in biomass and NDVI along the Arctic climate gradient, and more thoroughly examined in both continental and maritime portions of the extreme High Arctic. More detailed studies are needed to evaluate the effects of site moisture on Arctic BSC spectral reflectance. This work was funded by NASA grant NNX09K56G. We thank other members of the expedition for their support and help, Martha Raynolds who provided the AVHRR NDVI values. Complete information regarding descriptions of the expedition and data collected are at http://www.geobotany.uaf.edu/yamal/reports.

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Long-Term Field Observations of Sorted Circle Dynamics at Sites in Central Alaska

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Introduction

Sorted patterned ground features are widespread and well developed in the Maclaren Summit/High Valley and Tangle Lakes regions along the Denali Highway of central Alaska. I have had the opportunity to study these features, and in particular, the sorted circles, since 1982, a period of almost 30 years. Although not examined every year in that period of time, observations were made 18 times from 1982-2011. Most of these patterns occur in shallow depressions in the silty till that blankets the area [*Walters 1983*]. These depressions become inundated each spring with snowmelt, rain, and thawing ground ice. Heavy rains during summer or fall can also temporarily fill the sites. Over 300 lakes and ponds containing patterns were identified by aerial reconnaissance, air photo interpretation, and field observations. All patterns, whether underwater or subaerially exposed, occur in situations of fluctuating water levels. Cryostatic and hydrostatic processes are most active in sites subject to temporary ponding, and patterns are best developed at such sites. The purpose of this paper is to provide a summary of field observations and findings dealing with sorted circles since 1982.

Study Area

The Maclaren Summit/High Valley and Tangle Lakes regions are located within the Amphitheater Mountains on the south side of the central Alaska Range (Fig. 1). This is within the zone of discontinuous permafrost, and although frozen ground is often absent in well drained till ridges and hills, fine-grained sediments in shallow depressions are typically frozen at depths of 0.5 to 1 m. Elevations range from 880 m in the area of the Tangle Lakes to approximately 1,190 m in Maclaren Summit/High Valley area. The region experiences a continental climate, with extreme summer and winter temperatures, light precipitation, and light surface winds. A 30 year climate normals record from 1981-2010 for Paxson, approximately 20-50 km east of the study areas, shows a mean annual temperature of approximately -3.3 °C and mean annual precipitation of about 47 cm (NCDC/NESDIS/NOAA, 2010). Several periods of glacial activity have taken place in the region, and the area is characterized by classic ice-stagnation topography. Ice-contact features such as eskers, kames, crevasse fillings, kettles, and pitted surfaces dominate the surface. The sorted circles examined in this study are found in shallow depressions in the silty till that covers the region.

Description of the Patterns

Sorted patterned ground forms include sorted circles, polygons, stripes, and pits. Circles and polygons are the most common forms and vary in diameter from about 0.25 to 2 m. Average diameter is about 60 cm (n=238). They occur on level to very gently sloping surfaces (< 2°) and are present both in depressions subject to temporary ponding and in depressions subject to seasonal wetting but no ponding. Because of the lack of vegetative cover, they are more obvious and more active in depressions in which seasonal ponding takes place. The sorted circles examined in this study consist of coarse stones enclosing a circular area having a concentration of fine-grained sediment with scattered stones. The central area of the circles is typically convex upward, with as much as 30 cm of relief between the center and the edges of the fines at the coarse border. The contact between the fine-grained centers and the coarse borders is usually quite sharp. Excavations through circles showed that stones in the border areas display a preferred vertical orientation of their long axes, and scattered stones near the surface in the fine-grained circle centers show the same tendency. The circles also display a lateral sorting of stones, whereby the stones along the inner margin of the border are significantly smaller than the stones within the center of the border. The fine-grained sediment associated with the patterns is predominantly loamy, with sand, silt, and clay averaging 32%, 40%, and 28% respectively (n=62). This sediment is characterized by a low liquid limit (16-32%) and a very low plasticity index (2-11%). In late summer the depressions in which the patterns occur are usually no longer inundated, but sufficient moisture remains in the sediments such that they become thixotropic in response to disturbance.

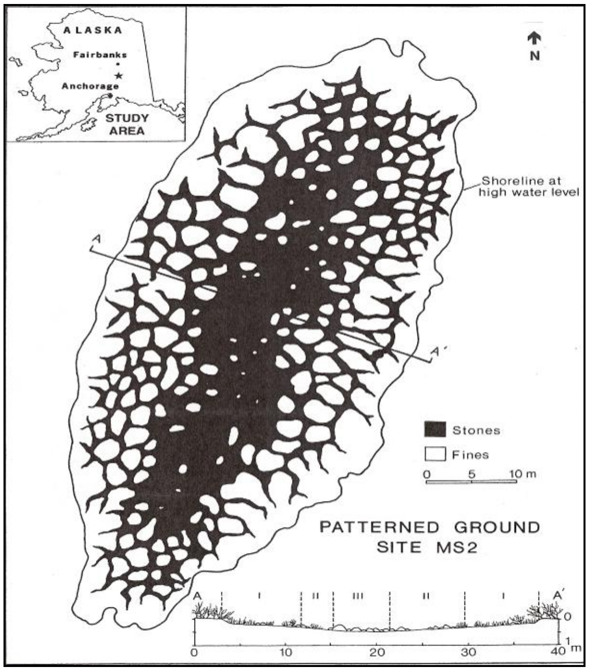

Figure 1. Map view of a patterned ground site in the Maclaren Summit/High Valley area of central Alaska. Map drawn from air photos and ground surveys.

The sorted circles do not occur uniformly distributed within a patterned ground site, i.e., a shallow depression subject to temporary ponding. Instead, there is a regular distribution of types of patterns in a more or less concentric fashion within a given patterned ground site (Fig. 1). In a typical situation, larger circles and polygons (1-2 m diameter) occur along the outer margin of the shallow depression (zone I in Fig. 1). Nets and stripes may be found in this location depending on the degree of slope. Fine-grained sediment is abundant here, and some vegetation exists. Inside this outer zone, an area occurs where smaller patterns (0.5-1 m), usually circles, can be found (zone II in Fig. 1). These circles are more widely spaced than patterns in the outer zone and there is much less fine sediment at the surface. Little or no vegetation exists in this zone. In the innermost zone in the center of the depression, circles are the only types of patterns present (zone III in Fig. 1). They are very small (0.1-0.5 m) and widely spaced. Fines are present only in the circle centers and no vegetation exists. Often the former existence of sorted circles is indicated by the presence of smaller stones within a circular pattern of larger stones, but no fines occur on the surface. At some sites only circles such as these are present in the central area of the depression.

Circle dynamics

Since 1982 eight depressions containing sorted circles have been studied to determine their degree of activity. Four to six circles have been monitored at each site using repeat photography and surveys of wooden dowels, metal spikes, and marked stones. Although photos have been taken of all of the monitored circles from 1982-2011, dowel and spike movement studies were carried out during 1982-1987, 1992-1997, and 2001-2011. Prior to 2008 all photos were taken as colored slides, but since then all of the images have been digital. In addition, several trenches were excavated through nearby nonmonitored circles and portions of circles, and data were gathered on soil temperature, moisture, texture, and consistency. The excavations showed that in cross-section these features consist of domal mounds of fine-grained sediment with scattered pebbles and cobbles enclosed by the coarser stony borders. For smaller circles, the fines appear as plug-like or pillar-like features below the circle.

The total of 48 monitored circles displayed considerable variability in their activity over the period of study. Average vertical displacement of markers was approximately 2.6 cm/yr, although maximum uplift was sometimes as great as 12 cm. Horizontal displacement of markers averaged 0.4 to 2.5 cm/yr, but not all markers showed lateral movement each year, and the direction of movement was not always consistent from year to year. Overall, the stones showed less horizontal movement than the dowels or spikes. Other factors being equal, it appears that the larger the object the greater its resistance to movement. Other summary findings are that vertical displacement was greatest in the center of the fines, with the amount of surface heave decreasing toward the coarse borders, and the horizontal displacement showed an overall pattern of radial movement, with markers moving outward from the center of the fines toward the stony border.

Discussion and conclusions

A direct relationship was found to exist between the degree of circle activity and the amount of soil moisture, vegetative cover, and pattern microrelief. Sorted circles occurring at sites that experience temporary ponding show the greatest degree of activity and the most strongly convex-upward pattern centers. These sites have the highest soil moisture and a lack of vegetative cover. Circles found at sites subject to wetting but no ponding show less activity and only moderately convex-upward pattern centers. Such sites have less soil moisture and contain some vegetative cover.

Several workers, either by way of field observations or theoretical models, have noted the importance of water content in the development of sorted patterned ground [*e.g., Haugland, 2006; Peterson & Krantz, 2003*], and this is supported by the observations of the patterns in the Maclaren Summit/High Valley and Tangle Lakes regions. The fact that different types of patterns occur in a zonal fashion within these depressions (Fig. 1) suggests that there exists an evolutionary development of patterns that is dependent on amount of soil moisture. Amount of soil moisture, in turn, influences the degree of frost action and the presence or absence of vegetation.

Given optimum conditions of soil texture and moisture, such as is found in the Maclaren Summit/High Valley and Tangle Lakes regions, frost action processes such as differential frost heave will produce well-developed sorted circles. As circles evolve, the coarser material moves progressively upward and outward, away from the circle center to concentrate along the stable border. Fines also move up and into the circle center where they dominate. At the surface the fine sediment is slowly removed by deflation, rainwash, sheetwash, etc. and the circle center becomes stonier as more coarse material continues to move upward. Eventually the fines become separated from their source below and the circle progresses to an end point: a circle consisting of smaller stones within a circular pattern of larger stones.

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Causes and Treatment Measures of the Construction Quality Problems in the Permafrost Region of Mohe

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Mohe is located in the northernmost of Da Hinggan Mountains, So as the northernmost of Heilongjiang Province, China. It is an island-shaped permafrost area with an average ground temperature of -0.5 °C ~ -2°C. In recent years, with the development of tourism, construction increases year by year, more and more quality problems of the buildings appeared. This paper describes four typical quality problems of the buildings, cause analysis, treatment measures and recommendations; and warns to avoid the recurrence of similar quality problems.

Introduction of the quality problems

The four projects are: the bus terminal office building in Mohe, Minsheng home district of Mohe shantytowns transformation engineering, Building B in Jianxing cuilinyuan home district, and Xing'an 220kv substation. All the project are on the island-shaped permafrost region. The foundation of these four buildings are artificially dug filling pile (of which the diameter is 900mm, and the length is 9m), drilled grouting pile (the diameter is 400mm and the length is 16m), strip foundation (with a foundation depth of 3.5 m), artificial hole inserted pile (with a diameter of 800mm and a length of 5-8m). The problems of these projects are cracking in the walls after six months to one year after completion. The maximum crack width is up to 50 mm, and the subsidence of the single pile in substation building is up to 17cm. Cracks and subsidence has seriously affected the normal use of the projects.

Cause analysis

On the basis of site investigation, testing and analysis, the causes of quality problems are summed up as follows: 1) in the exploration stage, the number of exploration point and spacing arrangement can not cover the venue and does not meet specification requirements. 2) In the design stage, the influence of permafrost on buildings has not been taken into consideration, and design is not in accordance with the *Code for Design of Soil and Foundation in frozen soil Region*, which is a specification for building design in permafrost region. 3) Because of the improper construction technology, collapse of the hole or insufficient of the depth of the pile, it is resulted that the piles construction does not meet the design requirements. It leads to a reduction of the pile capacity, subsidence and deformation of the foundation. 4) In the process of use, the thermal effects of the building and influence of the surface water are not taken into account, the temperature of the permafrost soil increases, and even results in thawing of the soil. All these factors lead to the quality problems of the buildings.

Treatment measures

In permafrost region of Mohe, measures that have been implemented in foundation treatment are: 1) grouting the foundation soil to increase the bearing capacity; 2) using the elevated ventilating foundation to slow down the further thawing of the foundation soil; 3) artificially cooling the foundation soil by hot rod, lowing the ground temperature, increasing the bearing capacity of foundation soil; 4) keep monitoring the building subsidence and temperature of the permafrost soil to ensure timely detection of problems and deal with.

Conclusions and recommendations

In this paper, the quality problems of 4 buildings in Mohe were analyzed. The causes for the quality problems were summarized. It provides experience for similar projects in the future, and gives some treatment measures. In order to prevent the recurrence of similar quality problems in the permafrost regions, survey, design, construction and use should fully consider the change of permafrost soil, and the influence on the foundation. Long-term monitoring of foundation subsidence and the temperature change of permafrost soil below is necessary to ensure the stability and security of the buildings in permafrost region of Mohe.

A Review of the Sunshading (Awning) Method in Embankment Engineering on the Qinghai-Tibet Plateau in China

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With the opening and running of the Qinghai-Tibet Railway (QTR) and the maintaining of the Qinghai-Tibet Highway (QTH), a lot of new ideas, methods and techniques were adopted and applied to the embankment engineering. There had built different roadbed of ventilation duct, the ballast revetment and ballast roadbed, the roadbed of heat pipe, and the roadbed of awning to compare and discuss them superiority, respectively [*Ma wei 2002*]. As one of the measures, which was be bring out by Kondratjev, V.G. in 1996 at the first [*Kondratjev 1996*], and was put into use to control the roadbed temperature field effectively by adjusting the solar radiation, and had got a very remarkable effect on the QTP [*Feng Wenjie et al., 2006, 2009a*]. The awning measure on the embankment side slope is one of the effective engineering measures to protect permafrost in cold regions, with the opening and running of the QTR and others embankment engineering running and maintaining, some researchers had got some results. For example, Shi lei et al. had do some study at the awning structure mechanics [*shi lei et al., 2007*], Feng wenjie et al. had study the the wind speed below the awning and the awning headroom [*Feng Wenjie et al., 2009b*].

The awning board measure at first was adopted on the QTH in China. The awning was set 40 cm headroom on the sunny slope, and we found the ground temperature under awning is almost lower about 8°C than the common embankment. The Fig.1 shows the awning embankment and The Fig.2 shows the temperature curve between the awning embankment and the common comparison embankment [*Feng Wenjie et al., 2009a*].

Fig.1 the awning measure embankment

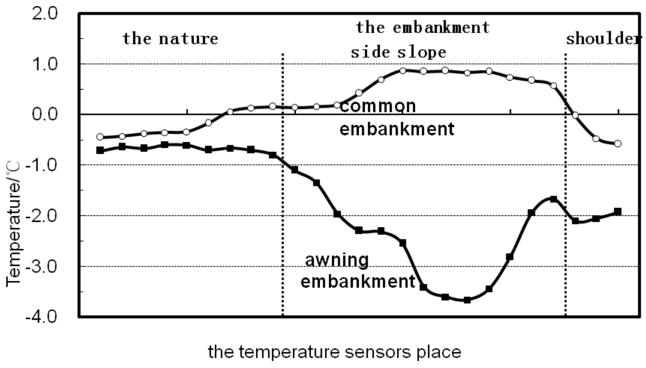

Fig.2 the ground surface temperature curves between the awning and common embankment in Nov. 2003 on the QTP

As the awning measure field test, was be built on the QTP by the Lanzhou branch of railway science academia, from the field test results, we can found that the average ground surface temperature(AGST) of awning inner is lower about 8°C～20°C than outer, the most value is 24°C, the difference is lesser in low temperature season (winter) and the difference is more in high temperature season (summer), but the ground surface annual temperature of awning inner always kept at about 0°C. The Fig.3 showed the Comparison between the average ground surface temperature(AGST) curves for awning inner and outer at 14：00 in one year [*Feng Wenjie et al., 2006*].

With the QTR opening and running, the awning measure was adopted on the QTR embankment. Fig.4 shows the awning measure on the QTR side slope.

Based on the observation results, we can found that the awning can raise the permafrost table and reduce the embankment soil temperature effectively [*Feng wenjie et al. 2006*].

Feng wenjie et al. had simulated the air speed under the awning measure and the headroom of the awning measure. The simulation results showed the headroom of the awning is not less than 20cm and the maximum not more than 70cm is better. And suggested the best headroom of the side slop awning would be used 50cm high. With the calculation results, the semi-experience formulary was be taken out of the wind speed variation under the awning with the awning headroom and the original wind speed, and it give a reference to protect the embankment side slope on the cold regions [*Feng wenjie et al., 2011*].

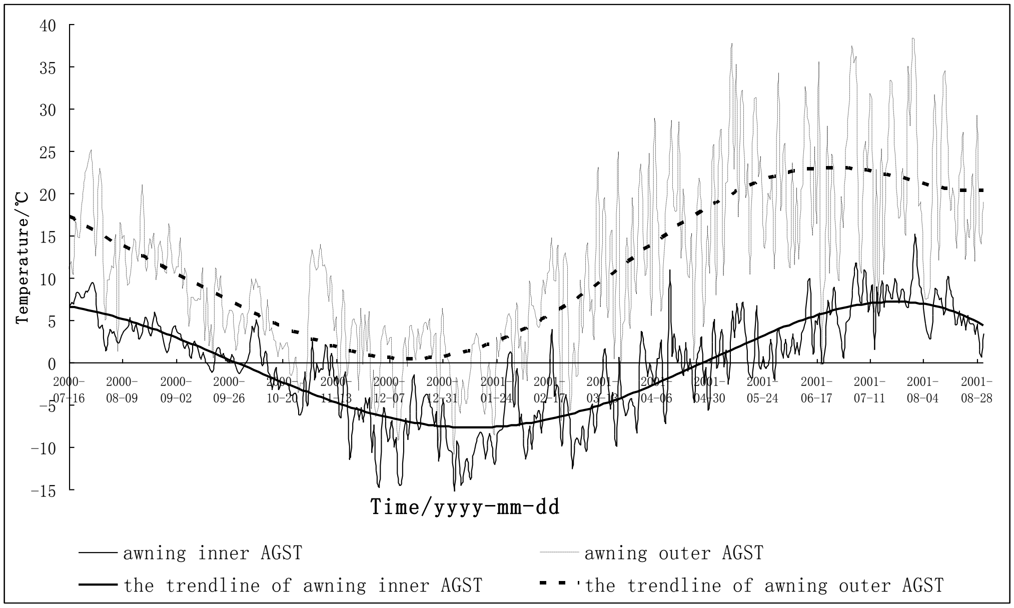

Fig.3. Comparison between the AGST curves for awning inner and outer at 14：00 in one year

Fig.4 the QTR awning embankment

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Towards operational permafrost monitoring in Norway

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Introduction

Thawing of permafrost is projected to occur over large areas in the 21st century as a consequence of climate change. This could be a trigger for various climatic feedback mechanisms on the local to global scale. As the vast and remote permafrost areas can not be sufficiently covered by ground-based monitoring of soil temperatures in boreholes alone, it is desirable to exploit the wealth of multi-sensor-multi-source data to assess the thermal ground conditions on large scales.

In Norway, a wide range of different permafrost conditions is found, from mountain over partly organic-rich wetlands especially in northern Norway to high-arctic permafrost in Svalbard. Furthermore, gridded data sets of atmospheric variable, which can serve as input for spatially distributed permafrost modeling, are available from various sources. Thus, Norway constitutes an excellent test area to evaluate the performance of different permafrost models [*e.g. Etzelmüller et al. 2011, Gisnås et al., 2012*] and input data sets, which is crucial for benchmarking requirements on model and data quality.

Theory and Methods

Soil temperatures can be modeled using Fourier's law of heat conduction in one dimension

$$c_{\text{eff}}\frac{\partial T}{\partial t}-\frac{\partial}{\partial z}\left(K\frac{\partial T}{\partial z}\right)=0\,,$$

where c_{eff} denotes the effective heat capacity and K the thermal conductivity, which both depend on the properties of the soil and are thus variable in time and space. While the heat conduction equation can be easily solved numerically, the key challenge is to supply accurate time series of three key input variables at adequate spatial and temporal resolutions: 1. surface temperature, 2. snow depth, and 3. thermal properties of soil and snow.

We developed a framework for transient and spatially distributed modelling the ground thermal regime in Norway, CryoGRID 2.0. In the model, the subsurface heat flow is treated in terms of 1D-heat conduction using the land or snow surface temperature as upper boundary condition. The model features a dynamical representation of the snow cover and explicitly accounts for the heat flux through the snow pack [*see Westermann et al., 2011a*]. A particular emphasis is put on computational efficiency, so that CryoGRID 2.0 can be applied for a large number of grid cells (on the order of 100,000) and for modeling periods of one century. In a first run, the spatio-temporal distribution of ground temperatures is calculated for a spatial resolution of 1 km for mainland Norway. The model is driven by operationally gridded data of daily air temperature and snow depth available at http://senorge.no (denoted Senorge in the following). These datasets are available for the period 1957 to date with a spatial resolution of 1 km. Spatial distributions of the ground thermal properties (e.g. heat conductivity), surface cover (e.g. vegetation, block fields) are derived from geological maps, borehole measurements and remotely-sensed data.

Results

We present preliminary results from model runs to demonstrate the capacity of the approach to simulate permafrost distribution. The model is initialized to steady-state conditions for the first five *Senorge* years, and subsequently driven by time series of air temperatures and snow depth until 2010.

Fig. 1 displays the modeled average soil temperatures at two meter depth for the decade 2000 to 2009. The modeled permafrost distribution agrees well with borehole and BTS (Bottom temperature of winter snow cover) measurements for subregions, where such ground validation is available. The modeled permafrost distribution is very sensitive to the thermal conductivity K of the snow, for which field measurements remain sparse. Furthermore, the gridded *Senorge* data of snow depth can not account for the considerable snow redistribution by wind on scales of meters to hundreds of meters, so that the snow depths in exposed mountain settings with permafrost may be overestimated.

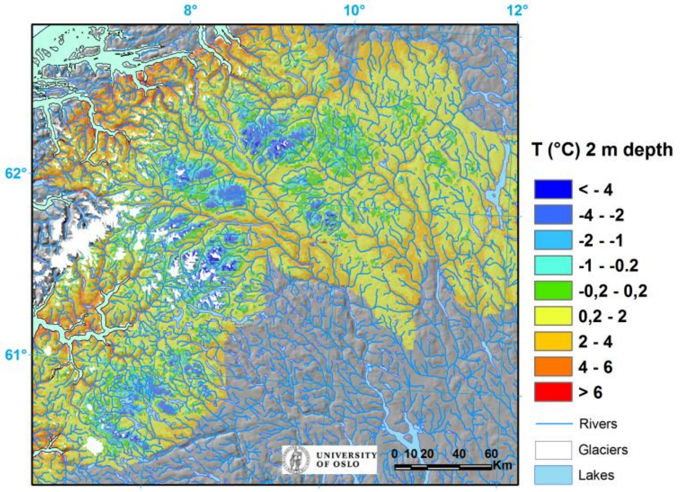

Fig. 1: Average 2 m soil temperatures for the period 2000-2009 modeled with CryoGRID 2.0 for the main permafrost area in Southern Norway. The simulation was performed for an area of 55,000 km^2 at 1 km spatial resolution.

Discussion

The *Senorge* data set may have two significant shortcomings in mountain areas with permafrost: a) the snow depth may be overestimated, as wind redistribution is not accounted for, and b) the winter air temperatures may be cold-biased, since atmospheric inversion settings are not resolved in the *Senorge* algorithm. While snow redistribution models of various complexity are a possibility to resolve a), data fusion of *Senorge* data with remotely sensed land surface temperatures [*Westermann et al. 2010, Westermann et al., 2011b*] from the “Moderate Resolution Imaging Spectroradiometer” (MODIS) could improve model performance with respect to b).

Furthermore, even the relatively detailed spatial scale of 1km, for which the CryoGRID simulations are performed, is still much coarse to capture the considerable small-scale variability of soil temperatures typical for the mountain settings of Norway. Here, probabilistic or statistical downscaling of the most sensitive model input data sets, in particular snow depths could provide a probability density function of soil temperatures (instead of a single temperature profile) within a 1km grid cell.

The simulation of soil temperatures with CryoGRID 2.0 can easily be operationalized to spatially distributed monitoring of soil temperatures, from which both thaw depths in permafrost areas and seasonal frost depth on non-permafrost areas could be inferred. With the present-day soil temperatures obtained from the simulation (Fig. 1), soil temperatures could be updated using CryoGRID 2.0 on a daily basis along with the already operational *Senorge* data set. Before such an operational soil temperature product can be implemented, it is necessary to shed light in possible error sources of the simulation and test and benchmark improvements.

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The Joint German-Russian POLYGON Project – Environmental Studies in East Siberian Tundra Wetlands

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Introduction

A joint German-Russian project (Polygons in tundra wetlands: state and dynamics under climate variability in Polar Regions) started in 2010 and aims on investigating polygonal tundra wetlands in a gradient transect comprising three representative sites across the northeast Siberian lowlands of the lower Indigirka River (70 °N, 147 °E) and the lower (68 °N; 161 °E) and the middle (67 °N; 153 °E) Kolyma river (Figure 1). The study sites cover large gradients in terms of July temperature and precipitation, are accessible without expensive logistics and are situated close to meteorological stations.

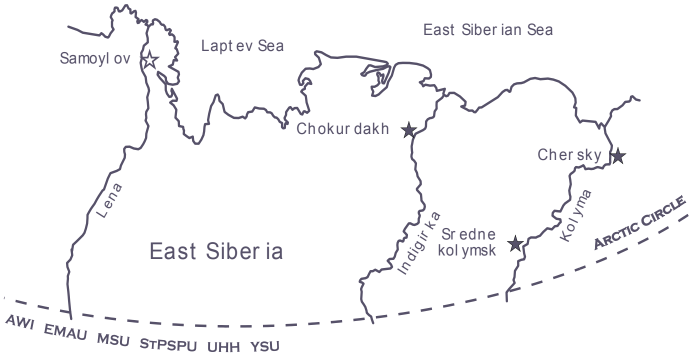

Figure 1. Study sites of the POLYGON project

Using an interdisciplinary approach, modern, sub-recent, and fossil environments will be characterized and compared in order to understand temporal and spatial polygonal dynamics in relation to climate change.

Project aims

The POLYGON project aims at answering three interrelated questions:

(I) How do polygon ponds, cryosols, and permafrost in the polygonal tundra of the northeast Siberian Arctic lowlands interact and how have they reacted on climate change on seasonal, annual, decadal, centennial, and millennial time scales?

(II) Do the biotic and abiotic states and interactions in polygonal wetlands differ along the climatic gradient from the Lena River region to the Kolyma River region?

(III) How will the components of the polygonal tundra wetlands change when permafrost degrades due to climate change?

Geocryological, limnological, pedological and ecological features will be combined to link past, present and future environmental dynamics in polarregions. Present day environmental conditions and their main forcing parameters will be thoroughly assessed, faunal and floral communities in ponds, mires and cryosols as major parts of the polygonal patterned ground will be described and cryogenic processes affecting these structured landscape units will be observed and evaluated. Species and assemblages that are indicative for modern ecosystem conditions will be identified and used as indicators to reconstruct Quaternary climate variations and their ecosystem reactions.

Based on interdisciplinary research that combines modern and past environmental records, the proposed project will contribute to the understanding of small-scale variations of the climate sensitive permafrost landscapes units and allow a differentiation between external climate impact and internal polygon dynamics.

Ongoing work

First inventories of e.g. diatoms, rhizopods, and plant communities have been accomplished in 2011, highlighting small-scale differences in the biota of single landscape units. Together with instrumental data of seasonal abiotic parameters (e.g. water, air and ground temperature, the moisture regimes, hydrochemical data, electrical conductivity and water level), environmental controls on species diversity and distribution have been estimated using multivariate statistical calculations. Representations of past polygon systems have been studied in exposures of late Pleistocene Yedoma deposits.

Using this multidisciplinary approach, several stages of polygonal systems were studied as modern tundra habitats in the surrounding of the WWF station Kytalyk at the Berelekh River, a tributary of the Indigirka River in 2011. Our studies were realized in co-ordination with the Dutch groups from Amsterdam and Wagenningen. The floral and faunal associations of the polygonal tundra landscape were described. Ecological, hydrological, meteorological, limnological, cryological and pedological features were analyzed in order to evaluate modern environmental conditions and their essential controlling parameters. A monitoring program was carried out to measure changes of air, water and ground temperatures as well as water conductivity, water level and soil moisture and to collect water, zooplankton, phytoplankton and ostracods [*Wetterich et al. 2008*] in polygonal ponds in alas, Yedoma and river flood plain landscapes. In addition, exposures, pits and drill cores were studied to understand the cryolithological structures of frozen ground and the active layer and to collect samples for detailed paleoenviromental research of the Quaternary past.

The answer to questions of external or internal controlled polygon dynamics requires high resolution temporal and spatial studies. Therefore, a model polygon was mapped and sampled in 1 x1 m spatial resolution concerning active layer depth, surface relief and vegetation cover. In addition, peat cores from different places of this polygon were taken, to understand and compare the dynamics of sub-recent and fossil ice-wedge polygons in correlation with climate data.

Outlook

Samples of phytoplankton, zooplankton, and zoobenthos, of ground ice, of precipitation and surface water, of permafrost and lake deposits, soil profiles and peat monoliths as well as modern plant collection were taken from different sites of the polygonal microrelief. Analytics are in progress at the POLYGON partner institutions in Potsdam, Hamburg, Greifswald, Yakutsk, Moscow, St. Petersburg and Kazan.

Polygon mires show short-distance diversity in vegetation and site-conditions. Ice wedge polygons are complex and highly dynamic ecosystems with a complex interplay of water, ice, vegetation and peat. Over a period of a few decades a polygon may change from wet to dry vegetation [*de Klerk et al. 2011*]. A comprehensive understanding of the nutrient dynamics in arctic soils is important to predict further responses of arctic ecosystems to climate change. Preliminary results suggest that there is a great variability concerning the nutrient availability within the polygonal tundra. The distribution of extractable nitrate and ammonium is apparently mostly driven by the hydrology regime in the soils.

The obtained results will be used for explaining and forecasting future environmental dynamics in permafrost regions. Based on the experience from the fieldwork in 2011 in the Indigirka lowland, the expedition continues in 2012 in the lower Kolyma region.

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Frost tubes in Alaskan Schools

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Introduction

Soil temperature is an important parameter to understand because it affects microclimate, plant growth, the rate of decomposition of organic material, and other chemical, physical, and biological processes that take place in the soil. This type of information is also valuable to engineers (e.g., for foundations, plumbing, construction). In general, the pattern of soil temperature over the course of a year tends to stay similar, if snowfall is similar (e.g., the mean summer soil temperature, mean winter soil temperature, and mean annual soil temperature stays relatively constant from year to year). However, if a change in mean winter or annual soil temperature occurs from one year to the next, it could be due to some significant change in the surrounding environment, such as increased snow depth or some type of disturbance (deforestation, removal of the insulating soil surface, or urbanization). Monitoring the timing and depth of the freezing and thawing of soil helps scientists understand how the temperature of the soil is changing over time so that they can identify the effects of climate change, such as warming or disturbances on the ecosystem. In southern Alaska, soil near the ground surface freezes in the winter. In most of Alaska and at high elevations, some soil layers/earth materials remain at or below 0°C for at least two consecutive years; this is known as permafrost. The soil frost tube program allows students and scientists to see what part of the soil freezes and when the freezing starts and ends in different parts of Alaska. Unlike permafrost monitoring, the frost tube program is much more dynamic and active for students. A frost tube is an instrument that measures when and how deeply soil freezes. Once a week, students measure the depth at which water in the frost tube has frozen to get an indication of when the surrounding soil has also frozen. Our large network of sites provides greater comparison of timing and depth of freezing in soils in different regions around Alaska [*Yoshikawa 2009*]. Working with temperature data, advanced students can predict the timing and depth of freezing for upcoming seasons or in a future scenario following climate change.

The presence or absence of frozen ground has a strong effect on hydrology. Frozen soil acting as an impermeable layer affects water availability to root systems of plants and the recharge of groundwater reservoirs. The frost tube program has been a great success in Alaska communities because it is relatively easy to implement, is cost-efficient, and is a highly dynamic student activity. We have installed a small one-channel data logger connected to an air temperature sensor next to the frost tube. From the surface temperature data, freezing °C*days (freezing index) and thawing degree-days (thawing index) as well as mean annual temperature can be calculated.

Study Area

Monitoring stations are located all over Alaska, including the Aleutians, the Bering Sea Islands, and Southeast Alaska. Two hundred schools in Alaska are involved in the project, and a monitoring site has been established at Denali National Park and Kenai Fjord National Park [*Yoshikawa 2008*]. The monitoring sites collect temperature measurement data on permafrost and the length and depth of the active layer (the layer above the permafrost that thaws during summer and freezes again during winter).

Methods

Frost tubes are made of three tubes that fit inside each other (see Figure 1). The innermost tube is marked every 5 cm and filled with colored water; it fits inside a radiant heat tube (sealed on the bottom), which fits inside a PVC pipe, open on both ends. The innermost tube of the frost tube is about 12 mm in diameter. When inserted in the hole drilled in the ground, the underground end of the frost tube reaches to the deepest level of frost or to the permafrost layer. The aboveground end (about 1 m long) is capped to prevent air temperature from influencing the underground temperature reading and to keep snow and water out [*Lipovsky & Yoshikawa 2009*]. The innermost tube with colored water shows where ice has formed underground. We lift this tube out from the two outer tubes and note at what depth the ice has formed. It is easy to see the boundary between ice and unfrozen water, because the ice is clear and the water is colored. During frost heaves, only the outermost tube is affected. Students can monitor the timing and depth of freezing in soil at a frost tube site.

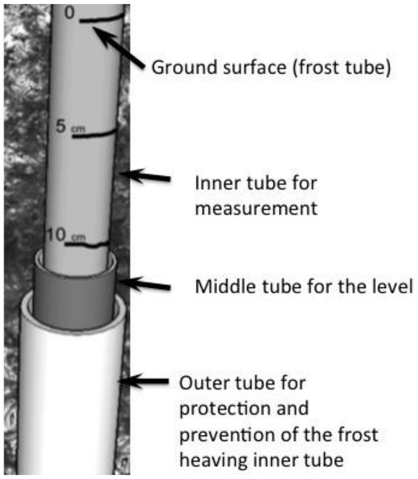

Figure 1. Frost tube structure inside of the PVC pipe

Results and Discussion

This program reveals much of the thermal structure of ground in Alaska, especially in many of the remote communities on the southern boundary of permafrost (i.e., the northern end of the seasonal frost region). Though there are many interesting aspects to this program, here we discuss (1) the distribution of the maximum freezing and thawing layer thickness, and (2) freezing and thawing °C*days ground surface distribution in Alaska.

The summary of maximum seasonal frost depth includes areas along the Gulf of Alaska, but not along Bristol Bay (see Figure 2). The reason for this difference is that Bristol Bay is usually frozen during winter months, while the Gulf of Alaska remains unfrozen during this time. Communities in the Prince William Sound area (Valdez, Cordova, Chenega Bay) and Yakutat usually have a lot of snow, which prevents ground freezing during most of the winter. A few centimeters of ground freezing is observed only at the beginning of winter. Maximum ground freezing is observed in Interior Alaska in areas that were glaciated. Dryer glacio-fluvial sediments freeze deeply during winter, with seasonal frost typically 2–3 m deep.

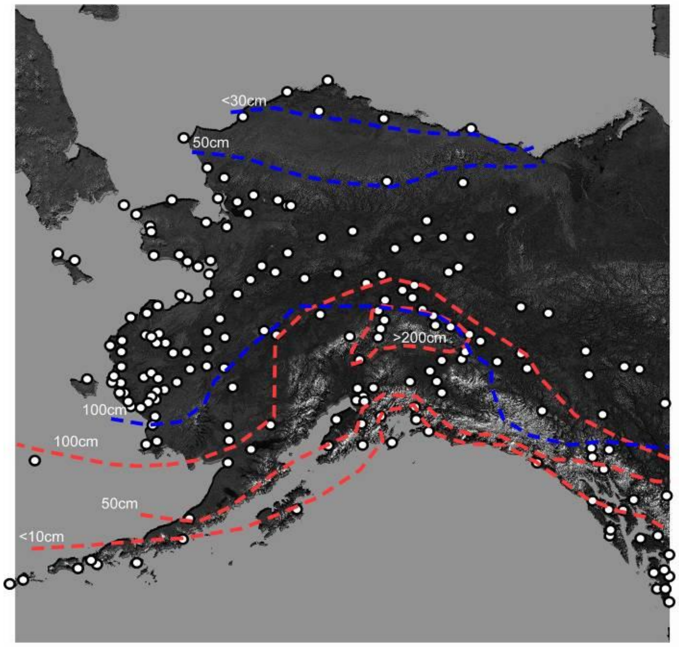

Figure 2. Maximum seasonal frost depth (red broken line), maximum active layer (blue broken line), and observed schools (white dots)

Ground surface freezing °C*days (FDD) and thawing °C*days (TDD) are calculated at all the schools. The results are a reasonable fit with maximum ground freezing depth and active layer thickness. Snow depth is one of the important parameters for FDD at most coastal communities in southern Alaska. Figure 3 shows the relationship between FDD and TDD with classified annual mean ground temperature. Mean temperature is clearly divided by the FDD/TDD relationship.

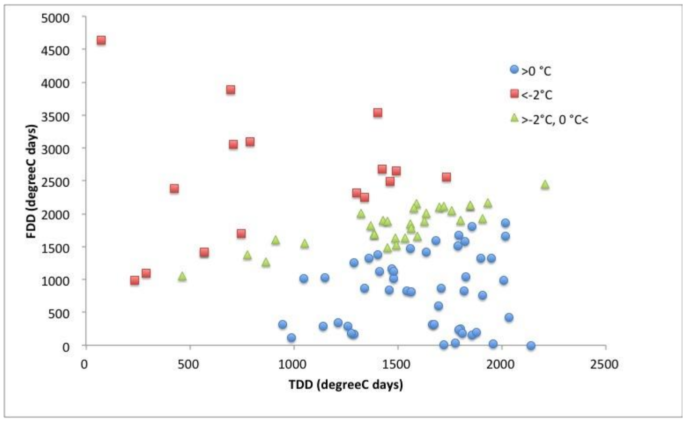

Figure 3. FDD and TDD distribution of Alaska schools: squares indicate colder villages (annual mean ground temperature colder than -2°C); triangles indicate warmer permafrost villages (annual mean ground temperature colder than 0°C, but warmer than -2°C); and circles indicate warmer villages (annual mean ground temperature warmer than 0°C)

Acknowledgments

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Predicting CO_2 and CH_4 Emissions from the Active Layer in Response to Climate Warming

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Observations and models suggest that permafrost is warming and thawing, the active layer is thickening, and previously frozen old soil carbon is being converted and released as CH_4 and CO_2. GHG release amounts and rates are poorly constrained, as is the ratio between CH_4 and CO_2. This ratio is important because CH_4 is significantly more powerful as a greenhouse gas than is CO_2. The arctic is projected to experience more precipitation, and more thermokarst pond and lake formation, both of which could result in wetter conditions that favor CH_4 production. At the same time, thermokarst depressions drain the surrounding soil and can lead to thermal erosion and drainage network expansion that promote drier soil conditions that favor CO_2 production.

We are developing and testing a model to assess how climate warming will drive changes in GHG emissions under a range of soil moisture conditions, from very wet to very dry. Our numerical model (named ARCHY) is designed to simulate coupled surface and subsurface processes in freezing environments. It can operate in 1-D, 2-D or 3-D, is time-dependent, and includes vertical and lateral water and vapor and gas movement in heterogeneous soils and between soils and atmosphere, snow cover, heat transport, solar irradiation, precipitation, temperature, small scale topography, change of phase between water, ice and vapor, and three spatially distributed species of microbes including aerobes, anaerobes, and methanotrophs. In this study, we apply the ARCHY model to a set of thermal, precipitation and GHG emissions data from 1993 provided by the Toolik Field Station, Alaska (68°37’39”N, 149°35’51”W) to test and partially calibrate the model. First, thermal data pin down uncertain thermal parameters of the model, and then GHG emissions allow estimation of uncertain microbial respiration parameters. Temperature recordings at several depths over a one-year cycle were used to calibrate the thermal transport and freezing/thawing features of the ARCHY model. Data at 0 cm depth provides the top boundary temperature condition for the simulations, thereby avoiding complications of possible snow cover, solar irradiance/ cloud cover, shielding or vegetation. Further, the calibrated model is used to quantify the impact of rainfall, soil moisture dynamics and climate warming on GHG production at this site. After confidence building with the Toolik data sets, we simulated the impact of future climate scenarios under both fully saturated and relatively dry soil conditions, by slowly increasing the mean of the current annual temperature cycle to +3°C, +4°C and +6°C over a 100 year time period.

For these simulations, talik occurs within 80 and 40 years for the +4°C and +6°C scenarios respectively. While the +3°C scenario does not develop talik, the active layer remains thawed for a greater portion of the year as time progresses. In addition, ARCHY biogeochemistry simulations show the potential for very large increases in GHG emissions from the active layer. CO_2 fluxes rise from 600 to 4000 $gm/m^2/yr$ under moderately dry conditions, and CH_4 fluxes rise from 70 to 1350 $gm/m^2/yr$ under wet conditions, over 100 year warming period when carbon supply to microbes is unlimited.

Ice-wedge Polygons on Hillslopes in the Umimmalissuaq Valley (Kangerlussuaq, West Greenland)

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Introduction

Ice wedges are a widespread periglacial landform in poorly drained tundra landforms underlain by continuous permafrost [*French 2007*]. Thus they have a great importance in periglacial research with a main focus on ice wedges in flat areas and rarely on ice wedges on hillslopes. So far only few publications exist about ice wedges on hillslopes [*Mackay 1995, Sørbel & Tolgensbakk 2002*]. It is only Mackay who developed a theory for the evolution of ice-wedge polygons on hillslopes.

Study Area

The Umimmalissuaq valley (66°56'N/ 50°2'W) is located about 30 km southeast of Kangerlussuaq in West Greenland. The valley is located within the Kegelen moraine system. So far there are only two dating referring to the Kegelen moraine system around Kangerlussuaq: (a) a radiocarbon age of 6500 ± 120 years B.P. from a marine shell (Ten Brink 1975) and (b) a radiocarbon date of 3095 ± 40 years B.P. from the base of a peaty horizon in the Sandflugtdalen [*Dijkmans 1989*].

Climate conditions can be described as cold arid with MAP of 149 mm and MAAT around 5.7°C (1961-1990, Danmarks Meteorologiske Institut). The valley is part of the continuous permafrost region.

Material and Methods

Geomorphological mapping of around 12 km^2 was carried out at a scale of 1:10 000 in summer 2011. Additionally aerial photographs from 1968 were used (Kort & Matrikelstyrelsen, Danmark). Around 40 soil profiles ordered in four catenas with different distance from the ice sheet were investigated including the depth of active layer. Size of ice-wedge polygons of 10 networks (Fig. 1) was measured as well as aspect and inclination. Vegetation assessments were done according to the principles of the Braun-Blanquet method on plots with 4 m^2.

10 Samples for AMS ^{14}C dating were taken from the lower part of the active layer and the upper part of the permafrost. The samples are still under process at the AMS ^{14}C laboratory in Erlangen.

Results

All ice-wedge polygons were found on steep hillslopes (16° to 35°) with an aspect ranging from NE to NW. No polygons were found on hillslopes with southern aspect. The size of the ice-wedge networks varies from approximately 110 m in length and 15 m in width to approximately 130 m in length and 120 m in width (Tab. 1). The slopes showed no indications of mass movements like e.g. solifluction lobes.

Table 1. Aspect, inclination, length and width of 10 analyzed ice-wedge networks on hillslopes in the Umimmalissuaq valley.

Ice wedge network	Aspect	Inclination [°]	Length [m]	Width [m]
1	NNE	25	95	35
2	NNE	29	110	40
3	NNE	30	120	35
4	N	32	45	20
5	NE	27	110	15
6	N	26	35	30
7	NNE	21	65	15
8	NNW	20	30	10
9	N	28	130	120
10	NE	24	60	140

In the valley bottom high-centered polygons and intermediate-centered polygons were found. The high-centered polygons predominantly occur in mid-valley positions while intermediate-centered polygons were found next to toeslope positions with northern aspect. The troughs of the high-centered polygons have a depth of around 150 cm and a width of around 80 cm. Excavations in the high-centered and intermediate-centered polygons showed ice-wedge pseudomorphs at least in the upper 90 cm without reaching permafrost.

The vegetation on ice-wedge polygons consists mostly of *Betula nana*, hydrophilic plants like *Equisetum arvense*, *Ledum palustre* (syn. *Rhododendron tomentosum*) and different species of mosses. The coverage is between 85-100 %.

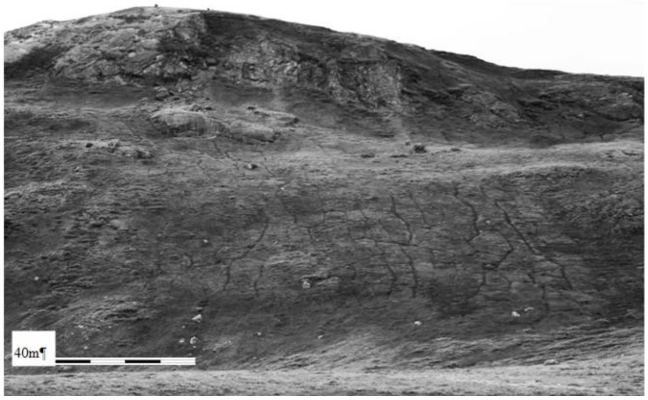

Figure 1. Ice-wedge network, aspect NNW; inclination ranges from 16° (upper slope) to 35° (middle to footslope).

Generally *Betula nana* grows along the lines of the bordering ice wedges while in center part of the polygons a mix of *Betula nana*, *Ledum palustre* and *Equisetum arvense* was found.

The topography of each ice-wedge network showed a concave mould on the upper part of the hillslope. In these moulds the beginning of the ice-wedge networks was found.

Conclusions

The analyses of ice-wedge polygons in the Umimmalissuaq valley show that particularly mesoclimatic conditions in the valley are responsible for ice wedge polygons on hillslopes with northern aspect. The warmer and dryer south-facing slopes are not underlain by permafrost in the upper meters. Therefore no ice wedges can be found there. These climatic differences can be also seen in different distribution of shrubs, grasses and herbs. Our main conclusions are:

(1) The concave moulds on the upper part of the hillslopes can be regarded as snow-traps. This leads to sufficient water supply for the downslope occurring polygons during spring time.

(2) The different size of the networks is mainly influenced by the morphological situation of the hillslopes and generally limited by the occurrence of unconsolidated sediments.

(3) The theory of anti-syngenetic ice-wedge formation after Mackay [*1995*] does not apply to the ice-wedge polygons in the study area. Mackay proposed a downward ice-wedge growth caused by contemporary removal by mass wasting. We propose that the ice-wedge polygons are mainly epigenetically formed including syngenetic processes.

(4) Well developed ice-wedge polygons on hillslopes indicate stable slopes with no or very few solifluction processes in the study area since maximal 6500 years.

(5) High-centered and intermediate-centered polygons in valley bottoms of the study area may indicate thawing permafrost or at least a thick active layer (> 2 m). Ice-wedge pseudomorphs indicate thawing processes.

(6) Dating of the base of the permafrost on hillslopes will give a minimum age of accumulation of organic material and therefore for carbon sequestration in permafrost. This dates will also yield more precise data for the deglacition history of the Umimmalissuaq valley.

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Thermal impacts of forest vegetation on frozen ground in the Da Xiang'anling Mountains in Northeast China

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Instructions

The vegetative cover, which is found at the boundary of the atmosphere and the lithosphere, participates actively in the heat exchange between them [*Tyrtikov 1959*]. It dampens the impact of changes in air temperatures and exerts an insulating effect on the soil thermal regimes [*Shur & Jorgenson 2007*]. Vegetation shields the soil from maximum penetration of heat by shading, by decreasing air circulation, by retaining moisture in and just above the soil, and by intercepting rain [*Benninghoff 1952*]. Meanwhile, vegetative cover decreases air current velocities within its stratum, and thus impedes heat radiation from the soil to the cold air [*Benninghoff 1952*], especially in permafrost areas [*Cannone & Guglielmin 2009*]. As vegetation is a dynamic factor, its influences on the ground thermal regime vary with time and space [*Brown 1963*]. In the Da Xiang'anling Mountains, Northeastern China, ground surfaces are generally characterized by extensive presence of forests, which significantly affect the temperatures of the underlying permafrost and soils in the active layer, and the freeze-thaw processes and formation and evolution of the Xing'an-Baikal permafrost.

Material and Methods

In order to study the thermal effects of vegetation on ground temperatures in the active layer and at shallow depths, seven representative sites were chosen. They include a *Ledum palustre var. dilatatum- Bryum- Larix gmelini* forest (A); a *Bryum- Larix gmelini* forest (B); a *Carex tato- Larix gmelini* forest (C); a *Betula Larix gmelini* forest (D) and in the experimental area at the China Forest Ecological Research Network (CFERN) Station near Gen'he on the west slope of the Da Xing'anling Mountains; grass-*Betula fruticosa* shrubs (E) in the backyard of 721 Launching Station in the outskirts of Gen'he city; a bare-ground site (F) outside of the Gen'he Meteorological Station and; a *Carex tato* swamp (G) in the nearby Yituli'he.

For each forest site, the ground temperatures were monitored by thermistors installed at various depths (0, 10, 20, 50, 80 and 160 cm) in each borehole. The data were recorded manually by multi-meter Fluke 189once a week at 10:00~12:00 on Saturday .

Results and Conclusions

Ground temperatures vary considerably due to the combined influences of constituents and densities of various vertical structures in the forests, vegetative coverage and albedo, water absorption and retention capabilities of plant roots and soils, and interception of snowfall by various vegetation types at these seven experimental sections. The main conclusions are as follows:

a) In spring, the thaw beginning dates are various in these sections due to differences in vegetative coverage in the permafrost area. With the highest water retention capability by plant roots system, the *Carex tato- Larix gmelini* forest was the latest in ground thawing and the slowest in the ground surface warming rate. In the talik area, the frozen soils usually thaw quickly, with a significant feature of bi-directional thawing (Fig. 1).

b) In summer, forest vegetation can shade portion of solar radiation from reaching ground surfaces, leading to a lower ground surface temperature in the forest in comparison with that of bare land. Statistical analyses show that the cooling effect of the *Carex tato- Larix gmelini* forest has the best shading effect in all types of forests under the same climate conditions, with the mean annual ground surface temperature 4.9°C lower than that of bare land. the cooling effect of *Betula Larix gmelini* forest, the *Carex tato* swamp, the *Ledum palustre var. dilatatum-Bryum- Larix gmelini* forest, the grass *Betula fruticosa* shrubs and the *Bryum- Larix gmelini* forest on the mean annual ground surface temperatures are 3.4, 3.4, 1.7, 1.5 and 0.6°C, respectively (Table 1).

c) In autumn, the temperatures of ground surface with various vegetation declines rapidly in the order of the *Bryum-Larix gmelini* forest with poor-grown larch and shrubs (Table 2); the *Betula Larix gmelini* forest which withered most rapidly; the *Carex tato* swamp (with cooling rate at the depth of 0.1 and 0.2 m almost equal to that of the *Bryum- Larix gmelini* forest due to lack of trees and shrubs), and; the *Carex tato-Larix gmelini* forest with the lowest cooling rate due to its highest water retention capability by plant roots system. In the meantime, seasonal freezing proceeds both downward and upward in the active layer in the permafrost areas. The freeze-up was completed rapidly, whereas it penetrates slowly downwards in in areas of seasonally frozen ground.

d) In winter, average soil temperatures under various vegetation types vary significantly due to the variable retention of snowfall. In general, the average winter ground surface temperatures decline in the order of barren land outside the meteorological station, *Carex tato-Larix gmelini, Ledum palustre var. dilatatum, Bryum-Larix gmelini, grass-Betula fruticosa* shrubs, *Betula Larix gmelini* forest, and *Carex tato* swamps (Fig. 2).

Table 1 Statistics of ground surface temperature and shading effect for each forest

No.	Forest type	Annual ground surface temperature (^{o}C)	Shading effect(^{o}C)
A	*Ledum palustre var. dilatatum -Bryum- Larix gmelini* forest	1.7	1.7
B	*Bryum- Larix gmelini* forest	2.8	0.6
C	*Carex tato- Larix gmelini* forest	-1.5	4.9
D	*Betula Larix gmelini* forest	0	3.4
E	grass *Betula fruticosa* shrubs	1.9	1.5
F	Bare ground	3.4	0
G	*Carex tato* swamp	0	3.4

Table 2 Ground surface temperature cooling rate for each forest during the late autumn

Depth *(m)*	*Ground surface temperature cooling rate(^{o}C/day)*						
	A	B	C	D	E	F	G
0	0.8	1.2	0.1	1.0	0.4	0.1	0.7
0.1	0.4	0.6	0.0	0.5	0.1	0.1	0.5
0.2	0.2	0.3	0.0	0.2	0.0	0.1	0.4
0.5	0.1	01	0.0	0.0	0.0	0.1	0.1
0.8	0.1	0.1	0.0	0.0	0.0	0.1	0.0

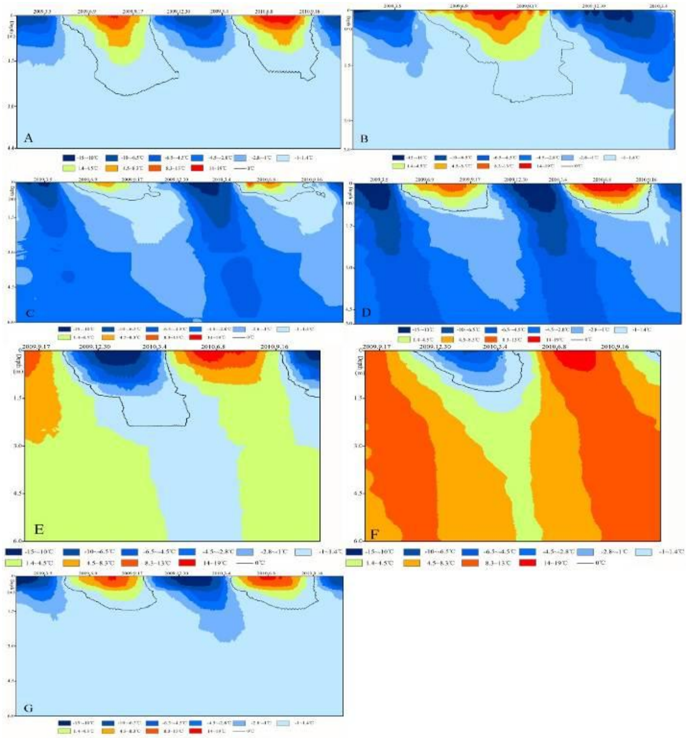

Fig. 1 Ground temperature distribution of different forest types in the Da Xiang'anling Mountains

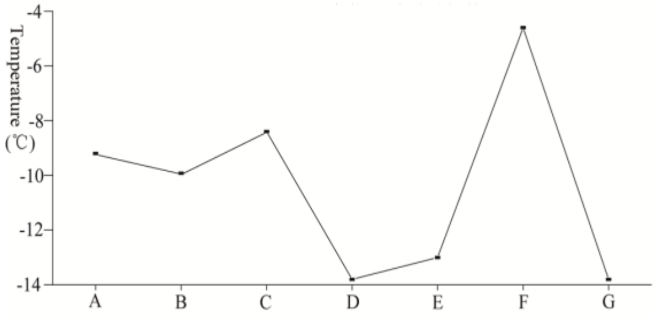

Fig. 2 Ground surface temperatures of each forest in winter in 2009

Acknowledgments

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Variations of Active Layer Thickness beneath Embankment along the Qinghai-Tibet Railway

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Construction of embankment along the Qinghai-Tibet Railway (QTR) in permafrost regions was completed in 2003. After embankment construction, active layer thickness (ALT) beneath embankment changed considerably.

A long-term monitoring system was installed along the QTR, ground temperature and embankment deformation were monitoring simultaneously at 44 monitoring stations within the 550 km permafrost regions. In the system, ground temperature were measured by thermistor strings installed in four boreholes, including natural ground borehole, right shoulder borehole, left shoulder borehole and central borehole, and data were collected by data logger (DT500) automatically on a daily basis (Figure 1). Based on the ground temperature, variations of ALT beneath embankment can be monitored in real time.

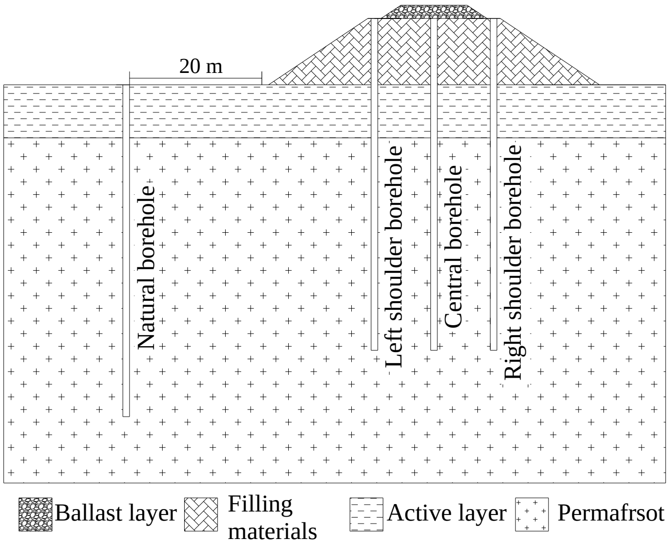

Figure 1. Ground temperature monitoring in the long-term monitoring system along the QTR

The monitoring results showed that beneath crushed rock embankment, an embankment structure applied extensively along the QTR, ALT decreased significantly after embankment construction due to cooling effect of crushed rock layers. In colder permafrost regions with mean annual ground temperature (MAGT) lower than -1.0 °C, upward movements of underlying permafrost table ranged from 1.8 m to 5.3 m with an average of 3 m. And consequently there was no active layer existing beneath most of these embankments. While in warm permafrost regions with MAGT > -1.0 °C, upward movements of underlying permafrost table were relatively slight, ranging from 1 m to 5.7 m and with an average of 2.7 m. Along the QTR, there were still some sections of railway in permafrost regions constructed by conventionally method with earthen materials. Monitoring results showed that ALT either decreased or increased beneath these embankments after construction. In regions with MAGT < -0.6~-0.7 °C, ALT decreased beneath embankment with sufficient height. Permafrost tables beneath these embankments rose 1.63 m or so on average. While in regions with MAGT > -0.6 °C, ALT increased and underlying permafrost table declined. But increases of these ALTs were not significant and most of them were smaller than 1 m up to 2011.

Variations of ALT beneath embankments above mainly occurred in first three years after embankment construction. And after then the primary factor that determines the ALT was air temperature. Figure 2 showed time series of depth of permafrost table beneath crushed rock embankment at some monitoring stations along the QTR, and from the figure the significant upward movement of permafrost table can be identified clearly. It should be noted that due to the orientation of the QTR, from northeast to southwest, ALTs beneath south-facing and north-facing slopes of embankment differed obviously. In cold permafrost regions, the maximum values of the differences were 0.9 m and 2.5 m for crushed rock embankment and earthen embankment. While in warm permafrost regions, the differences were more significant with maximum value reaching 3 m for two kinds of embankment. The differences could result in differential embankment deformations and hence, are detrimental to the embankment stability. Engineers had adopted some measures, such as inserting thermosyphons at south-facing slope toe or placing thicker crushed rock revetment on south-facing slope, to diminish those differences.

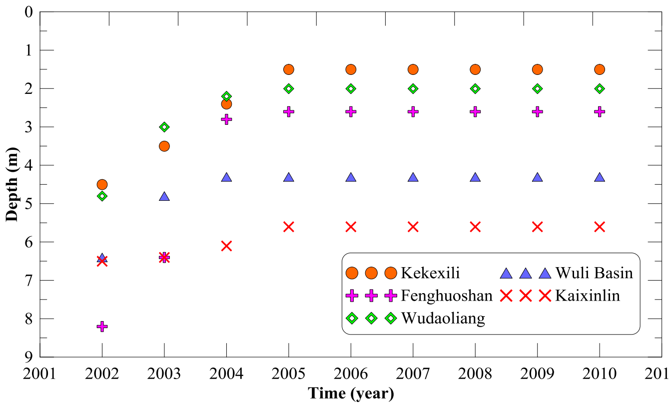

Figure 2. Time series of depth of permafrost table beneath crushed rock embankment at some monitoring stations along the QTR.

Increases of ALT beneath embankment give rise to thawing consolidation and consequently considerable embankment settlement. And embankment deformation along the QTR had indicated this settlement on earthen embankment. At present, engineers firstly placed more ballast layer on embankment surface to keep lines smooth. And then, crushed rock revetments or thermosyphons were applied on embankment to prevent further decline of underlying permafrost table and increase of ALT.

Acknowledgments

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Maps of Geocryological Zoning Arctic Regions of the Cryolithozone

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The beginning of industrial development of the northern regions of the cryolithozone that are rich with mineral resources caused an urgent need in the elaboration of the maps aimed to demonstrate the formation patterns and the existing status of geocryological conditions of the developed regions, as well as information on the presence and mode of occurrence of thick ground ice that is widely distributed in these regions.

As it is proved by ten-year map-development efforts of the authors, maps of geocryological zoning are most informative in terms of remote and practically undeveloped permafrost regions. The principles and methods of elaboration of such maps were developed by VSEGINGEO in the process of long-term engineering and geocryological investigations in the northern part of Western Siberia at the end of 20th century.

According to those investigations, geocryological zoning is based on the typification of the terrain by to the nature of heat and mass exchange between rocks and atmosphere as well as lithosphere. In this case, individual sections of various types, or multi-ordinal morphostructures, will be characterized by different components or complexes of geocryological conditions, along with different response of the geocryological environment to technogenic impacts. Separated parts of the territory characterized by similar conditions of heat and mass exchange (within the same geological structure and natural climatic subzone) demonstrate their geocryological and environmental-geological similarity [*Kritsuk & Dubrovin 2003, Kritsuk 2010*].

The developed method allows to typify the geocryological conditions and, depending on the map's scale, to identify permafrost types, groups or parts having a different stable complex of interval values of the cryolithozone parameters. Size and number of zoning elements show direct dependency on the zoning objectives and scale of the maps.

Terrain evidence of various morphostructures is the methodological basis for the use of the Earth remote sensing materials for zoning and mapping of the cryolithozone [*Dubrovin et al. 2011*].

The landscape indication maps used as a basis for geocryological zoning maps elaboration are compiled in the process of continuous interpretation of the orbital data with different spatial resolution (panchromatic and spectrozonal). The complex and individual landscape indicators of geocryological conditions identified in the process of comprehensive geocryological investigations allow to extrapolate the data of land works on to large territories.

The specific feature of the maps built under this method is the consideration of all the basic factors describing heat exchange between rocks and atmosphere as well as lithosphere that form the set of geocryological conditions of different areas and regions, including **natural-climate** (zonal), **geological-structural** (regional), and **landscape - geomorphological** (local) conditions, with regard to the scale of the maps.

The developed method was applied by the authors in the process of elaboration of multi-scale (from large-scale to general) maps covering various cryolithological areas of Western Siberia, the whole cryolithozone of Russia and the Kara Sea shelf, as well as the general map of Alaska and Canada.

One of the authors of the international circumarctic map compiled in 1991 by a team of scientists from different states initiated the idea to elaborate the above-mentioned general map of Alaska and Canada, in order to prove the universal character of the formation and spatial distribution of deposit-forming ground ice found in Western Siberia [*Kritsuk 2010*]. The Circumarctic map of permafrost and ice conditions published in 1997 was used as the basis for the elaboration of the geocryological zoning map of Alaska and Canada [*Heginbottom et al. 1993*]. That map provided the boundaries of geocryological zones (updated for the territory of Alaska using the larger-scale map [*Broun et al. 2008*]) that characterized the spatial distribution of permafrost, as well as the information on the distribution of natural ice (ground and surface).

The main difference between the map developed by us and the maps published before is the consideration of geological-structural and neotectonic peculiarities of the mapped regions. Their significance for the formation of components of geocryological conditions has been stated during the study of the Western Siberia cryolithozone [*Kritsuk 2010*].

Three orders of regions were identified based on the analysis of the published physical, tectonic and geomorphological maps (by means of GIS technologies) and on continuous interpretation of orbital images with different resolution (Google Earth). These regions are represented by multi-ordinal morphostructures and differ in geological and hydrogeological conditions as well as in the set of geocryological conditions.

1st-order regions are tectonic structures shown in the tectonic map of the North America [*Tectonic maps of the continents 1967*], while 2nd-order regions are large morphostructures taken from the Geomorphological map of America, scale 1:30 000 000 (The Physical and Geographical World Atlas 1964). 1st- and 2nd-order regions are separated by the boundaries with corresponding indices, and 3rd-order regions represented by the latest morphostructures, which differ by relief elevations, are shown with the use of the basic decorative mean, i.e. color. Then the fault zones were shown by red color based on the general map of scale 1:45 000 000, and large circular and linear neotectonic morphostructures were identified based on the interpretation of orbital images. According to the view of the authors, thick macro-glacial bodies formed due to irregular freezing of underground water in different horizons and complexes may exist within these morphostructures [*Kritsuk 2010*]. It is typical that ground ice accumulations in the north of Alaska and Canada shown in the Circumarctic map of permafrost and ice condition are confined to fault zones.

Interpretation of orbital images allowed to make conclusions on special feature ground ice distribution in Alaska and Canada.

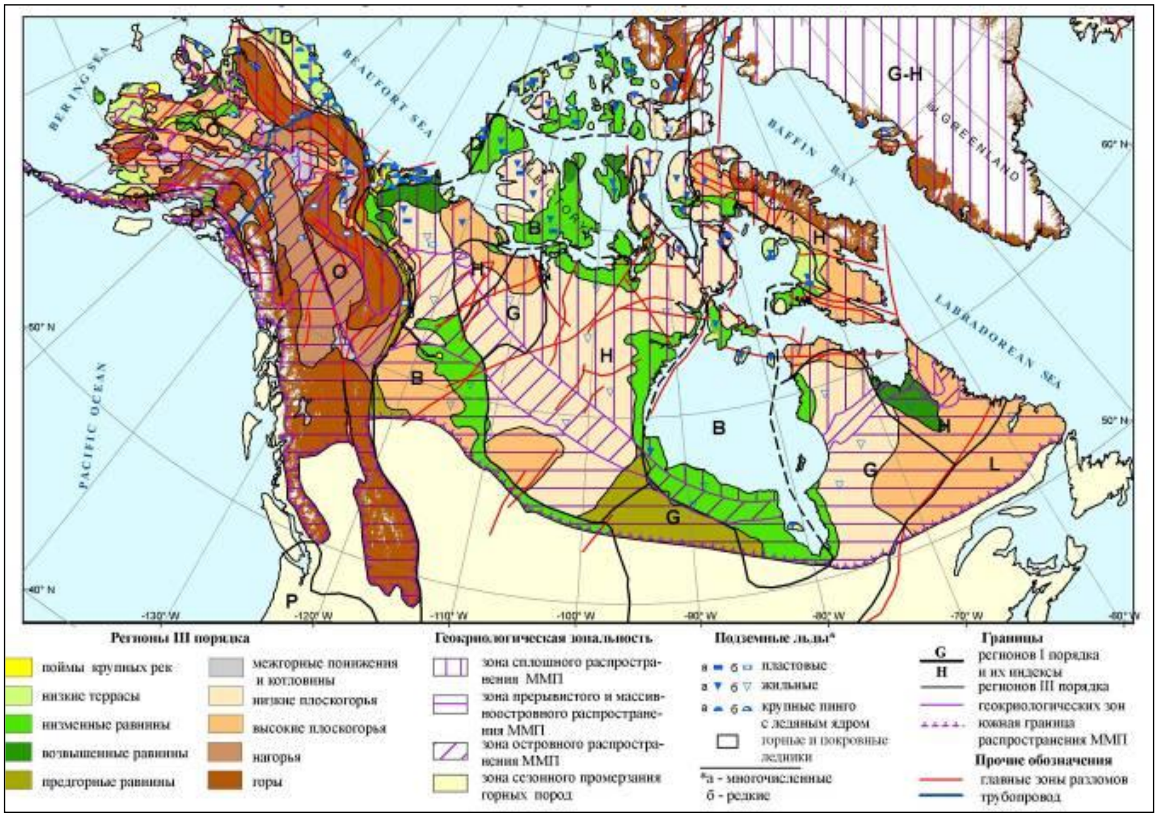

Figure 1. Maket map of geocryological zoning cryolithozone of Alaska and Canada 1:10 000

Permafrost distribution zones: 1 – continuous; 2 - discontinuous; 3 – island; 4 – southern boundary of permafrost distribution.

Here, like in Russia, ground ice distribution is characterized by its confinement to tectonically active Earth's crust sections connected with the zones of deep faults revived in the Cenozoic Era. Thick ground ice exposures are observed on the sea coasts, lakesides and in the river valleys (where they are currently breaking up or existed in the past), and on the sites with large loop-shaped meanders that cut the steep banks. Numerous pingos of Canada, which were studied by J.Ross Mackay in 1970-1980's, are genetically connected with the ancient lake beds of the expressed tectonic origin. This is proved by their elongated shape and linear orientation towards the main fault lines. Drainage of these lakes causes the formation of polygonal (patterned) concentric morphostructures in their beds. These morphostructures comprise ice wedges that are paragenetically associated with ice pingos. Similar polygonal structures are widely developed in the river valleys in the northern part of Alaska, where they are confined to modern or ancient blown-down lakes (alases) on floodplains and low terraces.

The constructioned map, unlike the «Circumarctic map of permafrost and ice condition», allows to make conclusions on peculiarities of geological, hydrogeological and geocryological conditions and their differentiation through the whole permafrost thickness down to permafrost bottom, to extrapolate the data on permafrost temperatures and thicknesses on to the areas with similar conditions of heat exchange between the rocks and atmosphere and lithosphere. As for the analysis of fault tectonics, it allows to estimate the probable presence of thick ground ice. In addition, this map may serve as the basis for the construction of large-scale maps based on interpretation of orbital images with high spatial resolution. The authors of this paper have published a similar study on construction of the maps of geocryological zoning of the Bovanenkovo – Baydaratskaya Guba gas pipeline with scale 1:10 000 [*2011*].

Maps geocryological zoning construction under the developed method are easily readable, since they are not overweighed with actual data that are represented in tabular legends.

Compared to other types of maps, digital maps geocryological zoning compiled under this method are most preferable in terms of comprehensive assessment of the cryolithozone status, the development of geocryological estimate scenarios, and the representation of estimate variations.

The representation of the basic regularities of the formation of geocryological conditions on the small- and medium-scale maps geocryological zoning helps to assess peculiarity geocrylogical conditions of large areas, to predict their changes caused by industrial development, to choose optimal sites in terms of stability of the geological environment and the designed structures, and to plan environment-protection activities.

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Sensitivity of Thermal Parameters Affecting a Cold-Region Ground Temperature Prediction Model

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Abstract

This study formulates a heat-flux upper boundary to model ground temperatures in the Qinghai-Tibet Plateau. This model considers the impacts of the environmental conditions, e.g., air temperature, ground-surface albedo, wind speed, and solar radiation on the ground-surface heat flux and on subsequent subsurface temperature profiles. It discusses why in the Qinghai-Tibet Plateau, neglecting the evaporation-induced heat flux does not compromise the ground-temperature predictions. The model is validated by uses of both climatic data and stratum information of a typical section along the Qinghai-Tibet Railway corridor to simulate the ground temperatures, and to compare these temperatures to the observed ground temperatures. These observed ground temperatures are also compared with the temperatures predicted by a model using a temperature-controlled upper boundary. The observed temperatures, along with climatic data and stratum information of this typical section, are utilized to conduct the sensitivity of ground temperatures to the environmental conditions. The subsequent discussion describes effects of the evolution of the ground-surface albedo on the redistribution of the ground temperatures.

Permafrost Soil Water Content Evaluation using High-Frequency Ground-penetrating Radar in Amdo Catchment, the Middle of Tibetan Plateau

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Ground-penetrating radar (GPR) is a convenient noninvasive technique that can monitor subsurface structure and soil-water content in permafrost regions. An excellent introduction to GPR in hydrological applications is available in Davis and Annan [*1989*]. In this paper, we present a fast ground-penetrating radar measurement technique to evaluate soil permittivity and permafrost soil moisture in each site. The GPR Measurement were carried out at one line and thirty-four points in October 2011, all located in Amdo catchment (Fig. 1) (91°37′E, 32°14′N, about 4700m above sea level), which lies in the middle of Tibetan Plateau and distributes plenty of permafrost. Furthermore, the multiple measurements at several sites were not made on the same day. Some authors perform several common-offset measurements over the same line with different antenna separations and subsume them to a large set of CMP gathers [*Fisher et al.1992; Bradford 2006*].

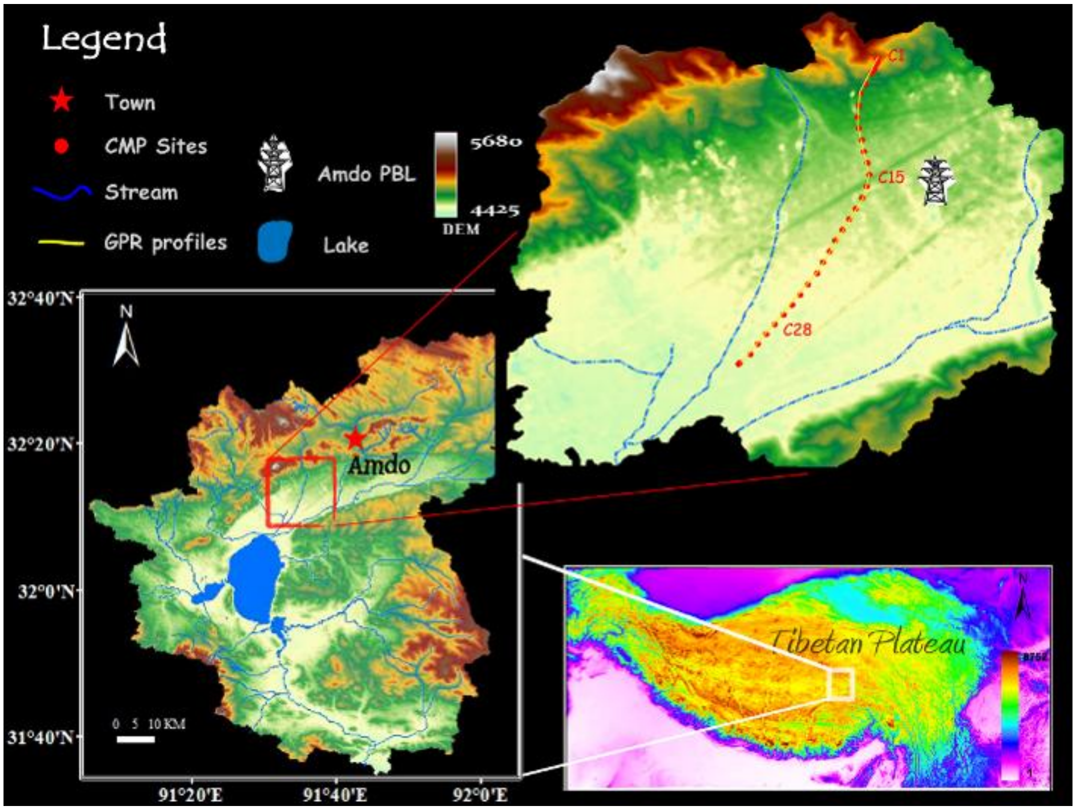

Fig.1: The sketch map of the research area

In this survey, reflection travel times and common-mid point (CMP) GPR measurement were used together along the whole survey, which travelled from the top of a mountain to a seasonal stream. Besides, the journey was separated into two parts: one was from the peak to bottom of hill, and the other from the bottom to the stream direction, where topographic factors were mainly taken into consideration. In each point, different kinds of subsurface structure can be detected and permafrost soil-water content will be interpolated in different active layer depths. By mathematical analysis, there is a certain correlation between soil-water content and depth in the permafrost active layer. In all, noninvasive estimates of reflector depth can be gained from common-midpoint (CMP) GPR surveys that provide local information (e.g. soil moisture) on the permafrost regions. Interval travel-times from reflection profiles were then converted to wave velocity by estimating the interval thickness and a volumetric permafrost soil water content estimation using an appropriate petrophysical relationship. Besides, time domain reflectionmetry probes which were installed at six levels (from 4 to 258cm below the ground surface) for measuring soil moisture could be used to interpret and validate the GPR data.

In all, permafrost soil water content would be indentified from GPR survey, which is an interesting measurement technique for hydrological application at an intermediate scale in between point and remote sensing measurements. We hope that this thesis will further encourage the community to consider high-frequency ground penetrating radar as one of the possible tools to evaluate permafrost soil moisture.

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Comparison of Long-Term Equivalent Clayey Silt Cohesion by Two Forecasting Equations

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Frozen grounds are grounds with rheological properties manifested as creep, stress relaxation and strength reduction over time.

This work is devoted to determination of long-term strength by ball stamp method developed by N.A. Tsytovich and S.S. Vyalov and widely used in practice. It consists in applying steady load P to a stamp and determination of the depth of its penetration into ground after time period t. Based on the settlement of ball stamp S_t , the equivalent cohesion C_{eqt} in time is determined.

$$C_{eqt} = \frac{0.18P}{\pi d S_t} \text{, where d–stamp diameter} \qquad (1)$$

5 samples of clayey silt with different density and moisture content were tested at the temperature of -1 and -4 °C. The obtained dependencies of the equivalent cohesion on physical properties and temperature of ground showed that equivalent cohesion decreases, when ice content grows and density decreases. The temperature drop caused an increase in the strength, which is connected with the decrease of unfrozen water content.

On the basis of testing data, a prediction of the equivalent cohesion C_{eq30} was made for the period of 30 years, using equations (2) of S.S. Vyalov and (3) Wu, Zhang, Zhu.

$$C_{eq30} = \frac{\beta}{\ln \frac{t+t^*}{B}} \qquad (2)$$

$$C_{eq30} = \frac{C_H}{\left(\frac{t}{t_H}\right)^{\beta_\theta}} \qquad (3)$$

where t*- unit time; β and B - test parameters (Fig. 1); β_θ – test parameter; C_H, $t_н$ – equivalent cohesion for the initial test period $t_н$ (Fig. 2).

On the basis of obtained predicted values C_{eq30}, resistance R to normal pressure was also calculated. The results of calculations are given in the Table 1.

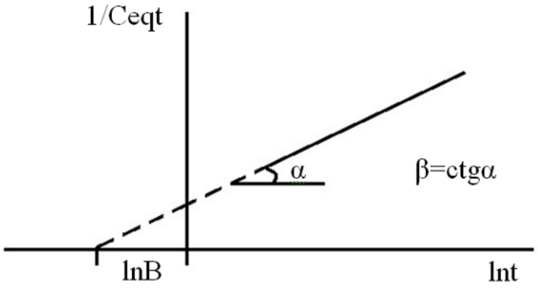

Figure 1. Graph for determination of parameters of equation (2)

Comparison of the results of both equations showed that the logarithmic equation of S.S. Vyalov gives a higher value of long-term equivalent cohesion, as compared with the polynomial equation of Wu, Zhang, Zhu. This points out the necessity of careful selection of forecasting equations of long-term strength on the basis of test data.

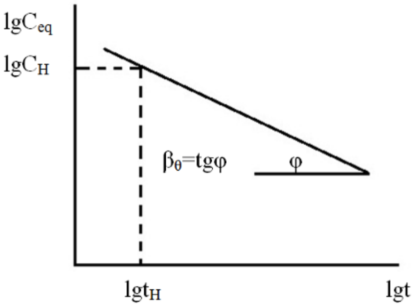

Figure 2. Graph for determination of parameters of equation (3)

$$R=5.7C_{eqt} \qquad (4)$$

Table 1

Sample No..	Characteristics of clayey silt, alluvium of Pleistocene age	According to the equation of S.S. Vyalov (above) Wu, Zhang, Zhu (lower)			
		C_{eq30}, MPa		R, MPa	
		-1°C	-4°C	-1°C	-4°C
1	ρ=1.87г/см³,	-	0.098	-	0.556
	W=30.6%	0.013	0.049	0.074	0.279
2	ρ=1.89г/см³,	-	0.092	-	0.523
	W=29.0%	0.024	0.045	0.137	0.257
3	ρ=1.67г/см³,	-	0.049	-	0.278
	W=36.6%	0.025	0.044	0.143	0.251
4	ρ=1.94г/см³,	0.041	0.060	0.233	0.342
	W=18.2%	0.003	0.040	0.017	0.226
5	ρ=1.92г/см³,	-	0.079	-	0.453
	W=26.5%	0.026	0.026	0.148	0.148

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The Time Factor in the Assessment of Risks Connected with the Infrastructure Modeling in Permafrost Zones.

A.V.Zakirov

As complicated and often unique complexes appear as research objects the study of which presupposes the joint work of different specialists, the modern synthesis of the achievements made in various sciences is going on under the conditions when large complex programs and problem-oriented interdisciplinary investigations start to play more and more significant role in scientific cognition. This gave a strong stimulus for the development of new approaches to modeling.

The investigation experience from University of Colorado (the USA) can serve as one and a very effective modeling example. Pursuing the goal to identify the increase of the sea level resulting from the melting of glaciers, the scientists carried out a comprehensive analysis of satellite data that is the first in its kind. They used the results of the measurements made within the framework of the American-German Gravity Recovery and Climate Experiment (GRACE) in 2003–2010. The following conclusions were drawn:

for the indicated period the glaciers and the ice caps lost about 4.3 trillion tons of their mass and gave approximately 12 mm to the World Ocean;

about a quarter of the mean annual loss of the ice is related to the glaciers and the ice caps outside the limits of Greenland and Antarctica (about 148 billion tons);

the ice decrease in Greenland and Antarctica as well as at their periphery makes up on average 385 billion tons per year.

It is not a secret that more multitask experiments are carried out as well as all kinds of prognoses are made that focus on the investigation of the future relief of the Earth. Such tasks are also of current interest in Russia. The science of our country is interested in the issues that concern the changes in the tundra, arctic and subarctic zones located within the cryolithozone. There is no doubt that the conclusions drawn by scientists will affect the further strategic planning of the infrastructure and the mode of life. However, there are a great number of details here that determine the view itself on the problem. It is this view that will define the further development of a strategy.

It may be assumed that "the providers" of super-tasks important for the entire 21st century are not chemistry, physics, biology and ecology but psychology and history. Firstly, this is due to the fact that the depth of understanding in these two spheres directly determines to what extent a prognosis of the humankind development will be reliable and reasonable. This prognosis exerts an influence on the change of the development strategy of our civilization, on what changes the humankind can and must accept and, certainly, on many specific decisions. Secondly, we deal with complex, irreversibly developing and often unique systems in these spheres. Such systems challenge the traditional methodology accepted in natural science and require a deep comprehension as well as the use of the analysis experience that is available in humanities. Thirdly, the processes investigated by history and psychology have a deceptive "transparency" because we ourselves represent a part of the system under study. It makes it necessary to utilize a peculiar approach that allows us to mistrust the "obvious" things. The search for new approaches is linked with the change in the concepts of the essence of the objective reality in which the motives of human behavior are formed.

The rapid change in technologies and values that greatly influence the taking of strategic decisions in the modern world leads to the conceptual shifts of historical and temporal scale where the correlation is very strong. Despite the fact that the analysis of historical events acts as a peculiar ground enabling the practice of various methods for analysis, computer modeling and prediction, we are dealing with the system in which the possibilities of modeling and the probability of a prognosis represent only the tip of the iceberg. We cannot give full and "long-term" prognoses even of simple mechanisms because the system of the world presupposes the construction of numerous models and the interactions between different systems (mechanical, chemical, biological, social, ecological etc.) under various conditions. The most prospective approach to the research into the indicated problem is the hermeneutic-phenomenological approach.

From these points of view, the central problem for all the disciplines is "the problem of time". It is very important here to take into account the point that the historical development is found in the conditions which scientists call "time reduction". A great number of futurological and even utopian projects are implemented in shorter periods of time than in prognoses and models themselves. There arose a necessity to coordinate all possible approaches for preserving a unified picture of the dynamic perception of the world.

An interesting point of view on this problem belongs to the American philosopher, futurologist and sociologist A. Toffler. According to this point of view, "the acceleration of the pace of life no longer fits into the framework of normal human existence; its pressure shakes all the social institutions of a society" and, as a result, the lifestyle of a human being. The acceleration of the changes in our time is itself a spontaneous force. This force has personal and psychological as well as sociological consequences. The most important property of the indicated force can be the susceptibility to the initial factors performing the role of a trigger when insignificant causes lead to the consequences having the global and universal scale. The major questions arising before us are: are these consequences unforeseen and is there a possibility of avoiding them or taking advantage of them? Such a phenomenon is called the butterfly effect. This is due to the fact that a slight flap of a butterfly that signifies nothing at first sight can eventually induce a storm in an unstable system, change the weather in a large region and lead to catastrophic consequences.

We can only outline the expected horizon that is found in a constant motion. The direction of the motion is chosen by a human himself, a group of people, based on the structure that restricts the actions of a person. A structure dynamically develops and is very elastic, which becomes possible with the help of many different combinations created by a human.

"The realization of the time and the future that consists in a brave combination of a human will and prophecy transitioned into the philosophy of progress" This, in its turn, gives an impetus to the development of science.

The society became such a developed and complex system in the course of historical development that the role of a prognosis came to be more required than ever before despite all the complexity of forecasting. "Now the progress opens the future exceeding the natural space of time and experience that is covered by a prognosis. The future that provokes the dynamics and the geometric progression to new trans-natural and long-term prognoses. The future of this progress is characterized by two points: on the one hand, by the acceleration with which it approaches us and, on the other hand, by its uncertainty. As the accelerated time, i.e. our history, reduces the experience space, it deprives it of permanency and introduces new unknown elements into the play again and again in the way that even the present time loses the recognizable view due to the complexity of these unknown values. In order to withstand the challenges of the time, the scientific thought of the 21st century has to introduce new unknown values.

This was keenly felt by the representatives of natural sciences and, first of all, by those who engage in mathematic modeling because it is necessary here to deal with a wide range of problems: from the problems of strategic stability and the projects of economic reforms to specific physical processes or technical constructions. Now these problems are most required in ecology and, first of all, when it comes to all sorts of climate consequences. The euphoria connected with the possibilities of modern computers and computing experiment gave place to the understanding of the limitation in the possibilities of obtaining the answers with the help of a computer and our abilities to pose fundamental questions. Giving an explanation to the principles of the universal evolutionism, N.N. Moiseev expressed it approximately in the following way: "When we realized that the direct imitation of many processes is simply impossible, there arose a necessity in new notions and concepts" The humankind found themselves in the situation when they lacked imagination for the application of modern computer models.

Thus, we can see how the role of a prognosis increases in the contemporary philosophy and science. Normally, the time is used as the main factor of an argument in scientific and technical, as well as economic prediction. It is quite obvious that the values of a predicted indicator are determined not by the course of time but by the action of numerous factors influencing it. However, each moment of time is represented by certain characteristics of all these factorial signs that eventually change to a various degree. The time may be regarded as an integral indicator of the overall effect exerted by all factorial signs.

"Experience" and "expectation" are constantly exposed to shifts and changes in time. The tension arising between them "provokes" different variants of new solutions and actions, establishing the framework of the historical time. According to Koselleck, this can clearly be seen in the example of a prognosis. The probabilistic content of a prognosis does not provide a basis for the fact that somebody expects something. One can expect something that is absolutely unbelievable. At the same time, the probabilistic recreation of variants of the future that could take place represents the only means that makes it possible to disclose the reasons and establish their hierarchy in the history. The imagination for which the article persistently appeals is not a pure fantasy. It is true that the unreal constructions created by imagination are certainly a fiction but they have nothing to do with nonsense or a dream. They are based on reality and fit into the facts reconstructed by a historian. The probability of a predicted future is inferred from the premises of the past enriched by experience. A prognosis includes this experience the "space" of which forms a certain "horizon of expectations". As Koselleck expresses himself: "Experience frees a prognosis and manipulates it". Because it is only on the basis of experience that a human can speak of such processes as an ice age and extrapolate them from the past into the future.

Whatever happens in the past, it really affects the people of the present. Events take place because their potencies occur in close connection with their preconditions. This excess of possibilities must be processed so that it could be implemented "in some time". For this reason, there must occur situations that enable the accumulation of certain potencies which can be implemented in a certain time and space. Crises, conflicts and turning points may take place in this horizon. And this poses a question about the ability of humans to adaptation: how will they live in this new society? Can they adapt to its imperatives? And if not, can they change these imperatives?

Is it possible to register the acceleration of changes? Because there is no absolute way to measure changes. In the frightening complexity of the Universe, even within the framework of any given society practically an endless number of change flows is ongoing simultaneously. All the "things" – from a tiny virus to a vast galaxy – are not at all things but processes. There is no static point and there is no nirvana-like invariability relative to which it is possible to measure a transformation. Therefore, a change is relative.

In conclusion, it may be said that a development strategy will depend on the certainty of further processes and the time of their occurrence. Because if a prognosis is made that the territory of modern Magadan Oblast of the Russian Federation will in some time turn into the modern Alps, then it will be quite reasonable to expect a change in the strategy connected with the development of this region and not the other regions that may appear to be in poorer conditions. However, the key question is when it will happen.

New CALM plots at the limits of Permafrost Zone in Russia

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Introduction

Since the ninth international conference on permafrost the active layer thickness was extensively monitored in the framework of an integrative ecosystem studies and the new Circumpolar Active Layer Monitoring (CALM) sites were set up. They located at the westernmost and easternmost limits of permafrost zone in Russia. This paper is devoted to the short description of the new sites, how could they be compared to analogous sites, and the purpose of their organization.

Study sites

The sites R27-Lavrentia, and R23-Talnik are well-studied [*Zamolodchikov et al. 2004; Mazhitova et al. 2004*], and there is no need to provide their description as it is presented at the CALM site.

R41-Lorino

Lorino (N 65.5397°, W 171.6302°) entered the list of CALM sites in 2011, after the second year of observations. This 100x100 m plot is located just 28 km from R27-Lavrentia site. Thus the closest weather station is the same to that is used for Lavrentia WMO 25399 Mys Uelen situated 108 km north-west. Lorino site lies south of the Genkanyi (Tenianyi) Ridge (up to 907 m high) within the Second Marine terrace of Middle Pleistocene constituted with sand and covered with peatland. This 40-50 m a.s.l. plain is typical for Bering seashores of Chukotka. R27-Lavrentia thus lies on a higher level of about 100 m, at another side of the ridge, and is underlain with moraine loams as a substrate. All this facts reflected in vegetation structure, with grasses and moss-lichen dominating Lavrentia site, and shrub-dwarf-shrubs with mosses and lichens at Lorino site. Active layer thickness (ALT) in Lorino predominantly lies in the range of 0.3-0.5 m (0.47±0.12 in 2010, and 0.47±0.10 in 2011), with about 25% of deeper waterlogged localities (up to maximum of 0.85-0.89 m). ALT in Lavrentia is 1.4-1.6 times higher.

Umbozero

Umbozero (N 67.7724°, E 34.1820°) CALM 100x100 plot was established in 2011, and did not listed among the CALM sites yet. Located in the center of Kola Peninsula this is the westernmost CALM site in Russia. It lies within the area of sporadic permafrost in northern taiga at the second lacustrine terrace on the western shore of Umbozero Lake constituted with peat up to 2.5 m thick underlain by coarse sands [*Olyunina et al. 2008*]. The nearest weather station WMO 22127 Lovozero is 47 km northwest of the site at the fluvilacustrine plain surrounding the rising Khibins massif same to the site location. The site represents peatland, waterlogged in 7% of the nods. It mainly covered with shrub-dwarf-shrub lichen vegetation. The open forest grows at the 27% of the site area. Permafrost is found in peatlands at depths 1.4-1.7 m (1.45±0,48 m). The lowest ALT (0.3-0.9 m) is usually found at the 13% of nods located the highest. About 27% of nods have the ALT above the measurable with 2 m probe with none topography or vegetation reflecting this.

Comparing this site to the other located at the southern limit of permafrost R23-Talnik (closest weather station Vorkuta) showed this is the warmest permafrost observed with the 100x100 m grid probing method. To compare, the 1973-2002 mean annual air temperature in Lovozero was -1.4°C, and currently it is -0.9°C. Vorkuta is much colder site with its -5.7 in 1973-2002 and -5.3 currently. Summer air temperature (11.2 to 11.2°C in Lovozero, and 10.2 to 10.4°C in Vorkuta for the same periods) does not increase as much as winters. However positive tendencies are observed for the length of thawing period (166 to 176 days in Lovozero, and 126 to 133 days in Vorkuta).

The observed warming takes place mostly in winter. Insufficient winter cooling results in the fact that anchored, non-anchored permafrost and probably seasonally frozen soils are represented at one site at the southern limit of permafrost zone, as shown at Figure.

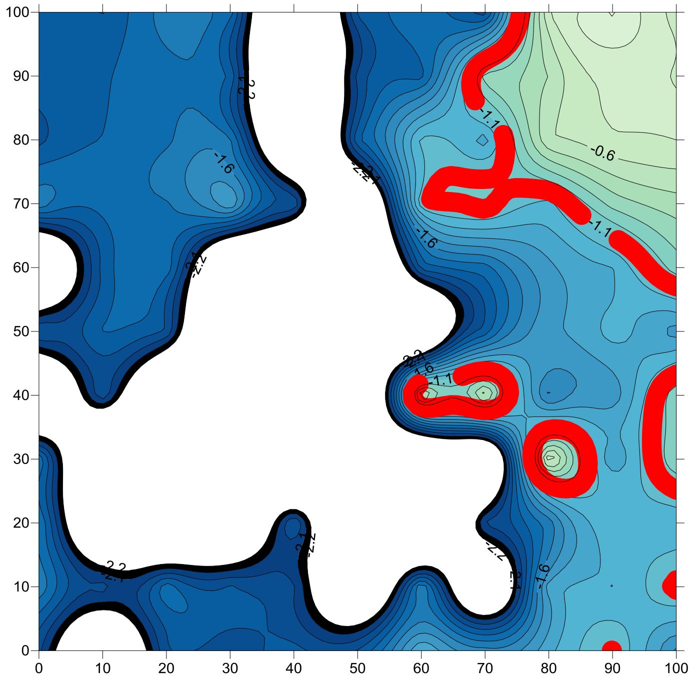

Figure. Permafrost at Umbozero Site: ALT (contours, fill), anchored permafrost (red contours), non-anchored permafrost at depth more than 2 m or seasonally-freezing soils (white).

The overview of the ALT registered at start year of observations and in 2011 on discussed CALM sites is presented in the Table. Cited above clear trends to warming in Western sites can lead to suggestion that ALT on Umbozero site has increased in last decade. Strong thaw depth increase was found on other CALM sites at European Russia Arctic [*Mazhitova et al., 2008*]. Eastern sites do not demonstrate so strong trends to increase the ALT. The difference between Western and Eastern sites is explained by regional climate trends as well as initial permafrost conditions.

Table. Maximal annual ALT on 4 CALM sites in western and eastern parts of the Russian Arctic

CALM site	Start year	End-of-season thaw depth, cm	
		start year	2011
R23 Talnik	1998	89.3	143.7
R27 Lavrentia	2000	58.8	64.8
R41 Lorino	2010	47.3	46.8
Umbozero	2011	144.8	144.8

Prospects

High ALT at the southern limits of permafrost zone often exceeds the probe's length, with increasing amount of nods with unknown ALT in case of permafrost degradation. The 3 m screwed or locked probe is proposed especially for the peaty and sandy soils of Umbozero site. Another way to solve the problem is to set up the thermometric borehole in the places of deep thawing, and interpolate ALT.

Topographic survey is to be conducted at all sites. R27-Lavrentia, and R23-Talnik are already measured in early 2000s. Repeating it is believed to evidence any surface changes at the sites due to ground ice melting and long-term subsidence. This especially is a must for R27-Lavrentia site due to visually observable deformations of the grid lines as a result of slope processes and growing temperature of permafrost, containing ice sheets. Measuring elevations at other sites is needed for digital elevation models of the sites to be used in various studies.

Usually at all sites the vegetation projective cover and productivity are studied to better understand the effect of changing climate on tundra and north taiga ecosystems (see Pochikalov et al. in this book). Thus, the CALM sites play the key role in organization of stationery long-term studies.

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The Life Time of the Supercooled Water in the Water-Saturated Montmorillonite

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Abstract

Within the temperature interval of (-8, -3) °C, there were experimentally determined latency periods before the beginning of spontaneous crystallization of the supercooled water in montmorillonite clay with the moisture content of 340%. Hystograms of the distribution of the experiments number according to the latency periods before the beginning of water crystallization were constructed for a series of identical samples. There were determined average values of life times of the supercooled state of water in the samples of montmorillonite clay.

Keywords: montmorillonite; nucleation; phase transition; supercooling; unfrozen water.

Introduction

Evaluating strength and thermophysical properties of frozen grounds, it is necessary to take into account that they contain unfrozen water. The quantity of this water can vary even under unchanged external conditions [*Ershov & Akimov 1979*]. It was determined that the equilibrium content of unfrozen water $W_{unfr}(T)$ is not established immediately after the sample temperature becomes equal to the environment temperature but after some time [*Chistotinov 1973*]. Due to a number of reasons [*Grechishchev et al. 1980*], the time of establishment of the equilibrium phase composition of water in isothermic conditions varies within a wide range and depends on moisture content, dispersion and the chemical-mineral composition of the environment [*Nesterov et al. 1984*].

To correctly determine the $W_{unfr}(T)$ value and to give proof to the similarity criteria during establishment of the correspondence between the results of laboratory and field measurements of frozen grounds' parameters, it is important to obtain information about the characteristic times of the processes that determine the mechanism of establishment of the equilibrium content of unfrozen water.

Forecasting a high probability of a long-term existence of metastable water in grounds with a high moisture content under slight supercoolings, which in the end predetermines their frost heaving, we used water-saturated samples of montmorillonite clay as the object of research of pre-nucleation phenomena in finely dispersed environments.

The materials and methodology of experiments

Clay samples with the required moisture content were prepared at the room temperature by a thorough mixing of dry dust-like montmorillonite powder with water until a plastic mass of a homogeneous consistency was obtained in the process of adding of the required amount of water by small portions. To finish the swelling process of the clay and to reach the regular distribution of water across its entire volume, we placed the clay into a desiccator and kept it over the water bath for several hours.

Before the beginning of the experiment, aluminium weighing bottles with the radius of 10 mm were filled with the prepared clayey mass. The fill level did not exceed 20 mm. After that, a hot junction of a differential thermocouple was installed at the center of the study sample and the weighing bottles were thoroughly sealed. After a weighing bottle with a clay sample was placed into a thermostat with the given negative temperature (Fig. 1), the sample temperature and the current experiment time were automatically registered.

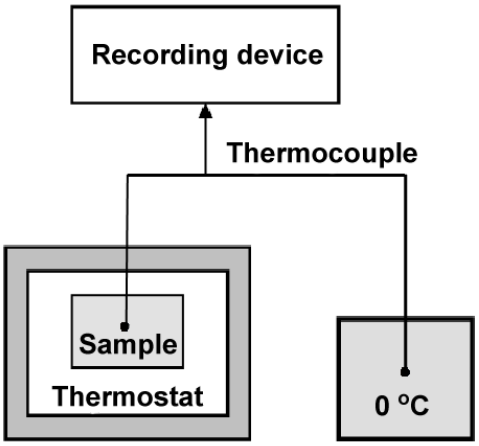

Figure 1. The flow chart of the experimental apparatus that determines the life time of the supercooled ground water in isothermal conditions.

In the process of the sample temperature decrease, the initial moment of the establishment of isothermal conditions in the sample was registered. Later, the stable thermocouple readings within the measurement error of ± 0,1 °C were observed. The experiment was finished after a characteristic temperature jump as a result of spontaneous crystallization of the main volume of supercooled water in the clay was confidently registered. During the life time of the water metastable state (the latency period before crystallization beginning), the time interval from the thermostabilization moment of the sample to the beginning of water crystallization was assumed in the area of negative temperatures.

The prepared samples' moisture content was precisely determined after the experiment according to the requirements of State Standard 5180-84.

Research results

As a result of the research, we obtained a set of data on the life time of the supercooled state of water τ_l in montmorillonite clay samples with the moisture content of 340±5% in the temperature interval of (-8 , -3) °C.

The randomness of the registered crystallization acts in the end led to a noticeable time variation of τ_l in the equivalent samples ensemble. To interpret the obtained results, a statistical analysis of the set of data on τ_l.was carried out. For this purpose, we counted the number of experiments N_i that fit the *i* interval of water crystallization latency periods in the samples. Based on the results of sorting of the crystallization acts, we constructed the histograms of experiments distribution over the corresponding periods of life time of the supercooled state of water. Meanwhile, we considered only the experiments in which isothermic conditions were invariably realized before the beginning of spontaneous crystallization of water.

The histogram of distribution of water crystallization acts presented in Figure 2 reflects the probabilistic nature of the heterogeneous nucleation of ice in a water-saturated montmorillonite under the environment temperature of - 3 °C. In this case, with the total number of experiments (equaling 49) considered for analysis, the average latency period before the crystallization beginning is 2.8 hours.

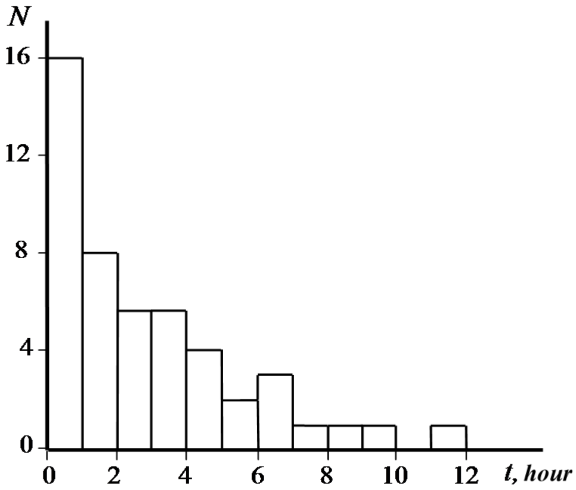

Figure 2. The histogram of experiments distribution over the latency periods before the beginning of spontaneous crystallization of pore moisture in the montmorillonite clay samples with the moisture content of 340% under the temperature of – 3 °C.

In the course of analysis of all the histograms constructed on the experimental data, we discovered a trend towards the decrease in the average latency period before the beginning of water crystallization under isothermal conditions with the lowering of the sample temperature. This indicates the increase in the heterogeneous centers activity in the formation process of sustainable ice embryos [*Skripov & Koverda 1984*]. This trend corresponds to the results of the research [*Grechishchhev et al. 2004*] in which similar change patterns of τ_l were observed when moist clayey silts and sands were supercooled in the area of negative temperatures.

We suppose that the possibility of existence of the supercooled water state for more than 10 hours (the possibility does not equal zero) can lead to the corresponding long-term changes of phase composition of water in the samples of clayey minerals with a high moisture content [*Ershov & Akimov 1979*]. There are grounds for assuming [*Vlasov et al. 2011*] that these changes will be most noticeable in the samples with heterogeneous moisture content.

Further, we plan to conduct systematic NMR studies of unbalanced crystallization of water in the montmorillonite clay within a wider range of temperatures and moisture contents.

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On the Prospects of Improvement of Coiled Tubing Equipment and Technology for the Far North Conditions

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Abstract

The necessity of using coiled tubing equipment and technology in conditions of the Far North with the occurrence of frozen grounds in well logs is proved in this work. The ways of improvement of coil tubing units aimed at the increase in their life cycle are described. The results of experimental work dealing with the improvement of corrosion and wear resistance of the surface of injector parts with the use of ion-implantation nanotechnology are presented. The prospects of application of the "flexible pipes" technology in field development of the shelf and in arctic seas under difficult ice conditions are also discussed.

Keywords: coiled tubing units; coiled tubing technologies; frozen grounds; repair work of wells; nanotechnologies; corrosion resistance; wear resistance; shelf; sea platforms.

Currently, the development of industrial potential and infrastructure in Siberian and northern regions of Russia as well as organization of connections between them are inconceivable without the adequate development of technologies and associated equipment. The specific nature of gas and gas condensate wells repair in severe climate conditions at the fields in the north of Tyumen region lies in the presence of frozen grounds and abnormal formation pressure zones in well logs, which influences the process and the quality of repair work as well as the subsequent wells operation. For example, the sand washing technology that is widely used at the fields of central and southern Russia turns from a simple technology into a complicated one in climatic conditions of the Far North. In such conditions, sand bridge removal is complicated by a possible hydration in the well. This requires new process liquids (non-freezing solutions) and additional equipment (mobile steam heaters), which entails an increase in the duration of repair works, the increased possibility of wellhead seal failure and the emergence of gas showings, blowouts and fires. For these reasons, the search for new wells service technologies and the improvement of the applied ones as well as of the technical equipment and devices is of high importance.

Over the recent years, the range of repair works carried out at the fields of the Far North noticeably changed. New kinds of wells repair work emerged. They are carried out with the use of wireline technique and coil tubing units. The share of difficult major repairs of wells increased by 2.0-2.5 times, their duration grew and the well control hazards during the conducted repair works increased [*Guseynov 2012*].

The application of coil tubing technologies is a cost efficient and effective solution for northern regions. However, their application is restricted by the absence of roads and maintenance centers [*Zozulya et al. 2008*]. In this situation, it may be suggested that the manufacturers of coil tubing units should design module devices that will be transported to the work site with helicopters, ships and other vehicles, and that will be assembled directly at the well. It is possible that such unit will be more expensive than the standard one, but the total work efficiency will grow due to a reduction in the operation costs.

Severe climatic conditions considerably reduce the service period of well repair units. The quality of the equipment itself and the maintenance of this equipment exert most of influence in this respect. An important role is played by the used process liquids and materials that support operational capability of the hydraulic system of coil tubing units [*Zozulya et al. 2006*]. In these conditions, in order to improve the operating reliability of the equipment, it is required to improve their physical-mechanical and physical-chemical properties, such as corrosion resistance and wear resistance of separate parts and details of a unit that are exposed to the largest mechanical loads and to corrosive environments. The improvement of the working efficiency of separate parts of units can significantly broaden the range of tasks that they may perform.

One of the possible solutions to this problem is the application of beam-plasma nanotechnologies of ion implantation that are based on the controlled implantation of ionized atoms or molecules accelerated in the electrostatic field into the material. During this process, the ions energy and the exposure dose determines the thickness of the layer and the concentration of the necessary elements in the doped layer as well as the structure of the doped layer and the formed nanostructured protective coat in general.

Currently, the experimental works connected with the increase in corrosion and wear resistance of the surface of injector parts of coil tubing units with the use of nanotechnologies is being conducted in the test facility of ion implantation processes research. The research results [*Zozulya et al. 2007*] showed that the corrosion resistance of the samples, as compared with untreated ones, increased by multiple times with consideration of the error limit of the methodology and of the analytical equipment accuracy. Moreover, the wear resistance of the working surface of the 40X13 steel plate increases by 3-6 times after the ion implantation of the metal near-surface layer and the protection coat formation.

As the tests results show, such treatment of separate energy-intensive parts and details of coil tubing units may considerably increase their life cycle and broaden the range of performed operations, which is of high importance in the conditions of the Far North and, first of all, for the prospect of field development in the northern seas with the presence of thick drift ices. Currently, semi-submersible drilling platforms "Polyarnaya Zvezda" and "Severnoe Siyanie" have been constructed for the development of such fields (specifically, the Shtokman field). They are considered to be the most advanced and the biggest in the world in their class. They are equipped with high-tech drilling, geophysical, navigation and power equipment produced by leading Russian and foreign companies. These units are designed for drilling wells with the depth of down to 7500 m at the sea depths of down to 500 m and are able to work in conditions of the Arctic within the ambient air temperature ranging from -30°C to +45°C, with the presence of broken ice having the thickness of up to 70 cm. However, during the field development in the Arctic Ocean, exploring and wells drilling even with such units may be performed only within short navigation periods. Therefore, it is reasonable to learn from the experience of defense plants that possess a well-proven production technology of nuclear submarines capable to be continuously submerged for several months with the purpose of creation of submersible drilling units [*Zozulya et al. 2010*], including the ones created with the use of flexible pipes. This way of creation of deepwater units currently seems to be the most prospective in the conditions of considerable depths and of a thick ice cover that does not enable the performance of drilling operations from traditional sea platforms.

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Freeze-thaw effect and variability of morianic clayey loam

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Instructions

Glacial deposits of the European portion of Russia undergo seasonal freezing-thawing, which considerably alters their properties. Study of changes in the properties of soils during cyclical freezing-thawing assumes major significance, since they are used as beds for structures and primary mineral for the production of construction materials, and may also be implicated in such natural phenomena as solifluction, frost heaving and weathering, collapse of banks, etc.

Data and Methods

We investigated the influence exerted by freeze-thaw cycles on the physico-mechanical properties of the morainic clayey loam extracted from the Zagorsk proving ground maintained by the Russian Geologic-Prospecting University at depths of from 1.9 to 2.0 m, i.e., below the depth of seasonal frost.

Tests were conducted on two series of specimens 20 mm in height with a diameter d = 56.6 mm and undisturbed (I) and disturbed (II) structures.

A model ensuring similitude of physical-property formation during freezing-thawing under field and laboratory conditions was preliminarily developed. In Series I, the specimens were cut from monoliths. The Series II specimens were prepared from the disturbed soil. The soil was dried, pulverized, passed through a 2-mm sieve, wetted with distilled water, and then maintained for 24 hours to attain a uniform moisture distribution. The soil 's surface was covered with film , which to ensure constant moisture content in the test process.

The specimens were placed in an insulated mold for plane-parallel freezing-thawing. Both series of tests included 40 freeze-thaw cycles;. The specimens were frozen for 16 h in a refrigeration chamber at -7 °C, and were then thawed and maintained for 8 h at +20 °C. The specimens of each series were subjected to a different number of freeze-thaw cycles (3, 6, 20, 40).

Results and Discussions

The experimental studies demonstrated that variation in the dispersivity of the soils is attenuating in nature. We evaluated the rate of change in dispersivity as a function of *n* on the basis of determination of the coefficient K_{var} [*Ershov 1995*], which makes it possible to characterize the variability of the entire spectrum of dispersivity and the dynamics of the process

$$K_{\text{var}} = \frac{1}{n}\Sigma\left|a_i - b_i\right|$$

Where *n* is different number of freeze-thaw cycles, *a* and *b* are the contents of a fraction prior to and after the cryogenic effect, respectively, and *i* is the number of the fraction.

Figure 1 shows the dynamics of K_{var} as a function of *n*.

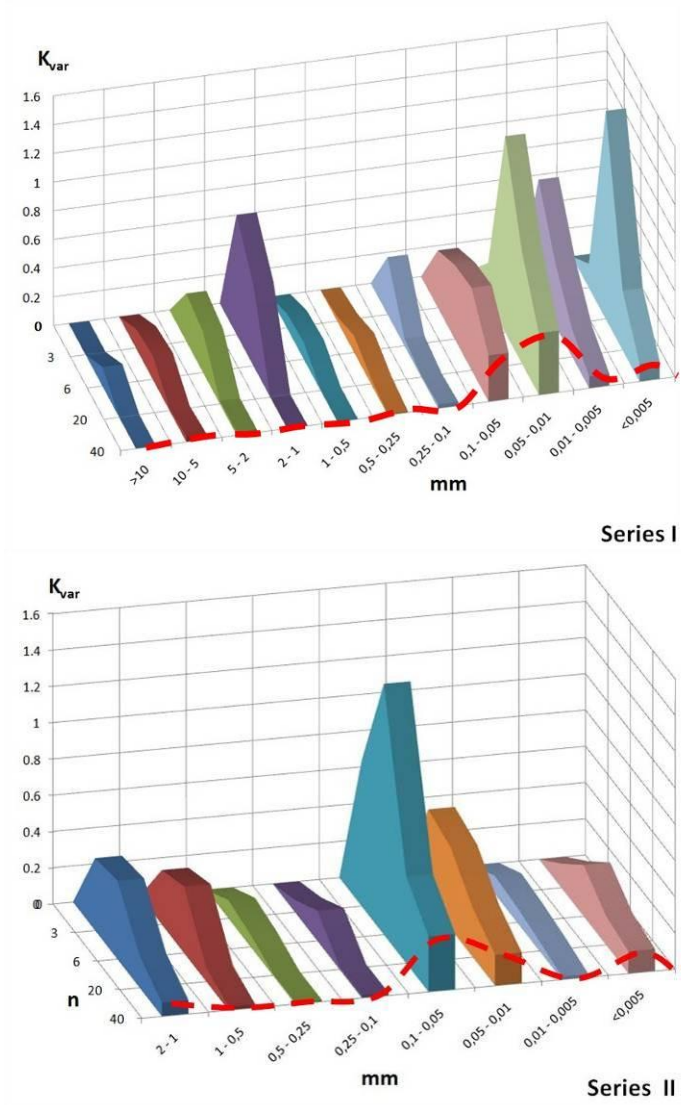

Figure 1. Dynamics of Kvar about grain distribution as a function of different number of freeze-thaw cycles (*n*): Series I – undisturbed and II –disturbed structures.

The variation of curves in the grain-size distribution in both series indicates asymptotic attenuation of the processes. Three segments are isolated (Fig.1): high rates of change in the grain-size distribution ($K_{var} > 1$), middle rates of change in the grain-size distribution ($0.1<K_{var} < 1$) and low rates of change in the grain-size distribution ($K_{var} <0.1$).

As the studies indicate, the 2-1mm and 0.05-0.005 mm fractions in the undisturbed clayey loam undergoes variability (Fig.1), and a reduction in their percent content is noted. The fine, 0.01-0.005 mm silt particles aggregate, and go over into the neighboring 0.05-0.01 mm fraction, while the 0.05-0.01mm size transitions into the 0.01-0.05 mm fraction.

An increase in the content of the finely disperse 0.1-0.05-mm fraction is characteristic; this is dictated by breakdown of the largest microaggregates. On the whole, transformation of the dispersivity of the clayey loam under investigation as a result of freezing-thawing results in both cryogenic aggregation, and also dispersion of silty-clayey and colloidal particles in both series.

Conclusions

Accumulation of the fine-sand fraction (0.1-0.05 mm) occurs during alternating freezing and thawing of a morainic clayey loam. Rate of change in grain-size distribution and all physical properties diminishes after six cycles.

The study was conducted with financial support in the form of grants from the State Key Laboratory of Frozen Soil Engineering, CAREERI CAS(No. SKLFSE-ZQ13).

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Monitoring Network and thermal dynamics of Permafrost in Western China

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Permafrost occupies a large area in high elevation zone in western China (more than 1 400 000 km^2), and has great influences on local hydrological processes, ecosystems, and regional climate, even on global climate system. Changes of permafrost, such as the changes in permafrost temperatures, active layer thickness (ALT) have been documented in a great deal of literatures in the past several decades. Monitoring on permafrost in these regions started from 1960s, and a well organized monitoring network was established now. More than 100 ground temperature (GT) monitoring boreholes equipped with thermisters was set up in the permafrost regions in Western China (Fig. 1). Most of them are distributed from Xidatan to Naqu along Qinghai-Xizang Highway and Railway with a range of more than 700 km in distance (31°59′—35°59′N, 91°58′—94°13′E). The others are located at Maxishan Mountain near Lanzhou (35°43′N, 103°59 ′E), and in western Kunlun Mountains (34°30’-36°0’N, 78°48’ - 81°30’N), in Tianshan Mountains (43°06′—43° 13′ N, 86°49′—87° 07′ E), in conjunction region of Eastern Kunlun, Southern Qilian and Qinling Mountains (99°06’- 99°36’N, 35°12’ - 35°42), in Gaize region of Ali Plateau (32°16’ - 34°00’N, 84°00’ - 86°18’E). Parts of the monitoring sites have been selected as the long-term monitoring sites of the Global Terrestrial Network-Permafrost (GTN-P), Circumpolar Active Layer Monitoring (CALM), and the National Snow and Ice Data Center. The monitoring data showed that ground temperatures well related with elevation and geographic locations where the climatic conditions are great different, and the permafrost was warming and the active layer thicknesses (ALTs) were thickening during the last decade, while the warming trends were more significant in lower ground temperature regions, but the thickening trends of ALTs were more significant in higher ground temperature zone.

Modeling by Land surface models revealed that both air temperature and precipitation play significant role during the formation of permafrost, and the spatial differences in precipitation are the main reason to result in the lower boundary of permafrost distribution increased from east to west in the Tibetan Plateau and Qilian Mountains, decreased westwards in Tianshan Mountains. It also indicated that the climate warming is the main reason for the permafrost degradation in the western China.

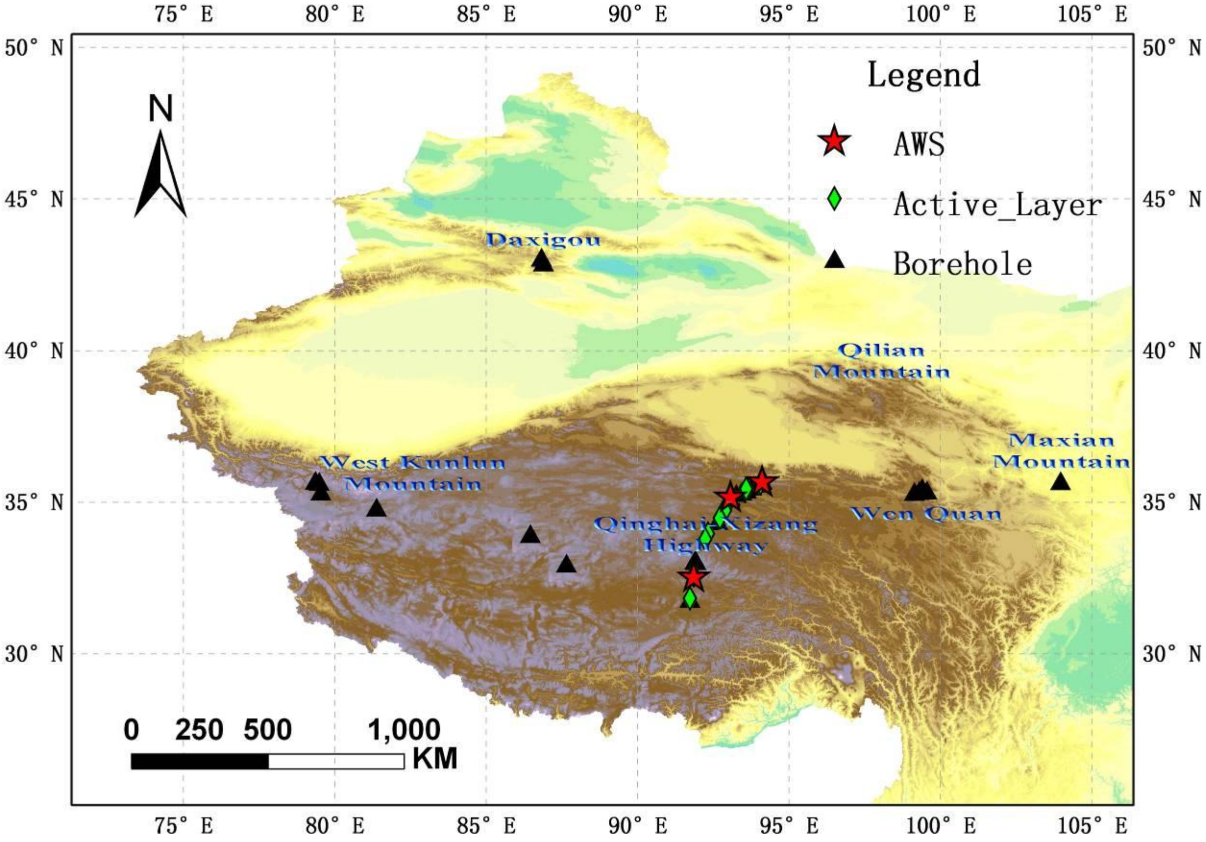

Figure 1: Ground temperature monitoring sites in permafrost regions of Western China

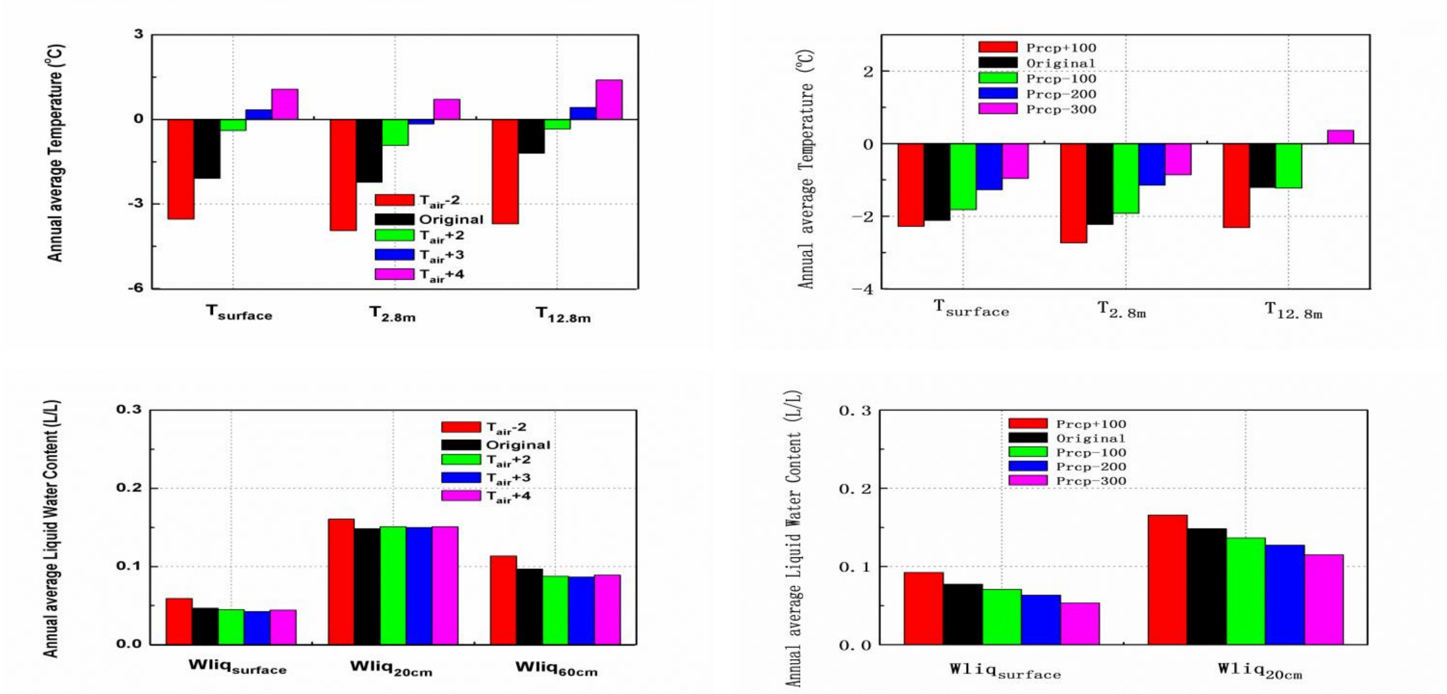

Figure 2: Modeled impacts of air temperature and precipitation on ground temperature and soil moisture in permafrost regions of the Tibetan Plateau by ColM

On the Need to Create a Geo-information Geocryological System

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It is impossible to understand the causes and peculiarities of the formation of the Earth's permafrost zone and its particular regions without having systematized information or, to be more exact, without an information system considered and developed by specialists.

The geoscientific and geocryological information that was accumulated during more than 100 years of natural resources development and scientific studies is now dispersed among dozens of various organizations. Definitely, such situation has made an adverse impact on the degree of preservation, quality and accessibility of such information.

According to statistical data, the absence of a unified system of information resources' management leads to the following: from 5% to 10% of the data is lost every year due to incorrect record and storage conditions; quality of the data in their conventional storage places is either not known or does not meet modern requirements; from 60% to 80% of working time is wasted for search, check and preparation of the necessary information.

The use of modern informational technologies will help solve the problems of reliable long-term data storage and management, as well as those of the provision of swift access to necessary information resources.

In case of a single data type, its processing is easy; however, if a data array includes hundreds and thousands of measurements, their processing, storage and analysis become challenging. For the time being, the creation of a computer database (DB) designed for swift statistical and analytical processing of large data arrays is the most reasonable solution in the formation of knowledge on the cryosphere, since it ensures a higher level of approach to scientific, technical, social, and economical problems of various regions. The databases should form the basis for the development of design solutions for engineering sites and facilitate scientific research and educational process.

Currently, there are no completed geocryological databases (GDB) in Russia or abroad. In early 1990, the International Permafrost Association launched the initiative aimed to create the Global Geocryological Data (GGD) system, and the Russian National Permafrost Committee supported this decision. In 1995, the SB RAS Permafrost Institute started the development of a geocryological database's structure. In accordance with the prepared provisions, a three-level architecture was proposed [*Balobaev et al. 1996*]. Within the framework of the pilot project, the Geothermics Laboratory of the Permafrost Institute of SB RAS started the creation of the third level, i.e. the base of actual data comprising structured permafrost and geothermal information. New solutions and changes in the database's architecture came to life during the work. Currently, the creation of the geocryological database on the Siberian Platform that can become an example or working model for the development of the Global Geocryological Data system is being completed.

The efforts on the creation of the geocryological database on the Siberian Platform (GCDB SP) are aimed to systematize the geological and thermophysical information based on the initial technical and geographical data on the mines, thermal regime and thermophysical rock properties. These data can form the basis for analytical works on identification of peculiar properties and regularities of permafrost, its properties by sites, fields, orographical areas, and geological structures [*Zheleznyak 2011*]. The existing data banks include:

1 – data bank on physico-geographical and technical information of mine workings where geological and thermophysical investigations have been conducted. This bank comprises the summarized information on 35 items, including temperature data at reference depths obtained by means of measurements or estimates.

2 – regional data bank on thermophysical properties that include a set of thermophysical and physical characteristics of rocks;

3 – initial data bank on temperature measurements in mine workings.

The geocryological database on the Siberian Platform can be seen as an element of the Global Geocryological Data system or as an individual database. Its systematization is based on the principle of geological structure (Fig. 1). The 2nd-order structures include: the Aldansk, Anabaro-Oleneksk, Baykitsk and Nepsko-Botuobinsk anteclises, the Vilyusk, Tungussky, Prisayuano-Eniseysk syneclises, the Lena-Anabarsk, Predverkhoyansk, Predpatomsk, Nizhne-Tungussky depressions, the Katang saddle, the Irkutsk dome, and the Eniseysk massif. The 2nd and 3rd–order structures include tinier structures: the Aldano-Stanovoy Shield, the Anabarsk Massif, the Oleneksk Dome, and others. Further zoning can be performed in accordance with the same geostructural or geomorphological principles. The 4th–order structures include the sites where geocryological investigations have been carried out.

By now, the Siberian Platform database comprises the materials on 200 sites (about 24 thousand mine workings). The database allows to view the available information in tabular or graphic formats, to select and statistically process the data.

The Siberian Platform database was created using the multi-functional system DELPHI and the database processor Borland Database Engine (BDE). The Structured Query Language (SQL) is used as a standard language. It allows to build relational databases representing a set of table-stored interconnected data and to perform operations on them. The Delphi special component TQUERY is designed to implement the queries. It has a series of features and methods that allow to use all advantages of SQL queries in operations with the data. This enables operations with large information retrievals.

This system is only the first stage in creation of the Global Geocryological Data system. In the future, it should be supplemented with the information from various sources and organizations, and all permafrost scientists of the world may and must become its creators. The global permafrost community should think over and initiate the creation of this system. Its basic objectives, in our opinion, will be the following:

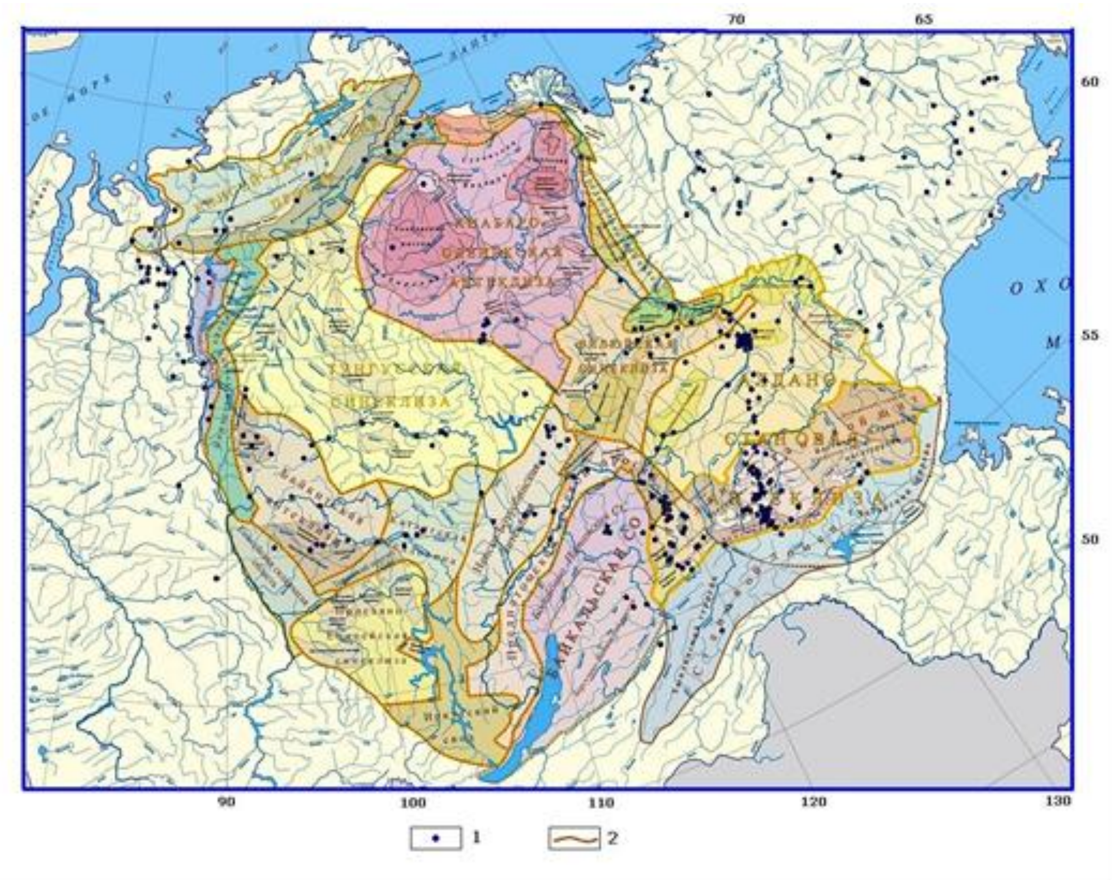

Figure 1. Scheme of geostructural zoning of the Siberian Platform
1 – sites of permafrost and geothermal investigations; 2 – boundaries of geological structures.

- Provision of centralized record and reliable storage of initial geocryological information accumulated during many years of development of various regions, as well as of the obtained modern information;
- Provision of unified formats of data storage and delivery, data completeness and quality; organization of swift regulated access to the Global Data system's resources by means of modern information technologies;
- Creation of the information basis for the formation of an integral system of information exchange management in research projects and in natural use management.

Undoubtedly, the creation of a unified geoinformational system will be conducted on the territorial (country) basis. However, the core and active initiator of this process should be represented by the International Committee which can take the responsibility for coordination and assistance in promoting the projects in individual countries and their integration in scientific investigations.

Such informational system should be created as quickly as possible, and this task should be of the first priority for permafrost scientists. All brilliant regional generalizations on the permafrost zone made by our colleagues and teachers of the past century should be supplemented and thought over, and this is caused by many reasons. It is quite evident that analytical capacities supported by the implementation of computer technologies have become higher, thus helping to enhance precision of the data on the permafrost zone as well as to identify new regional peculiar features and regularities of its development.

By now, the creation of regional geocryologial databases has become a necessity, and it cannot be possible within the framework of pilot programs only; on the contrary, it requires support and attention of the International Committee. The international status of the program will facilitate the efforts of territorial centers, becoming a serious step in the creation of such a system.

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Improvement of Protective Corrosion Resistance of Oilfield Equipment in the Northern Environment Using Zn-Ni Electrolytic Coatings

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The main purpose of Zn-Ni electrolytic coatings is protection of steelwork against corrosion in saline environment and seawater. In order to ensure high corrosion resistance, a coating shall be dense, uniform in thickness and have a corrosion speed close to zero.

Improvement of corrosion resistance of zinc-based coatings and preservation of their electronegativity with respect to a material protected (steel) at the same time can be achieved by introduction of metals which are able to create intermetallic compounds with Zn into zinc at a cathode.

Nickel, cobalt and iron are examples of such metals. Use of nickel as an alloying component is more promising from the practical viewpoint, because cobalt is more scarce, whereas Zn-Fe alloy is rather fragile.

Data found in literature concerns mainly Zn-Ni galvanic sediments, which are either a phase of solid solution of nickel in zinc (α-Zn) or a phase of solid solution of zinc in nickel (β-Ni).

The maximum corrosion resistance is typical for alloys that contain 18 wt% - 25 wt% of nickel.

The purpose of this work was to study impact of electrolysis conditions (cathodic current density) and composition of an electrolyte (organic admixtures) on phase composition of electrodeposited Zn-Ni alloys.

Electrodeposition was carried out in chloride-ammine electrolytes in the presence of aminobenzoic acids with different position of the substituents (o-aminobenzoic acid, m-aminobenzoic acid and p-aminobenzoic acid) at t = 25 °C, pH = 6.5.

Content of Ni in an alloy was determined spectrophotometrically by measuring the optical density of the solution. Content of zinc was determined based on the difference between quantity of the alloy weighed for analysis and the nickel mass increase.

At low cathodic current density ik (0.3 A/dm^2 - 2.0 A/dm^2), there appear Zn-Ni alloys (85-98 Zn) at a cathode which are a phase of the α – Zn solid solution with the following parameters: a = 0.270 nm; c = 4.99 nm.

At maximum currents ik (50 A/dm^2 - 75 A/dm^2), the coating is 2-phase sediments: α – Zn + β – Ni.

The highest content of the β – Ni phase in alloys was registered in the presence of m-aminobenzoic acid.

At moderate values of ik (5 A/dm^2 – 7.5 A/dm^2), there appear monophase sediments at a cathode which are Ni_5Zn_{21} intermetallic compound.

Composition of the chloride-ammine sediment electrolyte in case of Zn-Ni alloy provided diffusion limitations during discharge of Zn ions which was indirectly indicated by non-uniformity of the sediment mass microdistribution.

Microprofile chemical composition of the coating, however, remained almost constant according to the data of the X-ray microspectroscopy. This may be related to change in nickel sedimentation speed.

As regards electrodeposition of Zn-Ni alloy, distribution of the sedimentation speed of the alloying component depends on zinc.

This is an evidence of appearing of a chemical compound with a certain ratio of the components.

The X-ray diffraction method has demonstrated that formation of Ni_5Zn_{21} intermetallic compound (the γ – phase) occurs in the presence of all the three additives with different position of the substituents.

This phase has a distorted structure of the I-43m primitive cubic lattice resembling that of brass.

Parameters of crystal lattices of the coatings produced in the presence of o-aminobenzoic and m-aminobenzoic acids are almost identical to the parameter a of the γ – phase of the equilibrium diagram [*Khansen & Anderko 1962*].

As to p-aminobenzoic acid (the γ – phase), value of the parameter a is too high being equal to 0.8976 nm. It has been found that the most dense, even and compositionally uniform coatings are produced in the presence of p-aminobenzoic acid.

Appearing of Ni_5Zn_{21} intermetallic when aminobenzoic acids are added to the electrolyte solution is attributed to the process of appearing of cyclic complexes with intermolecular hydrogen bonds (o-aminobenzoic and m-aminobenzoic acids) and linear associates (p-aminobenzoic acids) [*Zhikhareva et al. 2006*].

In the latter case, the complexes containing p-aminobenzoic acid and ions of the metals which are produced in the electrical double layer cause a drastic inhibition of Ni^{2+} discharge.

The nickel content in the alloy is minimal (7.5 wt%). Increase in the parameter of the crystal lattice of Ni_5Zn_{21} (p – aminobenzoic acid) is caused by significant internal compressive stresses.

Conditions of production of Zn-Ni alloys which contain 19 wt% of Ni and have an output current efficiency close to 100% have been determined.

Corrosion resistance and microhardness of the sediments produced are 3.5 – 4.5 times higher than those of pure zinc and cadmium.

Thus, cathodic current density contributes to a change in the phase composition of Zn-Ni alloy, whereas addition of aminobenzoic acid increases homogeneity of a coating as regards its composition and thickness.

According to the study performed, it is recommended to use Zn-Ni alloy (the γ–phase, [Zn] = 85 wt%, ik = 7.5 A/dm^2 , t = 800 °C, monoethanolamine is added) for protection of the oilfield equipment on the shelves of the Tyumen North.

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Glaciation Stages in the Formation of Geomorphological Relief Forms in the Southern Verkhoyansk Region

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Abstract

The paper presents brief characterization of the relief formation in the Southern Verkhoyansk Region, including the stages of development of mountain-valley glaciation at different hypsometric layers, tectonic factors and their sequence reflected in the mountain relief.

Collision events that occurred in Late Cretaceous period in the south of the Verkhoyano-Kolymsk orogen caused the formation of the Verkhoyansk orogenic belt that comprised, in particular, the Southern Verkhoyansk fold-thrust belt. Since that time and for long, extensive areas of the Southern Verkhoyansk region with the continental regime have been impacted by geodynamical processes. These processes determined formation of ancient peneplainized relief and the mountain system that still exists. [*Parfenov et al. 2001*]

Branches of the Suntar-Khayat Ridge are located in the northern part of the Southern Verkhoyansk region. This is the main orographic structure that serves as a focal point for geomorphological zoning. Elevations of individual peaks reach 2200 m (Atlasova Mountain); however, most of them fall within the range of 1850 to 1950 m.

Climate conditions, in which large glaciers were formed, determined, to a significant extent, the formation of the modern relief of this area. Here, glacial topography is observed everywhere. It is most distinctly emphasized by large river valleys having a trough-like shape. (Fig. 1).

Figure 1. Trough valley of the Vostochnaya Khandyga River.

Studies in morphology and genesis of the peak relief of the alpine-type terrain allowed to assume that the pre-Pliocene uniform peneplaination plane had existed on this territory [*Korostelev 1982*]. In the Neogene-Quaternary period it was raised by weakly differentiated movements. Amplitude of raising varied among different tectonic blocks.

Pre-Pliocene peneplain relicts formed the first tier of the Suntar-Khayat Ridge's relief.

It is difficult to identify the formation time of the second peneplaination plane as well. Usually, by certain indirect features, the researchers classify it as a Late Quaternary formation connected with the first phase of mountain-valley glaciation of this era.

At the watersheds Vostochnaya Khandyga – Nekuchan and Nekuchan – Kharchan and in the upper reaches of the Lager Stream one can observe well-preserved traces of exaration activity of the glaciers on the second peneplaination plane, including the residues of the upper trough cut through by a modern river network down to the depth more than 300 m.

This region also comprises the third relief tier formed by large river valley beds (the Vostochnaya Khandyga River, the Setorym Stream, the Kurbelyakh Stream).

Investigations of peneplaination planes and the analysis of relevant results allowed to identify amplitudes (and velocities) of the latest tectonic movements and to create a tectonic relief model for the territory in question. The identification method is based on the fact that every forming peneplaination plane is horizontal or slightly inclined to the denudation base. Further movements are reflected in the deformation of this plane.

Figure 2. The Domokhotova Mountain (elevation 1800 m). Peneplaination tier in the middle part of the slope at level 1600 m.

Conclusions made based on the performed investigations and interpretation of their results are the following:

1) three peneplaination planes of the region correspond to three relief tiers; the averaged elevation of the upper tier is 2000 m, that of the middle tier – 1600 m, and that of the lower tier – approximately 1000 m (Fig.2);

2) average heights of slopes and sledges dividing the relief tiers are 400 m and 500-600 m, correspondingly;

3) modern elevations of all peneplaination planes were formed by upward movements and denudations, not but

glaciation, since continental glaciation did not occur there, and its mountain-valley forms did not impact the relief tiers' hypsometry;

4) upper plane is inclined to the north, the middle plane is almost horizontal, and the lower one is inclined to north-north-west;

5) the ancient (initial) peneplaination plane is dated by Late Cretaceous era or Paleogene, the middle one is dated as Mid-Late Quaternary, and the lower one is modern;

6) neotectonic and modern movements caused certain deformation of peneplaination planes due to the shift of the denudation base, probably, from north to west-north-west. This fact is confirmed by the existence of twinned glaciers in the upper reaches of rivers Kobyuma, Oganya, Dyby and others, where in the Mid-Late Quaternary era the glaciers changed directions, moving to north-west, to south-east, or to the south.

Most researchers studying the South Verkhoyansk region name two periods in its history. Glaciation in the Mid-Quaternary time was maximal and characterized by half-cover distribution in some areas, while the second Late Quaternary glaciation covered the smaller area and was formed in the mountain-valley environment.

Traces of the first glaciation are preserved in the points with highest elevations (more than 1600 m) in such forms as erratic boulders, glacier-treated saddles, upper trough beds, fragments of destroyed kars, cirques, etc.. The glacial moraines of this glaciation have practically not been preserved in this region, save the upper and middle current of the Setorym stream, where a Mid-Quaternary trough is inserted into the trough of further glaciation. Minor moraine formations of the first glaciations are preserved at the terrace at the height of 40-60 m.

As it can be traced by the erratic boulder distribution picture, the Mid-Quaternary glaciers were moving to the north and to the west, and their relatively wide lateral extension is proved by numerous exaration relief microforms of different states of preservation on the upper peneplaination plane. The area of the generation of the Mid-Quaternary regional glaciers was probably represented by the Suntar-Khayat Ridge, from which glaciers moved in different directions, including west and north-west. As for the local glaciers, they were formed in more elevated southern and eastern parts of the region, from where they moved to its lower parts. One of such local glacier centers was an ice-catchment field in the riverheads of the rivers Dyby, Oganya, Kerekhtyakh and Ugamyt.

The Late Quaternary glaciation in the region had a typical mountain-valley character and occurred in a mountain environment that was close to the modern one. Its traces have been preserved much better. They are observed almost everywhere. Exaration relief forms of this glaciation are relatively "fresh", they are clearly observed on the terrain and decoded on the orbital photos. Judging from elevations of the glacier trough's shoulder in the Vostochnaya Khandyga River valley, the thickness of the Late Quaternary glacier in this area reached 400 m. Accumulative relief forms and other traces of this glaciation are widely distributed in this region as well. They are represented by lateral and basal moraine coteaus, glacial depositions forming the planes of high and medium terraces of the region. The best-observed sections of the coteau relief are those located at the confluence of rivers Vostochnaya Khandyga, Kurbelyakh and Setorym. Their maximal distribution, which covers tens of square kilometers, occurs near the Aldan – Indigirka watershed.

Also, this latest glaciation caused formation of numerous kars and cirques as well as trough valleys of many little watercourses. In many cases, they are represented by through valleys in the riverheads and hanging valleys in the mouths: for example, hanging valleys of the Sever and Skvoznoy streams, as well as other left tributaries of the Kurbelyakh stream.

In addition, second Late Quaternary glaciation determined the intense exaration activity of the mountain-valley glaciers that destroyed almost all previous moraine and alluvial depositions, leaving glacial depositions everywhere behind them. Sections of coteau relief, numerous glacial through valleys, blown-down and existing lake dishes and other relief forms of this region are connected with the glaciers of that era.

The bending fold of the terrain is currently taking place. This is confirmed by deformation of terraces at different levels; deep erosion; abundance of brushes, rapids, waterfalls in watercourses' valleys; significant vertical (and horizontal) swifts along the neotectonically activated faults; formation of hanging valleys caused by the sliding of gravitationally unstable rocks from the slopes due to seismic shakes; and other features. Estimated total bending folding of this terrain in Late Quaternary period is 900-1500 m, that of for the full orogenesis stage – 1200-2200 m.

In conclusion, let us note that the main role in the relief formation was given to tectonic factors, glacier activity and erosion processes determined by significant annual and even daily temperature fluctuations. All of them still impact the modern relief formation.

The identified decoding features ensure precise determination of exogenous geological (permafrost) formations (frost mounds, thermokarst depressions, soilfluction terraces, polygonal systems, etc.), as well as icings and pools of open water in ice.

Taryn or icing signs are preserved even after their full thawing. They are notable on the orbital pictures through the composition and color of the surface, their position in the relief, and vegetation cover. Typically, this is a widened channel sandbank or low floodplain covered by pebbles that was formed due to the washout of small fraction fines (sands and tiny fines).

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Comparison of Thermal Regimes at Two Boreholes in Rock Glacier Furggwanghorn, Valais, Switzerland

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Introduction

Mountain permafrost is highly sensitive and susceptible to climate change due to having a ground thermal regime that is close to 0°C. The Swiss Climate Change Scenarios CH2011 imply that, for all Swiss regions considered, best estimates for the non-intervention scenarios predict increases of seasonal mean temperature of 3.2–4.8°C by the end of the century for the A2 emission scenario and 2.7–4.1°C for the A1B emission scenario (CH2011). The warming and thawing of degrading mountain permafrost significantly increases the risk of natural hazards. The general thermal regime of a place depends on its geographic location, which roughly determines air temperature and incoming solar radiation. Local factors such as type of vegetation, soil characteristics, snow cover, moisture conditions and micro-topography, however, have also a profound controlling influence on ground thermal conditions.

Study Site

The investigated site is Furggwanghorn rock glacier, which is located in the Turtmann valley, Canton Valais, Switzerland. Four 25 m deep boreholes were drilled in September 2010 to install thermistor chains to collect permafrost temperatures. Temperatures are measured every 0.5 m in the upper 5 m and every 1.0 m in the lower 20 m of the borehole. In addition, ten thermistor sensors were placed on the ground surface around each borehole to monitor the thermal state on the surface. Due to the movement of the rock glacier, many sensors were destroyed as the cables were sheared off. Among the four boreholes, borehole F3 is upslope from borehole F4 in a small depression at a distance of 11.8 m. The two boreholes are in a relatively flat ground, with the elevations of borehole F3 and borehole F4 at 2852.62 masl and 2853.35 masl respectively as measured by GPS. Point snow depth is also measured in the flat area, being 13.0 m away from borehole F3 and 6.5 m away from borehole F4.

Model

The CoupModel [*Jansson & Karlberg 2001*], a one-dimensional soil water and heat transfer model, is used in this study. It calculates vertical water and heat fluxes in a layered soil profile using a finite difference method. A submodel for seasonal snow accumulation, melting, heat conduction and energy exchange between snow and atmosphere is also included in the model.

As lateral outflow from saturated layers cannot be simulated in the CoupModel, a 3.65-m deep soil profile in the active layer was modeled, which ends just above the saturated zone forming on top of the permafrost in summer. The lower flux boundary was assumed to be unit gradient flow.

Results, Data Interpretation and Discussion

The simulation period is almost one year from 1 October 2010 to 23 September 2011. The model was calibrated with measured temperatures in the top 3.5 m of borehole F4. As there is no measurement of the soil moisture conditions, the initial soil moisture distribution and soil water characteristic parameters are determined by fitting the zero curtain periods. Most parameter values are default values from the model. Snow pack parameters are the most sensitive ones affecting the ground temperatures. These parameters are mainly adjusted to fit the simulated results with measured data. Figure 1 shows measured temperatures and simulated temperatures for four depths. Simulated temperatures fit relatively well with measured temperatures at borehole F4. The soil temperatures during the winter are controlled by snow cover. During the snow covered period, the ground temperatures are influenced by air temperature to a small extent due to the large thickness of snow cover which has an average value of 0.52 m. The simulated snow cover has a high correlation of 0.90 with the measured one.

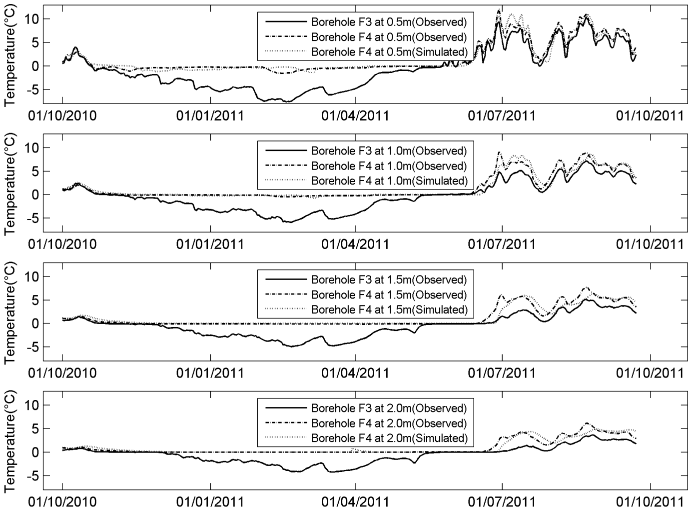

Figure 1. Observed temperatures at borehole F3 and borehole F4 as well as simulated temperatures at borehole F4 at the depths of 0.5 m, 1.0 m, 1.5 m and 2.0 m.

While the ground thermal conditions are mainly determined by climatic conditions, they can be also modified by vegetation cover, surface organic material, snow cover, soil composition, moisture condition and micro-topography. There is hardly any vegetation at the study site. Surface soil cover around boreholes F3 and F4 does not show obvious differences. As borehole F3 is in a small depression, the assumed snow depth at borehole F3 should be not less than that at borehole F4, where measurements are available nearby. Therefore, temperatures at borehole F3 should be similar to those at borehole F4. However, borehole F3 shows temperatures rather different from those of borehole F4, especially during the snow covered period from 16 October 2010 to 03 June 2011 (Figure 1). According to Luetschg et al. 2008, there is a very effective thermal resistance for snow depths larger than 0.6-0.8 m. From 17 December 2010 to 12 April 2011, the measured snow depth is above 0.6 m. During this snow covered period, the temperatures at borehole F4 are relatively stable and show small changes. On the contrary, even during this period, the temperatures at borehole F3 rise and drop frequently. By comparing temperature data at the two boreholes in Figure 1, compared to borehole F4, the curves of temperatures at borehole F3 have different trends and larger variations mainly in the snow covered period when the temperatures are far below 0°C. They are similar in trend, with smaller amplitudes, though, during the snow free period.

In general, the major ground heat flux is directed downwards and the temperature amplitude decreases with depth. The ground temperature reaches a stable value at a certain depth. The ground thermal regime at greater depths can generally be analyzed based on results from shallower depth. The active layer depth at borehole F3 is between 3.0 m and 3.5 m below the surface. The temperatures reach a stable value below the depth of 9 m. The active layer depth at borehole F4 is deeper and lies between 3.5 m and 4.0 m below the surface. The temperatures reach stable conditions below 4.5 m. By comparing temperature data at borehole F3 and borehole F4 at all measured depths, the temperatures at borehole F3 are much lower than those at borehole F4 in the top 8 m. Between the depths of 9 m and 11 m, temperatures at borehole F3 and borehole F4 are close with a difference within measurement error. From 11 m to 25 m below the surface, temperatures at borehole F3, which are still subzero, nevertheless, are all higher than those at borehole F4.

The stable temperatures at lower depth which are slightly affected by exterior disturbances may indicate the thermal state from a long time ago. Therefore, one possible explanation for the different thermal regimes at different depths of the two boreholes is that borehole F4 used to be colder than borehole F3. Based on Orthoimage in 1993 (Swisstopo), rock glacier Furggwanghorn displays a smooth morphology prior to the sliding behavior. A small crevasse began to grow after 1993 and evolved into two crevasses of 14 m deep and feature lengths of 150 m in the rooting zone until 2005 close to borehole F3 [*Roer et al. 2008*]. Besides, landforms featuring failures at the front in parallel indicate smooth surfaces with continuous horizontal displacements in their rooting zones [*Roer et al. 2008, Kaufmann & Ladstädter 2003*], which might be the cause of the flat area in rock glacier Furggwanghorn.

Therefore, it can be hypothesized that, when the rock glacier surface was smooth, the cold dense air went into the active layer by funnels in the snow at the top of the slope and moved down along the blocky slope by gravity replacing warm light air and cooling the active layer. This phenomenon might explain why borehole F4 which is down-slope from borehole F3 was colder than borehole F3 at the lower depth. Since 1993 when the crevasse started to form, the cold air in winter could cool borehole F3 with lateral air convection through the crevasse even under thick snow cover. Borehole F4 is mainly influenced by one-dimensional vertical heat flow while borehole F3 is influenced by both vertical and lateral heat fluxes. As a consequence, the top several meters of borehole F4 due to its lateral insulation are warmer than borehole F3 while the lower parts still represent the old thermal condition and are colder than at borehole F3.

Conclusion

A coupled one-dimensional heat and mass transfer model can explain the thermal regime at locations unaffected by lateral heat transport processes. The snow cover with its low thermal conductivity insulates the ground from the temperature changes of the air. The comparisons of thermal regimes at the two boreholes indicate complexities of thermal conditions in mountain permafrost which require the inclusion of lateral heat transport into the model to better describe ground thermal regime at mountain permafrost. The ground thermal regime is the interaction result of climatic, surface, and subsurface factors. There is no single factor that can alone explain local ground thermal conditions. The thermal states may be very different even at very close distance. Comprehensive monitoring is necessary to temporally and spatially describe the thermal conditions in a rock glacier and study its response to climate change.

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