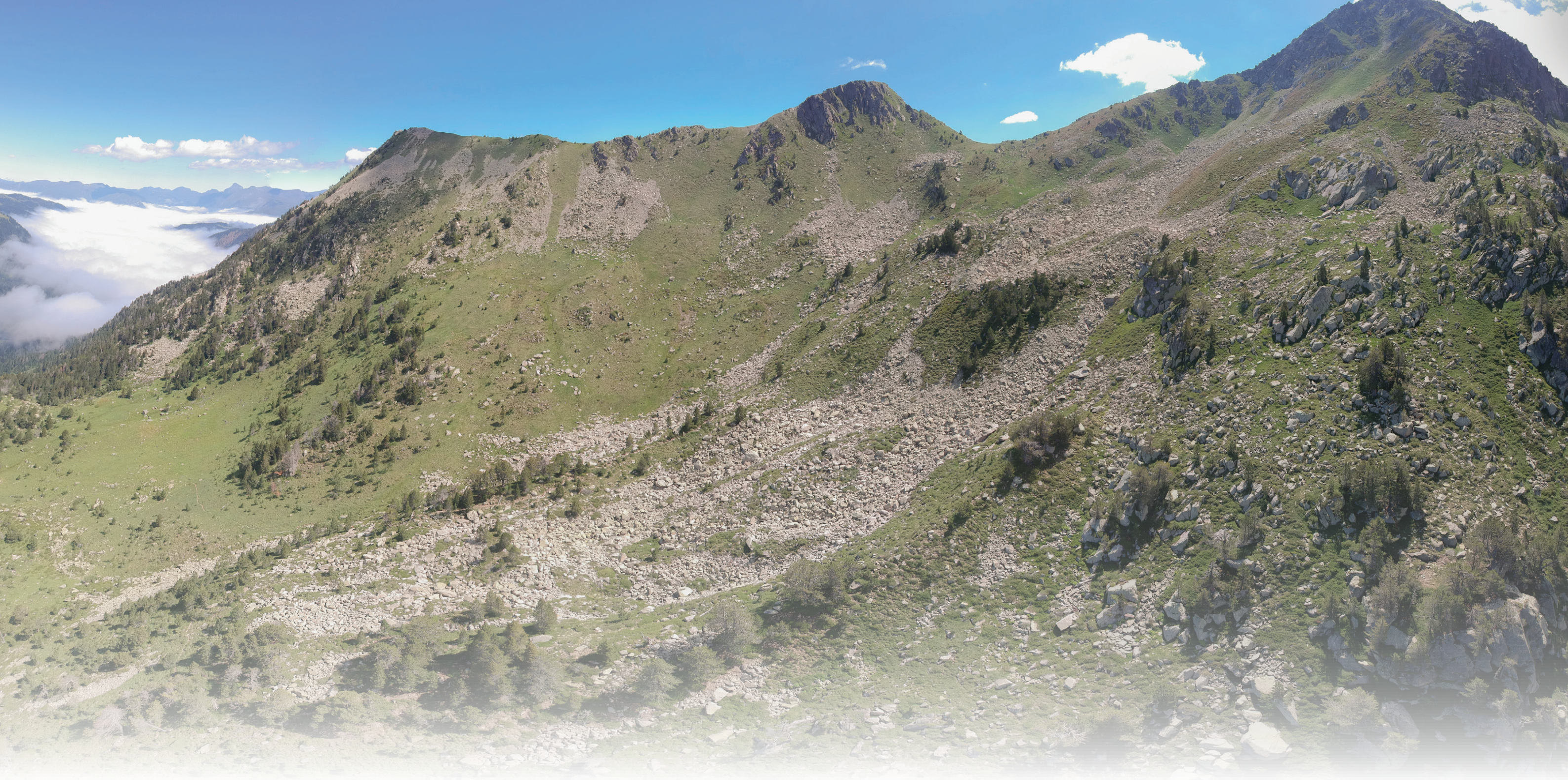

BOOK OF ABSTRACTS

José M. Fernández-Fernández · Josep Bonsoms
Julia Garcia-Oteyza · Marc Oliva
Editors

EUCOP6 PUIGCERDÀ
18-22 JUNE 2023

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PREFACE

Many things have happened at the international sphere since the last European Conference of Permafrost. Amongst them, a pandemic that has impacted scientific activity in many ways, e.g., constraints on the field campaigns, delays in the laboratory tasks and the limitation, adaptation or even cancellation of the scientific meetings. Indeed, the 6th European Conference on Permafrost (EUCOP 2023) should have taken place in June 2022 but we had to delay it one year due to the pandemic situation. Today, having overcome those difficult times and just a few days before the opening of the EUCOP 2023 conference in Puigcerdà, in the heart of the Eastern Pyrenees, it is a pleasure for us to briefly outline how this long journey has been.

Involving a Local Organizing Committee (LOC) was the initial (and the easiest) task. Our colleagues and friends showed a great predisposition since the very beginning of this adventure. Their commitment and invaluable support have been constant throughout this process and help also to engage a strong panel of world-leading scientists that form the International Scientific Committee (ISC).

The next step was to open the call for session proposals. The LOC received 24 proposals encompassing different topics within the permafrost science and engineering. Each session is coordinated by 2-4 conveners, one of them being member of the Permafrost Young Researchers Network (PYRN).

With the session sketch shaped, we opened the call for abstracts that was resounding success: over 510 abstracts were received, sent by 448 scientists and engineers from 52 countries. Then came the hardest (and invaluable) task of conveners, with the revision of the abstracts within a few weeks. They decided on their acceptance or rejection, the format of presentation and designed the program of the oral slots. After the reviewing stage, and due to some withdrawals of abstracts by colleagues that will not be able to attend the conference, the Book of Abstracts that you have in your hands includes a total of 485 contributions (224 orals and 261 posters).

It is now, after all these tasks and various meetings between the members of the LOC and ISC, session conveners, organizers of the workshops, local authorities, sponsors and all the people that have contributed to the organization and provided support for the Conference, we are pleased to deliver to the EUCOP 2023 attendees this humble Book of Abstracts. We are fully satisfied with the high quality of the submissions and the high level of the scientific production of the international permafrost community.

We hope that you will appreciate the result of this humble collective work that, for sure, will contribute to a step forward in the comprehension of the permafrost evolution and dynamics in our currently changing world.

José M. Fernández-Fernández

Josep Bonsoms

Julia García-Oteyza

Marc Oliva

ACKNOWLEDGEMENTS

We would like to express our sincere gratitude to all the authors of this book, which is a compilation of the 485 abstracts included in the 24 thematic sessions presented at the 6th European Conference on Permafrost (EUCOP 2023). We are very grateful to local and international organizations, institutions, conveners, presenters and participants attending the EUCOP 2023. Their efforts in writing and exposing their results, organizing the sessions and reviewing the abstracts have been crucial in the preparation of this conference.

The EUCOP 2023 includes a wide range of workshops, parallel meetings, oral and poster sessions, and local and regional field trips. The Local Organizing Committee warmly thanks the Ajuntament de Puigcerdà for providing all logistic and administrative support. The congress received also funding from several public institutions, such as the Diputació de Girona, Institut per al Desenvolupament i la Promoció de l'Alt Pirineu i Aran and the Universitat de Barcelona. We would like to thank the support offered by Cadí and Beadedstream companies, as well as by Ferrocarrils de la Generalitat de Catalunya providing access to the La Molina and Vall de Núria facilities during field excursions.

Special thanks also to the invited keynote speakers Dr Gonçalo Vieira (Universidade de Lisboa), Dr Isabelle Gärtner-Roer (University of Zurich) and Dr Hugues Lantuit (Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research), as well as to Dr Matt Strzelecki (University of Wroclaw) for moderating the round table on "The future of permafrost science". We are also grateful to the Permafrost Young Research Network (PYRN) for organizing a workshop for early career scientists interested in permafrost science.

Finally, we highlight the support and collaborative attitude of the International Permafrost Organization (IPA), which also provided travel support grants for early career researchers. We are indebted to Chris Burn and Emma Stockton, President and Executive Director of the IPA, respectively, for their support in the preparation of the scientific program and constructive comments on key questions on the organization.

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Session 24 /
Permafrost temperature changes and active layer dynamics: from local observations to global assessments of the permafrost System

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SESSION 1
Modeling of permafrost-climate feedbacks in future scenarios

Conveners:

- **Norman Steinert**. *NORCE Norwegian Research Centre, Bjerknes Centre for Climate Research;* nste@norceresearch.no
- **Sarah Chadburn**. *Department of Mathematics, University of Exeter;* S.E.Chadburn@exeter.ac.uk
- **Philipp de Vrese**. *Max Planck Institute for Meteorology, The Land ithe Earth System;* philipp.de-vrese@mpimet.mpg.de
- **David Wårlind**. *Department of Physical Geography and Ecosystem Science, Faculty of Science, Lund University;* david.warlind@nateko.lu.se

Summary:

Under global warming, permafrost degradation may accelerate climate change through increasing atmospheric CO_2 and CH_4 concentrations. Furthermore, the thaw of permafrost affects climate via numerous physical feedbacks leading to changes in water and energy fluxes to the atmosphere. Large inter-model differences in climate model projections indicate substantial uncertainties in the treatment of fundamental processes in Arctic regions, with permafrost areas as a significant contributor to this uncertainty. Depending on global warming trajectories, as in continuous-, zero- or overshoot emission scenarios, there is a wide range of possible permafrost futures- some of which may lead to irreversible changes in permafrost landscapes, altering feedbacks to the global climate. Understanding the combined impacts of permafrost physical, biogeochemical, and hydrological processes on regional and global ecosystem structure, functioning and interactions is of high interest to quantify uncertainty in future scenarios better and to reduce that uncertainty with improved modeling approaches. This session aims to bring together newly available projections of permafrost future scenarios and permafrost-climate interactions, with a particular focus on the modeling of biogeochemical and physical land surface dynamic. We invite all contributions that advance our understanding of the future of permafrost, whether by understanding cascading processes and interconnected risks, quantifying uncertainties, or making projections with improved process representation, using various methodological approaches from conceptual models to Earth system modeling.

Thaw depths and carbon release in adaptive emission driven MPI-ESM simulations

Goran Georgievski (Max Planck Institute for Meteorology), Thomas Kleinen (Max Planck Institute for Meteorology), Philipp de Vrese (Max Planck Institute for Meteorology), Victor Brovkin (Max Planck Institute for Meteorology) and Thomas Frölicher (Oeschger Center for Climate Change Research, University of Bern).

Abstract

The amount of organic carbon held in the frozen soil of high northern latitudes is with ~1700 PgC estimate, about twice as much as currently present in the atmosphere. As the earth's temperatures rise, the thawing of permafrost releases carbon into the atmosphere, exacerbating global warming. Irreversible soil-carbon losses in permafrost regions over centennial timescales suggest that these regions could act as a tipping element in the Earth System. However, the exact amount and rate of carbon release remain uncertain. Here, we apply the Adaptive Emission Reduction Approach (AERA) to calculate carbon emission trajectory to drive the Max Planck Institute Earth System Model (MPI-ESM), allowing free exchange of carbon dioxide between atmosphere, ocean, and land. The fossil fuel emissions in MPI-ESM simulations are interactively adapted to limit global warming to certain targets, for example to targets complying with the Paris Agreement. We perform a series of simulations until 2150 with the MPI-ESM, aiming to stabilize climate at 1.5°C, 2.0°C, and 3.0°C warming targets while interactively accounting for permafrost carbon thaw. These simulations allow us to quantify the impact of permafrost carbon-climate feedback on the remaining carbon budget for limiting global warming to well below 3.0°C, 2°C or 1.5°C above pre-industrial levels. Preliminary analysis suggests a twice as large deepening of the thaw depth by the end of the century in the 2°C simulation compared to 1.5°C target simulation. Simulations accounting for diagnostic thaw depth indicate up to ~0.3 m of deepening, and about 15 PgC release from the near-surface permafrost by the end of the century. An interactive accounting for released carbon in the atmosphere is still a work in progress and results will be presented at the meeting.

Representation of Arctic hydrology in a global land surface model

Tobias Stacke (Max Planck Institute for Meteorology), de Vrese Philipp (Max Planck Institute for Meteorology) and Victor Brovkin (Max Planck Institute for Meteorology).

Abstract

Earth System Models (ESMs) are the best available tools to project the coupled dynamics of the climate and biogeochemistry under future emission scenarios. However, the future trajectories simulated by individual ESMs vary substantially with most pronounced differences in the high northern latitudes. As recently demonstrated (de Vrese et al., 2022), a significant part of this uncertainty might result from the different approaches and parametrizations of surface and soil hydrology in the permafrost regions. However, this study did not account for sub-grid lateral fluxes.

To make a step forward, we further develop ICON-Land/$JSBACH_4$, the land surface model (LSM) used within the ICON-ESM. Our recent efforts are focused on improving the simulation of Arctic hydrology by accounting for lateral water flows on small spatial scales, i.e. within the grid cells of the LSM. For this, we apply a tiling structure in which we define the spatial relation between parts of the grid cell in terms of water exchange. In this way, the model gets information about the source and sink tiles of surface runoff (based on topography) but also of lateral soil water exchange (based on proximity and soil moisture gradient).

This approach results in a redistribution of surface and soil water within the grid cells with drier upland and wetter lowland regions and the correspondent changes in evapotranspiration. Comparing coupled land-atmosphere simulations with different prescribed fractions of upland and lowland areas, we see strong impacts of the tiling structure. Setups with a larger lowland-to-upland ratios lead to higher cloud cover and by up to 2K lower summer surface temperature over larger parts of the boreal regions. This result emphasizes the importance of representing the complex processes of Arctic hydrology, but also the need for detailed information about Arctic land surface properties.

Experimental and numerical evaluation of thermal properties of moss, lichen, and peat from a permafrost-dominated wetland

Simon Cazaurang (Institut de Mécanique des Fluides de Toulouse, Institut National Polytechnique de Toulouse), Manuel Marcoux (Institut de Mécanique des Fluides de Toulouse, Institut National Polytechnique de Toulouse), Michel Quintard (Institut de Mécanique des Fluides de Toulouse, Institut National Polytechnique de Toulouse), Sergey V. Loiko (BIO-GEO-CLIM Laboratory, Tomsk State University), Artem G. Lim (BIO-GEO-CLIM Laboratory, Tomsk State University), Oleg S. Pokrovsky (Laboratoire Géosciences Environnement Toulouse, Université Toulouse III - Paul Sabatier) and Laurent Orgogozo (Laboratoire Géosciences Environnement Toulouse, Université Toulouse III - Paul Sabatier).

Abstract

In arctic regions, a complex patchwork of low vegetation layer consisting of Sphagnum moss, lichen, and peat covers the permafrost active layer on millions of km², for instance in the lowlands of Western Siberia. Assessing the properties of this layer is crucial for modeling of soil thermal regimes, since this vegetation layer is the main interface between the atmosphere and the geosphere. Therefore, such an evaluation is compulsory to study climate change impacts on boreal regions.

In this work, the vegetation cover is assumed to be a fibrous porous media. Morphological and hydraulic properties of Western Siberian samples of this vegetation cover have been investigated in a previous study, showing high porosity and high water conductivity. The present work focuses on the evaluation of the thermal properties of the same Sphagnum, lichen, and peat undisturbed samples, using a coupled experimental and numerical approach. These samples consist of 12 dried cubes extracted in 2018 at Khanymey Research Station (Siberia). They are studied as well as some alive samples extracted from Clarens (Upper-Pyrenees). Macroscale thermal conductivity and thermal diffusivity are extracted from thermocouple data and heat flux data coupled with infrared thermography. The values are then compared to an analytic solution by bisection method. A two-phase numerical simulation is afterward conducted on macroscale sample reconstructions obtained by X-ray tomography in order to estimate the properties of the plant sprigs.

The preliminary results show that most of the samples are thermal insulators, in-line with field measurements. Infrared thermography shows high heterogeneity in thermal response. Yet, some further work is needed to better understand the linkage between water saturation and hydraulic and thermal properties' variability. Such study paves the way towards the generation of computationally-efficient surface boundary conditions for permafrost modeling in the considered site of Khanymey Research Station.

Modelling the effects of climate change on groundwater-surface water interactions in permafrost dominated regions

Radhakrishna Bangalore Lakshmiprasad (Institute of Fluid Mechanics and Environmental Physics, Leibniz Universitaet Hannover, Hannover, Germany), Thomas Graf (Institute of Fluid Mechanics and Environmental Physics, Leibniz Universitaet Hannover, Hannover, Germany), Andrew Frampton (Department of Physical Geography, Stockholm University, Stockholm, Sweden) and Aida Taghavi (Institute of Geodesy and Photogrammetry, Technische Universität Braunschweig, Braunschweig, Germany).

Abstract

The Qinghai-Tibet plateau is threatened by climate change. Due to its high elevation (average 4000 m.a.s.l), it experiences temperature increases which is twice the global average. Higher temperatures lead to an increase in permafrost degradation. As permafrost thaws, complex groundwater pathways are created that might either increase or decrease the surface water availability based on the hydrogeological conditions. This leads to spatial and temporal variations in runoff generation processes. Therefore, we aim to study the impacts of climate change on groundwater-surface water interactions.

The effects of climate change on permafrost can be quantified by coupling regional climate models with cryohydrogeological models. The regional climate models make predictions of atmospheric variables with a coarse spatial grid. A new statistical downscaling procedure is employed to determine the annual, seasonal, and extreme seasonal changes of the atmospheric variables from the regional climate model simulation results at the Yakou catchment. These changes are then translated as upper boundary conditions for the 2-D cryohydrogeological model. The advanced terrestrial simulator simulates cryohydrogeological processes: thermal and hydraulic subsurface processes with freezing/thawing, surface energy balance, overland flow with ice, and snow deposition/melting processes. The annual and seasonal changes in active layer depth and groundwater discharge are studied to assess the impact of permafrost degradation on surface runoff. Additionally, the effects of seasonal extremes on permafrost degradation are investigated. The results show that increased warming leads initially to an increase in active layer thickness and groundwater discharge. Therefore, groundwater discharge could be considered an indicator of permafrost degradation.

This abstract participates in the Outstanding PYRN Oral Communication / Poster Award

Modeling permafrost landscape evolution and greenhouse gas emissions from rapid thawing of ground ice with a new subgrid permafrost representation in CLM5

Esther Bender (Norwegian University of Science and Technology, Department of Biology), Matvey Debolskiy (NORCE Norwegian Research Center), Norman Steinert (NORCE Norwegian Research Center), Marius Lambert (University of Oslo), Kjetil Schanke Aas (CICERO Center for International Climate Research), Sebastian Westermann (University of Oslo, Department of Geosciences) and Hanna Lee (Norwegian University of Science and Technology, Department of Biology).

Abstract

Extended amounts of ground ice are common in the cold polygon tundra and sporadic permafrost zones, where palsas and peat plateau with permafrost have developed. With the accelerated warming in northern permafrost regions, ground ice has begun to melt. This ice melt leads to subsidence and changes in snow distribution, which are know to significantly influences hydrology, ground thermal regime and future greenhouse gas emissions (mainly the carbon to methane rate). Current land surface models do not represent micro-scale topographic processes in permafrost landscapes, resulting in large uncertainties in the prediction of future greenhouse gas emissions from the Arctic. Here, we extend the Community Land Model (CLM5) with a subgird representation of micro-scale topography of permafrost landscapes, based on the excess ice implementation of Lee et.al., 2014 and following the method of Aas, 2019. Typical patterned permafrost landscapes are represented by two dynamic tiles, with lateral heat and water transfer and snow redistribution. The height difference between the soil columns becomes dynamical and allows subsidence from melting of ground ice. With this an assessment of biogeophysical processes such the amount and ratio of carbon to methane emissions, due to subsidence and flooding, is possible. We evaluate the modeling approach on a thawing peat plateau in Norway and a polygon tundra landscape, by investigating the capacity to model current soil carbon content and greenhouse gas emissions. Our results illustrate the importance of micro-scale topography in modeling the evolution of complex permafrost landscapes. This model set up has the potential for global application and could significantly improve our understanding of future Arctic permafrost landscapes and greenhouse gas emissions.

Modeling influence of methane seeping on the water column carbonate system in the Laptev Sea Shelf

Evgeniy Yakushev (Norwegian Institute for Water Research), Anfisa Berezina (Norwegian Institute for Water Research), Matvey Novikov (Shirshov Institute of Oceanology RAS) and Igor Semiletov (POI RAS).

Abstract

Progressive permafrost thawing leads to excessive transport of organic matter (OM) from the land and massive bubbling methane (CH_4) release from degrading subsea permafrost in the Arctic shelf. The "extreme" aragonite under-saturation in the vast East Siberian Arctic Shelf (ESAS) reflects seawater acidity levels much higher than those projected in this region for the end of this century, as these are currently based only on atmospheric CO_2 (Semiletov et al., 2016). The changes in the carbonate system can be explained by an excessive production of carbon dioxide connected due to mineralization of land origin OM or /and oxidation of methane in the areas of intensive seeping. Here, we analyze consequences of CH_4 oxidation on the carbonate system state in the methane seepage areas. We used biogeochemical model BROM coupled with a vertical 2 Dimensional Benthic-Pelagic Model 2DBP and bubble fate model (Yakushev et al., 2021). BROM is a detailed biogeochemical model for the water column, benthic boundary layer (BBL), and sediments. BROM considers interconnected transformations of species (N, P, Si, C, O, S, Mn, Fe) and resolves OM in nitrogen currency. BROM includes a module describing the carbonate equilibrium; this allows BROM to be used to calculate pH and carbonates saturation states, as well as processes of formation and dissolution of carbonates. The model's alkalinity variations take into account changes connected with redox reaction consuming or releasing proton. Methanogenesis and aerobic and anaerobic methane oxidation are also parameterized. The gas bubble fate module parameterizes bubbles rising and dissolution. An application of the model allowed to estimate connection between an intensity of CH_4 release in the area (Shakhova et al., 2015) and changes in the carbonate system and to evaluate a volume of water affected. This research was funded by the Research Council of Norway: 315317 BEST-Siberian.

Climate response to improved permafrost hydro-thermodynamics in historical and scenario simulations

Félix García-Pereira (Complutense University of Madrid, Faculty of Physical Sciences, and Geosciences Institute (UCM-CSIC), Madrid, Spain), Jesús Fidel González-Rouco (Complutense University of Madrid, Faculty of Physical Sciences, and Geosciences Institute (UCM-CSIC), Madrid, Spain), Norman Julius Steinert (NORCE, Norwegian Research Centre, Climate and Environment, Bergen, Norway), Philipp de Vrese (Max Planck Institute for Meteorology, Hamburg, Germany), Johann Jungclaus (Max Planck Institute for Meteorology, Hamburg, Germany), Stephan Lorenz (Max Planck Institute for Meteorology, Hamburg, Germany) and Stefan Hagemann (Helmholtz-Zentrum Hereon, Geesthacht, Germany).

Abstract

Global warming is intensified across northern high latitudes due to polar amplification. Soil warming is particularly relevant therein since it enhances the release of substantial amounts of carbon from the degrading permafrost that acts as a positive radiative feedback. However, the increasing temperature is not the only factor affecting permafrost dynamics. Water availability changes induced by disruptions in the atmospheric general circulation considerably affect the soil moisture (ice) and thermal structure in permafrost regions. The interaction between hydrology and thermodynamics is still limitedly represented by some CMIP6 land surface models (LSMs), mostly regarding their depth, vertical resolution, and hydro-thermodynamic coupling.

This work explores the response of the Max Planck Institute Earth System Model (MPI-ESM) historical and scenario simulations to changes in the hydrological and thermodynamic features in permafrost-affected regions of its LSM, JSBACH. An ensemble of simulations was performed with varying soil depth and vertical resolution under two configurations of the hydro-thermodynamical coupling which generate rather “dry” or “wet” conditions over permafrost areas. Preliminary results show that deepening the LSM reduces the intensity of soil warming, delaying permafrost degradation and massive carbon release for some decades. Nevertheless, the largest influences on uncertainty are found in the dry and wet settings, which yield diverging water balance and warming conditions during the 21st century.

Surface-based temperature inversion impact on surface air temperatures and implications for permafrost distribution in Northwestern Canada

Nick Noad (University of Lethbridge) and Philip Bonnaventure (University of Lethbridge).

Abstract

One variable that is important to permafrost thermal properties is the mean annual air temperature (MAAT). In mountain valleys, elevation drives patterns of air temperatures. Often, temperature decreases with increased altitude (free-air lapse rates) or elevation (surface lapse rates, SLRs). When the reverse is true, a surface-based temperature inversion (SBI) is present. In Northwestern Canada, SBIs are semi-permanent during the winter season and are a frequent nighttime occurrence the remainder of the year. As a result, MAATs are colder in the low elevation areas compared to higher surrounding terrain. These patterns of surface air temperatures that are driven by SBIs are conceptualized to drive permafrost occurrence in the valley bottom and absence on surrounding slopes. We studied the influence of SBIs on surface air temperatures and subsequent permafrost distribution in Northwestern Canada. Radiosonde data from 1990 to 2016 for Whitehorse, Fort Nelson, Fort Smith, Norman Wells, and Inuvik were utilized to measure SBI characteristics of depth, frequency, and strength. These variables were combined into a new variable called SBI Impact which conceptualizes the impact of SBIs on surface air temperatures. SBI Impact ranged from 1.6 °C yr-1 in Whitehorse to 5.2 °C yr^{-1} in Inuvik. Second, elevational transect analysis was used in two dissimilar proximal (<10km apart) Northcentral Yukon valleys measuring SLRs and subsequent SBI strength and frequency. This research pointed to extraordinarily strong (2.67 °C 100 m^{-1}) and frequent (61%) SBIs resulting in annual average SLRs that were inverted (up to 1.2 °C 100 m^{-1}) in the first 100 to 150 vertical meters of the valleys. Permafrost was observed to occur in the valley bottom while being absent at some slope locations. This signifies the critical need to include the impact of SBIs for these high latitude mountainous landscapes in regional permafrost distribution modelling.

Modelling the impact of surface lapse rate changes on mountain permafrost distribution in four dissimilar valleys in Yukon, Canada

Madeleine Garibaldi (University of Lethbridge) and Philip Bonnaventure (University of Lethbridge).

Abstract

Due to the linear distribution of permafrost in low latitude and maritime mountains, it is hypothesized that with climate change the lower elevational limit of permafrost in these environments will move upslope as higher elevations are more prone to warming. This phenomenon is referred to as elevation dependent warming (EDW). However, in high latitude continental mountains this may not hold true due to the presence of persistent inversions (increasing air temperature with increasing elevation) and the non-linear elevational distribution of permafrost which may actually leave valley bottoms more susceptible to thaw than higher elevations. However, this is complicated by the presence of vegetation and organic material, which are more often found in valley bottoms, and may offer some protection to the underlying permafrost. To test the validity of EDW in high latitude, continental mountains, surface air temperature maps for four dissimilar valleys in Yukon, Canada (all wintertime inversion prone) will be modeled for several different future scenarios using downscaled climate reanalysis data and in-situ inversion measurements. These scenarios will include a combination of both incremental changes to the inversion strength and a baseline increase in the mean annual air temperature for each valley. The impact of warming considering changes in the inversion on the future ground thermal regime will then be assessed using the new air temperature distribution and current surface and thermal offsets. The ultimate aim of this study is to determine if the assumption of EDW applies to high latitude continental mountains or if the presence of persistent winter inversions results in a different distribution of warming. Understanding both the impact of inversions and the subsequent modification by surface characteristics on the ground thermal regimes in these high latitude continental mountains is critical to accurate prediction of permafrost response to climate change and potential related hazards.

Changes of permafrost environment under net-zero and negative emissions

Sowon Park (Pohang University of Science and Technology), Jong-Seong Kug (Pohang University of Science and Technology), Soon-Il An (Yonsei University), Ho-Jeong Shin (Yonsei University) and Hanna Lee (Norwegian University of Science and Technology).

Abstract

The Paris agreement aims to pursue efforts to limit global warming to well below 2°C, preferably to 1.5°C, compared to pre-industrial levels. In most analyzed pathways consistent with these climate targets, anthropogenic carbon dioxide (CO_2) emissions should reach net zero and then net negative. However, the possible temperature fluctuations under the net zero and negative emissions pathways may have significant impacts on the permafrost degradation and change the environment.

Here, we investigate the changes in permafrost environments under net-zero and negative emissions using Community Earth System Model 2; We examine the changes in terrestrial ecosystem processes, carbon balance, hydrological cycle, and energy budget in response to permafrost degradation.

We find that total amount of carbon loss in permafrost (~14PgC) is quite similar between two experiments despite their different CO_2 levels (~200ppm lower under negative emissions scenario). This is due to the significant warming caused by the recovery of the Atlantic meridional overturning circulation under negative emissions. In addition, increased inundated fraction and CH_4 production, including carbon loss, are irreversible under both scenarios and pronounced in the region with high organic matter fractions.

Permafrost-carbon feedback under emission overshoot scenarios

Norman Julius Steinert (NORCE Norwegian Research Centre AS, Bjerknes Centre for Climate Research, Bergen, Norway), Eleanor Burke (Met Office Hadley Centre, Exeter, UK), Jörg Schwinger (NORCE Norwegian Research Centre AS, Bjerknes Centre for Climate Research, Bergen, Norway) and Hanna Lee (Department of Biology, Norwegian University of Science and Technology, Trondheim, Norway).

Abstract

The permafrost-carbon feedback refers to the release of carbon dioxide and methane from permafrost soils due to increasing temperatures, with significant impacts on the global climate system, as these greenhouse gases contribute to further warming. Scenarios of temperature overshoot, in which temperatures temporarily exceed a target limit before being stabilized, present a complex challenge for predicting the permafrost-carbon feedback. Here, we investigate the permafrost-carbon feedback from the global perspective in response to idealized simulations of future carbon dioxide exceedance and removal with different modeling approaches ranging from complex to simplified Earth system models. Depending on the magnitude, length and timing of the overshoot, the corresponding temperature increase can lead to a more rapid and extensive thawing of permafrost than in the reference mitigation scenario. The associated permafrost-carbon cycle feedbacks indicate a strong response scaling with simulated overshoot warming. This leads to irreversible loss of soil carbon from permafrost regions, even after achieving net-zero emissions for some scenarios. However, shifts in the carbon sink fraction between the ocean, land and atmosphere after the overshoot may compensate for some of the carbon loss from the permafrost domain. Different modeling approaches generally agree on the direction of change but disagree on the magnitude of permafrost carbon and its effect on the global climate. This analysis highlights the relevance of considering the permafrost-carbon feedback in assessments of global climate change and sheds light on the dynamics of permafrost carbon under different emission overshoot scenarios, which allows refining thresholds for global carbon emission policies.

Impact of active layer thickening on vertical soil organic matter GHG emissions in a dynamic vegetation model

David Wårlind (Department of Physical Geography and Ecosystem Science, Lund University), Paul A. Miller (Department of Physical Geography and Ecosystem Science, Lund University), Lars Nieradzik (Department of Physical Geography and Ecosystem Science, Lund University), Stefan Olin (Department of Physical Geography and Ecosystem Science, Lund University) and Alexandra Pongrácz (Department of Physical Geography and Ecosystem Science, Lund University).

Abstract

With climate change happening at a faster rate at high-latitudes than the global average, it is important to understand the warming-induced permafrost thaw effect on high-latitude GHG emissions. As permafrost soils contain nearly half of the global soil C pool a change to active layer depths could substantially increase GHG emissions from the soil and hence the concentrations in the atmosphere. Here we present a version of the dynamic vegetation model LPJ-GUESS updated to include a new multi-layer soil organic matter scheme that makes it possible to simulate organic matter dynamics at all soil depths. Together with improved soil physics, hydrology, and snow representation, this new version of LPJ-GUESS can closely simulate the current best estimates of Arctic soil C at depths (e.g. NCSCDv2.2) making it possible to simulate emissions of CO_2, CH_4, and N_2O as the active layer thickens. We also present preliminary estimates of how the Arctic soil thermodynamics and biogeochemistry could change under different future scenarios, including overshoot scenarios, to see if the Arctic C balance will act as a net source or sink of greenhouse gases.

Estimation Rates of Permafrost Degradation and their Impact on Ecosystems across Alaska: Arctic and Subarctic Engineering Design Tool

Sergey Marchenko (Geophysical Institute, University of Alaska Fairbanks), Dmitry Nicolsky (Geophysical Institute, University of Alaska Fairbanks), Vladimir Romanovsky (Geophysical Institute, University of Alaska Fairbanks) and Kevin Bjella (U.S. Army Engineer Research and Development Center (ERDC), Cold Regions Research and Engineering Laboratory (CRREL).

Abstract

We presenting the modeling assessment of the impact of climate change on permafrost conditions in Alaska and products of the year first of the project funded under the U.S. Army Engineer Research and Development Center (ERDC) and addressing the CRREL-2 Terrain Properties and Processes Technical Area. The main goals of this research are to evaluate the vulnerability and behavior of permafrost under climate warming across the different ecosystems and surface conditions in respect of ecosystem stability, socioeconomic impact, and to provide U.S. Alaska and DoD stakeholders with information for better understanding possible future environmental changes. The first year (Part-1) of this three-years research, we described of our efforts on the estimation of climate impact to the natural conditions of the Alaskan ecosystems. We suggested the new version of the Geophysical Institute Permafrost Laboratory spatially distributed permafrost dynamics model (GIPL2-MPI), which is developed in the Geophysical Institute, University of Alaska Fairbanks (UAF) and simulating soil temperature dynamics and the depth of seasonal freezing and thawing by solving one- and two-dimensional parabolic non-linear heat equation with phase change numerically. This model based on the ecosystem approach to simulate the permafrost dynamics, which we are discussing in this paper. We combined ground-based observations and numerical freeze/thaw modeling (GIPL2-MPI permafrost dynamics model) using a climate-permafrost interaction to understand the physical processes and mechanisms controlling permafrost physical state. We predict the changes in permafrost conditions using two GCMs (NCAR-CCSM4 and GFDL-CM3) and Five Models Averaged Ensemble for the RCP-4.5 and RCP-8.5 scaled down to 1 by 1 km spatial resolution (https://uaf-snap.org/) across entire Alaska. The six GIPL2-MPI model runs were performed for the natural conditions. As a criterion of permafrost degradation, we used the active layer thickness (ALT), top of permafrost deepening and talik development (residual thawed layer between seasonal frost penetration and permafrost table) as well as position of permafrost base, which means thinning of permafrost. Initial results of simulations show that by the end of the current century the widespread permafrost degradation could began everywhere in Alaska southward the Brooks Range as well as across of some spots of the North Slope. The most significant changes in the upper layer (0.5 – 5.0 m) of ground could be occurred under the climate scenario provided by the GFDL-CM3 climate model with both 4.5 and 8.5 RCPs. Increase in soil temperature under RCP-4.5, the peak appeared around 2041-2060, then observed relative decline in soil temperature. In the RCP-8.5, ground temperature continues to rise throughout the 21st century.

How do limited observations impact predictions of complex systems?: a comparison of process model and machine learning approaches to estimate current and future high-latitude carbon balance

Ian Shirley (UC Berkeley), Zelalem Mekonnen (Lawrence Berkeley Laboratory), Robert Grant (University of Alberta), Baptiste Dafflon (Lawrence Berkeley National Laboratory) and Wiliam Riley (Lawrence Berkeley National Laboratory).

Abstract

Although the high-latitude carbon (C) cycle is an important, very complex, and highly uncertain component of the global climate system, data availability in the region is severely limited. Process models generally agree that the region is currently a slight sink of C, but some recent studies used machine learning (ML) upscaling to predict that the region is already a net C source. These ML predictions, however, were not tested against independent measurements. Regardless of methodology, there is little consensus on the trajectory of high-latitude C balance throughout the coming century. Here, we characterize drivers of current and future high-latitude C fluxes simulated by ecosys, a well-tested and process-rich mechanistic ecosystem model, and then evaluate the ability of ML algorithms to predict these simulated fluxes.

We first perform extensive additional evaluation of ecosys using site and observation-based data products. Then, we explore the large-scale controls on terrestrial C cycling across Alaska throughout the 21st century. Our results suggest that shifting seasonality of biological processes will increase the C sink strength of high-latitude ecosystems throughout the coming century, and highlight the importance of adequate representation of cold-season processes. Next, we show that ML methods incorrectly predict that Alaska is currently a net source of C when existing site coverage is used for training. ML predictions improve with increased spatial coverage of the training dataset. However, even a ML model trained with 240 Alaskan sites incorrectly predicts C fluxes under 21st century climate change because of changes in atmospheric CO_2, litter inputs, and vegetation composition that have impacts on ecosystem dynamics which cannot be inferred from the training data. Taken together, these results highlight the need for cautious interpretation of ML-derived data products and demonstrate the importance of capturing complex processes when predicting C fluxes.

Abrupt change in subarctic wildfires following future permafrost thawing

In-Won Kim (Institute for Basic Science, Center for Climate Physics), Axel Timmermann (Institute for Basic Science, Center for Climate Physics), Keith Rodgers (Institute for Basic Science, Center for Climate Physics), Sun-Seon Lee (Institute for Basic Science, Center for Climate Physics), Hanna Lee (Norwegian University of Science and Technology) and William Wieder (Institute of Arctic and Alpine Research, University of Colorado Boulder).

Abstract

Unabated 21st-century climate change will accelerate Subarctic permafrost thawing that can intensify microbial degradation of carbon-rich soils, which is expected to provide positive climate feedback. A lesser-known impact of permafrost thawing is changes in wildfires, which can also contribute to the release of greenhouse gases and aerosols. Here we present a comprehensive analysis of the effect of future permafrost thawing on land surface processes in the Subarctic/Arctic region using the 50-member CESM2 large ensemble, under a historical and SSP3-7.0 concentration pathway. The model captures the coupling between permafrost and hydrology, with projected permafrost thawing leading to substantial upper soil drying, surface warming, and reduction of relative humidity over the Subarctic. Collectively this leads to abrupt late-21st-century regime shifts and intensification in Subarctic wildfire occurrences by up to several orders of magnitude.

Similar Arctic methane emissions under wet and under increasingly dry conditions?

Philipp de Vrese (Max Planck Institute for Meteorology, The Ocean in the Earth System, Hamburg, Germany), Lutz Beckebanze (Universität Hamburg, Institute of Soil Science, Hamburg, Germany), Leonardo Galera (Universität Hamburg, Institute of Soil Science, Hamburg, Germany), David Holl (Universität Hamburg, Institute of Soil Science, Hamburg, Germany), Thomas Kleinen (Max Planck Institute for Meteorology, The Ocean in the Earth System, Hamburg, Germany), Lars Kutzbach (Universität Hamburg, Institute of Soil Science, Hamburg, Germany), Zoé Rehder (Max Planck Institute for Meteorology, The Ocean in the Earth System, Hamburg, Germany) and Victor Brovkin (Max Planck Institute for Meteorology, The Ocean in the Earth System, Hamburg, Germany).

Abstract

The strength of the permafrost carbon feedback will partly depend on the fraction of carbon that is emitted as methane instead of carbon dioxide. The global warming potential of CH_4 is an order of magnitude higher than that of CO_2 (Stocker et al., 2013), but the former is only produced during decomposition under anoxic conditions. This requires water-saturated soils, making methane emissions highly dependent on the soil hydrology in the Arctic and subarctic zone (Olefeldt et al., 2012, Knoblauch et al., 2018). Simulations using land surface models without considering atmospheric feedbacks suggest that the future, warming-induced rise in methane emissions in the continental Arctic will be severely limited by the drying of the landscape resulting from permafrost degradation (Lawrence et al., 2015). We used the MPI Earth system model (MPI-ESM) to demonstrate that accounting for land-atmosphere interactions challenges this understanding. In two sets of idealized simulations, capturing wet and increasingly dry conditions, a modification of the permafrost hydrology within the uncertainty range led to two very different climate trajectories which, however, result in similar terrestrial methane fluxes. While a wet future Arctic exhibits almost twice the wetland area than a dry Arctic, the latter may feature even higher methane emissions mainly due to an enhanced plant productivity caused by a warmer climate. The latter is the result of a reduction in evaporation which led to less cloud cover and more incoming solar radiation at the surface. We also find that land-atmosphere feedbacks in the high latitudes, usually neglected in studies of permafrost regions, affect the climate far beyond its boundaries, invoking differences in tropical wetland CH_4 emissions between the wet and the dry trajectories that are much larger than those in the permafrost regions.

SESSION 2
Education & Outreach: Cartoons, Communities, and Cooperation

Conveners:

- **Anna E. Klene**, *University of Montana*, anna.klene@umontana.edu
- **Xiangbing Kong**, *Université Laval*, xiangbing.kong.1@ulaval.ca (PYRN representative)
- **Ylva Sjöberg**, *University of Copenhagen*, ys@ign.ku.dk

Summary:

In our changing world, permafrost has become a topic of interest and importance beyond curiosity-driven academic research. Locally in and beyond the Arctic, changes in permafrost impact infrastructure and living conditions of societies and people in everyday life more often than before. But thawing of permafrost has also become a problem discussed far from the world's cold regions due to the feedbacks and connections to the global climate system. In this context, there is now increasing need and demand for communication and education about permafrost, with the general public, policy makers, and with schools and within higher education. This session provides a forum for the exchange of information and ideas for past, current, and future permafrost education and outreach activities. We welcome contributions focusing on science outreach projects targeted to K-12 audiences, the general public, elders and local communities, and audiences residing outside of the permafrost regions. We also welcome contributions focusing on educational initiatives for undergraduate and graduate students. Projects focused on communities ranging from local indigenous villages and small communities with creative solutions to living with permafrost or agriculture, to those targeted to large cities in multiple countries, as well as educational materials from cartoons to classroom-based lessons are welcome. We are also curious to hear about lessons learned in teaching and outreach during the special conditions of the COVID-19 pandemic. This session is not limited to permafrost scientists but invites participation from other polar or educational organizations.

So real, so cool - Sunny Smog Digs Permafrost in VR!

Deanna Ewers (Sunny Smog), Karen Stritzinger (Old Hara Studios), Frédéric Bouchard (Université de Sherbrooke) and Ylva Sjöberg (University of Copenhagen).

Abstract

Enter a story that connects kids from blazing hot California and Yakutsk, the coldest city on earth. In a Virtual Reality (VR) Permafrost Land, they learn about thawing permafrost, its effect on the kids from Yakutsk, the science behind it, and how it relates to the drought and more in California. They meet the scientists and artists who created Permafrost Land and learn that even though they are from different parts of the world, global warming is affecting them all and they actually have much in common.

Deanna Ewers is an artist with a focus on storytelling and educational contents and years of experience working on educational apps, games and animations. Sunny Smog is Deanna's systemic exploratory platform for unlocking the realization that creative, inspirational launching points to wondrous learning are everywhere. In Sunny Smog comics and immersive worlds, kids can see inspired and supportive characters connect to the art and science found in their neighborhoods illustrating a variety of ways to discover the world.

For Sunny Smog Digs Permafrost in VR!, Deanna teamed up with scientists and VR developers to create an immersive VR comic. This includes a permafrost storyline, interactive features, a soundtrack and theme songs, and an operating VR app. In the first Sunny Smog VR comic, permafrost scientists provide not only the permafrost data, but they also become characters in the story to share scientific inspiration.

The presentation will include a screencast of the brand-new VR experience, and an overview of the creative process and planned future developments, such as scientifically accurate dioramas and creation tools. Through a VR demonstration, attendees will be able visit VR Permafrost Land and travel through portals throughout the story to give them a more immersive and interactive experience.

"Introduction to permafrost": First outreach course (in Spanish) in Twitter

Rubén Ramos (Departamento de Geología, Geografía y Medio Ambiente. Universidad de Alcalá) and Miguel Ángel de Pablo (Departamento de Geología, Geografía y Medio Ambiente. Universidad de Alcalá).

Abstract

The popularization of social networks in recent years has provided a great opportunity for dissemination of content. In this context, Twitter is a tool that facilitates users' access to scientific knowledge given its immediacy and huge impact. On the other hand, Permafrost is one of the least studied elements of the cryosphere, despite its key climatic functions. It is also a great unknown by the general public, especially in countries where this cryosphere element is not present, such as Spain. For this reason and given the difficulties of science to approach a non-specialist audience, the opportunity, and the need for scientific dissemination on permafrost arises, choosing Twitter as the tool to develop this task. The analysis of existing dissemination on Twitter shows the great differences between Spanish and English, with very few profiles (personal or institutional) focused on permafrost. Therefore, there is a noticeable need to contextualize the situation of permafrost in Spanish-speaking countries. In this context, the "FIRST INTRODUCTION COURSE TO PERMAFROST" was developed at the @Permafrost_UAH twitter account (https://twitter.com/i/events/1438552472302366720), managed by Dr. M.A. de Pablo, head of the PERMATHERMAL network to monitor permafrost and active layer in Livingston and Deception Islands, South Shetland Archipelago, Antarctica. The course, obviously completely free, had a duration of 5 weeks and it was divided in 5 main topics: (1) Definitions and concepts, (2) The importance of the study, (3) Management and international protocols, (4) Methods and (5) The study of permafrost in Antarctica. All 94 tweets were published from Monday to Saturday, and on Monday, a link to a short test on Google Forms was published. After clicking "Like" in each tweet of the course, and completing a final evaluation test, the participants were awarded a symbolic document of completion of studies.

Promoting real-world working-life permafrost competence through internships

Ylva Sjöberg (University of Copenhagen), Britta Sannel (Stockholm University), Hanne H. Christiansen (The University Centre in Svalbard) and Julie Malenfant-Lepage (Norwegian University of Science and Technology, Trondheim).

Abstract

Thawing permafrost impacts human activities in and beyond the Arctic and creates a societal need for permafrost knowledge. Teachers in higher education must therefore look beyond traditional campus-based learning and theoretical-focused knowledge and promote the application of permafrost knowledge beyond university classrooms. Internships can help students realize their permafrost knowledge as a competence in a professional setting and at the same time provide platforms connecting students, academics, and professionals with interests in permafrost.

Through discussions among teachers and students from ten Nordic universities, we identified the values of an international permafrost internship service in the context of future educational needs and demands. Such service could address:

• Teachers' struggles to build a pedagogical structure that maximizes the learning outcomes from internships. • Students' struggles to connect with relevant internship hosts. • Struggles among local authorities, private companies (and other potential internship hosts) to access and apply permafrost knowledge to real-world problems.

The aim of the PermaIntern project is to develop a service to help students, teachers, and hosts implement internships related to permafrost and seasonal frost in university educations. Internships are already integrated in many university educations, but the extent and formats of internships varies between disciplines, countries, and university programs. Our vision is a high-quality, flexible program that can attract students from different institutions, levels and, disciplines to hosts in the Arctic or other permafrost areas. The service should provide pedagogical structure for students to apply permafrost knowledge in a professional context. The program will also generate a network linking professionals and academics around the topic of permafrost, which may serve as a pan-arctic resource of permafrost competence in a thawing Arctic.

We will present our proposed programme for a permafrost internship service developed by partners at Nordic universities and discuss planned and potential future developments, including expansion beyond the Nordic region.

UndercoverEisAgenten - The bird's eye view of permafrost degradation

Soraya Kaiser (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Resarch), Josefine Lenz (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Resarch), Oliver Fritz (Heidelberg Institute for Geoinformation Technology (HeiGIT gGmbH), Christian Thiel (German Aerospace Center (DLR): Institute of Data Science), Marlin M. Müller (German Aerospace Center (DLR): Institute of Data Science), Sabrina Marx (Heidelberg Institute for Geoinformation Technology (HeiGIT gGmbH), Alexander Zipf (Heidelberg Institute for Geoinformation Technology (HeiGIT gGmbH), Hugues Lantuit (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Resarch) and Moritz Langer (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Resarch).

Abstract

Where Permafrost degradation leads to ground subsidence it reshapes the landscape and threatens infrastructure and livelihoods of Arctic communities. Off-the-shelf photographic drones (UAV) allow a detailed imaging of the land surface of tundra landscapes and give an indication on where permafrost is destabilized. Together with students from Aklavik in Canada's Northwest Territories, the UndercoverEisAgenten project makes use of this technology to detect and analyze land surface changes based on drone images. In fall 2022 students from Moose Kerr School (grades 7-9), accompanied by a small research team from Germany, went on field trips in and around the hamlet of Aklavik to acquire images of land surface changes attributed to permafrost degradation. The joint effort resulted in 30,000 drone images building the basis for generating high-resolution 3D point clouds and orthomosaics. To derive land surface changes, these acquisitions will be repeated independently by the students. The images are further incorporated in a crowdmapping application, giving citizen scientists all over the world the opportunity to be part of the project by classifying the state of the permafrost landscape based on the drone footage. The citizen science project strives to connect Indigenous Knowledge about landscape changes with scientific research to advance our understanding of permafrost thaw, and raise awareness about climate change in the classrooms of Aklavik, Germany and beyond.

A New Model for Ice Cellar Monitoring Emphasizing Community Input and Practical Vulnerability Reduction Measures

Kelsey Nyland (George Washington University), Anna Klene (University of Montana), Frederick Nelson (Northern Michigan University), Nikolay Shiklomanov (George Washington University) and Dmitry Streletskiy (George Washington University).

Abstract

ñupiaq sigļuaq, or ice cellars, are excavated into permafrost to provide easily accessible cold storage for large quantities of game, fish, and other foods harvested for subsistence. This traditional food storage practice dates back at least a millennium in Alaska and represents a means by which permafrost offers cultural and regulatory ecosystem services to Iñupiat. Catastrophic flooding and collapses, among other issues have been related to warming climatic conditions and community residential development. This paper provides an update on an ice cellar temperature monitoring program in Utqiaġvik (formerly Barrow), Alaska, operational from 2005 to 2018 as part of outreach activities by the Circumpolar Active Layer Monitoring program in collaboration with several local whaling captains, and the Native Village of Barrow Iñupiat Traditional Government. Three of the five monitored cellars in the community exhibited slightly warming mean annual internal temperatures. Additionally, two cellars flooded and partially collapsed, while another was abandoned due to sloughing walls. Based on experiences gained from 17 years of ice cellar thermal monitoring in Utqiaġvik, consideration of a Source-Pathway-Receptor-Consequence (SPRC) model is recommended to aid evaluation of specific vulnerabilities of this example of a traditional frozen infrastructure, and to improve monitoring programs with increased community participation. Any attempt to provide data practical for community resilience decisions should begin with identifying and communicating process components, thereby bridging stakeholder heuristic and science-based knowledge.

Food Storage in Permafrost and Seasonally Frozen Ground in the Arctic

Kenji Yoshikawa (University of Alaska Fairbanks), Alexey Maslakov (Moscow Sate University) and Anna Klene (University of Montana).

Abstract

Food cellars are a natural form of refrigeration in permafrost or seasonally frozen ground used to preserve, age, and ferment foods harvested for subsistence, including marine mammals, birds, fish, and plants. Indigenous peoples throughout the Arctic have constructed cellars in frozen ground for millennia. Many traditions associated with cellars are threatened in communities in Russia because of the impacts of climate change, relocation, dietary changes, and industrial development. However, even with warmer temperatures, cellars still provide a means to age and ferment food stuffs following traditional methods. In cooperation with local stakeholders, we measured internal temperatures. Though cellars are widely used in permafrost regions, their structure, usage, and maintenance methods differ and exhibit influences of local climates, traditions, and economic activities. Monitoring internal temperatures and recording structural descriptions of cellars is important in the face of climate change to better understand the variety and resilience of living adaptations in different cold regions.

Interactive maps: A powerful and appealing tool for knowledge transfer

Alexander Bast (WSL Institute for Snow and Avalanche Research SLF, Alpine Environments and Natural Hazards), Kevin Patrick Helzel (WSL Institute for Snow and Avalanche Research SLF, Alpine Environments and Natural Hazards), Robert Kenner (WSL Institute for Snow and Avalanche Research SLF, Alpine Environments and Natural Hazards), Jeannette Nötzli (WSL Institute for Snow and Avalanche Research SLF, Alpine Environments and Natural Hazards), Marcia Phillips (WSL Institute for Snow and Avalanche Research SLF, Alpine Environments and Natural Hazards) and Frank Graf (WSL Institute for Snow and Avalanche Research SLF, Alpine Environments and Natural Hazards).

Abstract

In a world where the Internet is ubiquitous, and various social media channels and web apps are frequently used, researchers need to strive and focus on valuable and targeted content in their field of application. For this purpose, websites offer many powerful elements, one of which are interactive, dynamic maps for custom interface features. However, the challenge is that the content must reflect current research but also that the maps must be tailored to the user to provide the most up-to-date and unbiased, albeit modelled, image possible. With the web platform maps.wsl.ch, we explore new, innovative and creative ways of collaboration between science, industry and society. Our core idea aims to combine interdisciplinary research with transdisciplinary cooperation approaches. This way, we make our results accessible to users in a simple, comprehensible way. Therefore, we use digitization to explore new ways of knowledge transfer: cartographically, interactively, agilely, and dynamically. Almost 3.5% of Switzerland is underlain by permafrost. Our permafrost app primarily intends to support practitioners in the realization of construction projects or natural hazard management related to mountain permafrost. The web app currently shows the permafrost and ground ice map by Robert Kenner and others (doi: 10.5194/tc-13-1925-2019), which distinguishes between ice-poor and ice-rich permafrost and helps to assess the local and regional permafrost distribution in Switzerland. Furthermore, the sites of the Swiss Permafrost Monitoring Network (PERMOS) are mapped to link measured and openly available field data. The 3d visualization combined with high-resolution aerial images (www.swisstopo.admin.ch) creates a highly realistic impression of the terrain. Geoprocessing currently allows, for instance, the direct input of coordinates, the upload and visualization of own shapefiles or the creation of detailed elevation profiles. The integration of the SLF/PERMOS rockfall database and the key research sites are planned for future updates. Furthermore, we plan to link the permafrost app with the other apps on maps.wsl.ch to complement inter- and transdisciplinarity in natural hazard management.

Support education of climate change and permafrost at primary school, the PRISMARCTYC project

Antoine Sejourne (GEOPS - Universite Paris-Saclay), Lydie Lescarmontier (Office for Climate Education, Fondation La main à la pâte), Frederic Bouchard (Département de géomatique appliquée, CARTEL, Université de Sherbrooke), David Wilgenbus (Office for Climate Education, Fondation La main à la pâte), Laure Gandois (CNRS) and François Costard (Laboratoire Géosciences Paris-Saclay (GEOPS), UMR 8148, Université Paris-Saclay).

Abstract

Teachers have a key role to play in the climate change context and it is essential that they receive sufficient support from the scientific community as underlined by UNESCO Strategy for Action on Climate Change. Sharing the current evolution of the Arctic and the impact for the local population is a major issue. Teachers are key to success, and they need more than ever connections with the ongoing science and turnkey pedagogical tools on these complex issues. The PRISMARCTYC project aims to better understand the impacts of permafrost thaw on soils, surface/groundwater fluxes and carbon cycle, as well as their controlling factors. This project emphasizes the teaching of climate changes and outreach activities in local communities by involving four primary schools in Yakutia and in France, an association of Sakha ecological education and the Office for Climate Education. A first objective is to conduct outreach activities about climate change and permafrost in of primary schools. Since 2019, researchers have been visiting schools in small village in Central Yakutia and in France with the project “Describe me the country where you live” funded by the Universite Paris Saclay. Cultural, linguistic and scientific exchange are then organized between the school of Syrdakh (Central Yakutia) and two schools of Chatenay Malabry (Paris region, France) which were at the origin of a blog made for French children in order to help them to follow the field study in Central Yakutia and ask questions. A second objective is to design a teacher handbook with background and turnkey activities about climate change and permafrost in the Arctic. OCE has expertise in writing teacher handbooks. The aim of this guide is to support teachers in implementing a range of interdisciplinary activities on climate change and permafrost and to promote active pedagogies (inquiry, role-play, project-based learning).

International postgraduate training on rock glacier monitoring in the semiarid Andes, Chile

Shelley MacDonell (Lincoln University), Benjamin Robson (University of Bergen), Gidske Andersen (University of Bergen), Pål Ringkjøb Nielsen (University of Bergen), Jostein Bakke (University of Bergen) and Diego Cusicanqui (University of Grenoble).

Abstract

Hydrological stress in arid mountainous regions is increasing the need for better understanding of rock glacier processes. This motivation prompted the development of the first Summer school on cryospheric monitoring and water resources in the Chilean Andes held in December 2022. This summer school brought together twenty students from Europe, South America, North America, and Asia to integrate close-range remote sensing techniques (Unmanned Aerial Vehicles; UAVS and tablet-based GIS geomorphological mapping) with Earth Observation Data (satellite data and aerial photography) for the study of glacial and periglacial environments. The course was held over 11 days in La Serena, Chile, and combined three days of introductory practicals where students worked with deriving glacier and rock glacier volume changes and surface velocities, based on high-resolution satellite data, as well as extracting trends in regional snow-cover using Google Earth Engine. The students then spent five days of fieldwork in the La Laguna basin (30ºS) learning how to safely plan and acquire data using UAVs, measure kinematic points on the rock glacier surface, and performing geomorphological mapping to understand previous glacier fluctuations. Following fieldwork, the students had three additional days of data processing before presenting their final work to the wider scientific community in La Serena. Students were also introduced to the wider social context of working in the Andes, including meeting with stakeholders and members of the citizen science programmes ongoing in the region. In this presentation we will detail the activities undertaken as well as the lessons learned from undertaking a summer school in the high Andes.

The Story of Ground Surface Temperature

Raul-David Serban (Institute for Alpine Environment, Eurac Research) and Mihaela Serban (Applied Geomorphology and Interdisciplinary Research Centre, West University of Timișoara).

Abstract

Marv, the marmot, is telling the Story of Ground Surface Temperature through captivating comic strips for kids and youth. Ground surface temperature (GST), measured at 5 cm into the ground, is important for understanding the climate change impacts on various environments. The Marie-Curie Seal of Excellence project TEMPLINK focuses on improving the monitoring and modeling of GST from thermal satellite images and numerical modeling (https://www.eurac.edu/en/institutes-centers/institute-for-alpine-environment/projects/templink). An accurate estimation of GST leads to a better understanding of the complex interaction between atmosphere and soil, which impacts the physical, chemical, and biological processes of the terrestrial ecosystem. A cartoon booklet was created to better explain the project's purpose to kids by taking advantage of an animated story narrated by the marmot Marv. The commit strips are available online on Academia: https://www.academia.bz.it/strips/the-story-of-the-ground-surface-temperature. In addition, a 3D fiber-art object was also created to communicate the project's purpose to a broader audience. The fiber art object is a miniature 3D model of an alpine valley (Mazia Valley where the model is developed) with different cord colors and textures for every type of land cover. The object is accompanied by a hanging satellite also made from cords and a flyer that explains this mix of art and science. The fiber-art object can be exposed in art galleries, touristic info centers, or during workshops and science fairs.

"WWF Youth: Expedition Climate": Empowering young people to communicate Arctic climate change and the need for climate action to new audiences

Jan Nitzbon (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Katharina Jentzsch (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Josefine Lenz (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Laura Weniger (WWF Germany), Anne Wiebelitz (WWF Germany), Gesine Leidicke (WWF Germany) and Claire Treat (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research).

Abstract

Nowhere else in the world is climate change as noticeable and measurable as in the Arctic, and nowhere else it is happening faster. In the fight against global warming, most of the energy comes from young people who can reach out to society, politics and industry with their courage, urgency and emotionality. The WWF Youth Campaign "Expedition Climate: Exploring, communicating, and changing" is a two-year science communication project started in January 2023 and aiming to communicate the urgent need for climate action by novel means to a broad public audience. For this, 16 young people (age 18 to 26) from the WWF Youth organization have teamed up and committed themselves to a long-term campaign in which they first learn about various aspects of climate change and later realize their own communication projects. In the course of the campaign, the campaign team will be trained as multipliers who can reach people with their well-founded yet emotional reporting and strengthen understanding and courage for necessary changes in politics, industry and society. During the first phase of the project from January to June 2023, the participants attend regular online meetings where they get to know each other, grow together as a team, and get input by external experts about different aspects of climate change including the scientific basis, political and societal perspectives, as well as journalistic approaches. A particular focus of the campaign is on impacts and implications of climate change in the polar regions. For this, the WWF Youth cooperates with scientists from the Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research who are conducting field work and land expeditions in the Arctic. As a highlight of the first phase of the campaign, in May 2023 a part of the team is joining an expedition to the Hyytiälä Forestry Field Station in Finland, while another part of the team is staying in Germany in order to work with different press offices and targeted communication activities. Both teams give an exclusive media insight into the work of research institutes and explain the importance of climate research via diverse social media channels. In this talk, we give an overview of the science communication project and report on the activities, the progress, and the experiences from the first phase of the project. We discuss challenges along the way, reflect on the cooperation between scientific research institutes and NGOs, and give an outlook on the remaining phases of the project.

Progress in the development of an illustrated plain-language version of the Glossary of Permafrost and Related Ground-Ice Terms

Antoni Lewkowicz (University of Ottawa), Stephen Wolfe (Natural Resources Canada), Ashley Rudy (Government of the Northwest Territories), Pascale Roy-Léveillée (Université Laval), Vladislav Roujanski (Tetra Tech), Brendan O'Neill (Natural Resources Canada), Cassandra Koenig (BGC Engineering), Ed Hoeve (HoevEng Consulting), Stephan Gruber (Carleton University), Nick Brown (Carleton University), Heather Brooks (BGC Engineering) and Philip Bonnaventure (University of Lethbridge).

Abstract

The 12 members of the Permafrost Terminology Action Group (PTAG) of the Canadian Permafrost Association have been working since 2021 to update the Glossary of Permafrost and Related Ground-Ice Terms, first published in 1988, and subsequently updated as the IPA's Multilanguage Glossary. PTAG members have reviewed the 400 terms in the existing Glossary as well as about 100 potential new entries and are currently drafting or editing individual definitions and comments for subsequent approval by the group as a whole. More than 100 of the terms are being considered for inclusion in an illustrated plain-language version of the Glossary which is being drafted simultaneously. This version is aimed at education and outreach, with audiences such as northern residents, the media and non-specialists. The goal is to support clear communication about permafrost and permafrost change through the provision of clear definitions in accessible language. The list of entries includes fundamental terms such as permafrost, ground ice, frost heave, thermokarst, thermosyphon and rock glacier. It also includes certain terms that will appear in the full Glossary for the first time, such as air-cooled embankment, ice cellar, lithalsa, permafrost carbon-climate feedback and yedoma. The text used for entries in the plain-language version generally differs from the technical version, and frequently includes additional information under the heading "Did you know?", as well as an illustration (photo or diagram). PTAG aims to complete a draft of the illustrated plain-language version and the technical version for feedback in 2023, with publication in time for the 2024 ICOP in Whitehorse.

SESSION 3
Permafrost land-ocean interactions: fluxes, transport processes and degradation pathways

Conveners:

- **Michael Fritz**, *Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research*; michael.fritz@awi.de
- **Lisa Bröder**, *ETH Zurich, (PYRN);* lisa.broeder@erdw.ethz.ch
- **Jorien Vonk**, *Vrije Universiteit Amsterdam*; j.e.vonk@vu.nl

Summary:

Thermokarst, retrogressive thaw slumps and bank erosion of rivers, lakes and coasts remobilize large quantities of previously freeze-locked carbon, nutrients and pollutants. This has great significance for permafrost-carbon-feedback considerations as well as for the ecosystem response to increased (i) sediment load, (ii) nutrient supply, and (iii) pollutant exposure. Hydrological processes play a crucial role in determining the rate and type of material released from thawing permafrost, affecting its biogeochemical role and eventual fate in aquatic systems. In this session, we welcome contributions that: quantify and characterize the release of organic matter (OM), nutrients and/or pollutants from abrupt permafrost degradation and riverine discharge, present watershed budgets incorporating both terrestrial and coastal matter fluxes and transport modes, assess the composition, bioavailability and decomposability of OM, assess the biogeochemical fate of permafrost-derived carbon, nutrients and pollutants in terrestrial waters and in the coastal zone.

We welcome contributions that focus on field-based studies and modeling efforts, or a combination thereof.

Mobilization and export of permafrost carbon through groundwater flow

Alexandra Hamm (Stockholm University) and Andrew Frampton (Stockholm University).

Abstract

The fate of currently immobilized permafrost carbon is of paramount importance to understand the consequences of the permafrost climate feedback for global climate change. While estimates on the amount and spatial distribution of carbon stocks in permafrost landscapes improve, there is less certainty about the mobilization of the previously frozen carbon. On the one hand, this carbon might become available for microbial decomposition and gets turned into carbon-dioxide or methane, but on the other hand, the thawed out carbon might also get dissolved in groundwater and transported as dissolved organic carbon (DOC). At one point, the DOC in the groundwater will reach surface waters and might ultimately get deposited in the shelf sediments of the Arctic Ocean. This leads to a high uncertainty in the calculation of permafrost carbon that actually ends up in the atmosphere upon thaw. Export and deposition might have the potential to decrease the total amount of greenhouse gas release from permafrost to the atmosphere. Here, we present preliminary results of a modeling study that aims at quantifying the groundwater transport of solutes such as DOC thawed out of a mountainous, continuous permafrost landscape. We investigate transport velocities under different hydrological scenarios as well as changes in the overall hydrological connectivity due to increases in active layer depths. Furthermore, we investigate the differences in transport for different depths within the soil. This way, we can represent carbon transport of "young" carbon found close to the surface as compared to "old" carbon, which thaws out of the permafrost. The results will help us to further our understanding of the permafrost climate feedback and how we should account for transport processes in Global Climate Models.

Pulses of sub-ice microbial activity during winter: evidence from nitrate concentrations and silicon isotopes in the Lena River

Sophie Opfergelt (Earth and Life Institute, UCLouvain), François Gaspard (Earth and Life Institute, UCLouvain), Catherine Hirst (Earth Science Department, Durham University), Laurence Monin (Earth and Life Institute, UCLouvain), Bennet Juhls (Helmholtz Centre for Polar and Marine Research, Alfred Wegener Institute), Anne Morgenstern (Helmholtz Centre for Polar and Marine Research, Alfred Wegener Institute) and Paul Overduin (Helmholtz Centre for Polar and Marine Research, Alfred Wegener Institute).

Abstract

Large Arctic rivers are key locations for nitrogen processing, which controls the supply of this limiting nutrient to the Arctic Ocean. In a warming Arctic, longer ice-free periods increase riverine productivity and modulate nitrogen consumption and delivery to the ocean. In this study, the annual variability of nitrate concentrations at the Lena River outlet (Samoylov station) was investigated. Significantly higher nitrate concentrations in water were observed sub-ice (winter) than in the open water (summer), and the higher nitrate concentrations follow phases of colder air temperature at the Lena catchment scale (ERA5 reanalysis data). We hypothesize that colder phases result in thicker river ice leading to darker under-ice conditions preferred by nitrifying microbial communities, thereby inducing increasing sub-ice nitrification. We tested this hypothesis using silicon isotopes known to fractionate upon freezing. The high nitrate concentrations in the winter are associated with heavier silicon isotope compositions in river water. This can be explained by the supersaturation and precipitation of amorphous silica preferentially incorporating the lighter silicon isotopes, leaving the water isotopically heavier. Supersaturation of amorphous silica can result from thicker ice formation upon colder air temperature at catchment scale. The silicon isotope data support phases of thicker ice formation, and indirectly support darker sub-ice conditions at the river base creating pulses of increasing nitrification. Our hypothesis is also supported by a change in the value of an index for dissolved organic carbon aromaticity (SUVA) during the colder phases: this suggests that conditions favour the decomposition of dissolved organic matter during periods of thicker river ice. Air temperature, nitrate concentration, silicon isotopes and SUVA are supporting evidence for pulses of sub-ice microbial activity in the river during winter. It follows that decreasing ice cover duration throughout the catchment is likely to decrease winter nitrate fluxes from the Lena River to the Arctic Ocean.

Nitrogen dynamics in the Siberian Arctic Ocean and impact of permafrost thaw

Birgit Wild (Stockholm University), Nicholas E. Ray (Cornell University), Elena Kirillova (Ulyanovsk State University), Ivan Gangnus (Lomonosov State University), Evgeniy Yakushev (Norwegian Institute for Water Research), Denis Kosmach (Il'ichov Pacific Oceanological Institute (POI), Far-East Branch of the Russian Academy of Sciences), Oleg Dudarev (Il'ichov Pacific Oceanological Institute (POI), Far-East Branch of the Russian Academy of Sciences), Örjan Gustafsson (Stockholm University), Igor Semiletov (Il'ichov Pacific Oceanological Institute (POI), Far-East Branch of the Russian Academy of Sciences) and Volker Brüchert (Stockholm University).

Abstract

Ongoing rapid permafrost thaw transfers increasing amounts of nitrogen to the Arctic Ocean. This might stimulate emissions of the strong greenhouse gas N_2O from the ocean, but also CO_2 uptake by primary production, either directly or after re-mineralization of nitrogen in sediments or the water column. Scarcity of observational data from vast areas and limited quantitative understanding of the factors driving key nitrogen cycle processes prevent robust estimates of the magnitude of these effects under changing environmental conditions. This study targets the shallow continental shelves of the Arctic Ocean north of Siberia that receive substantial nitrogen input from several large rivers and from strong coastal erosion. We combine measurements of dissolved nitrogen and N_2O in the water column with on-board incubation of intact sediment cores to assess nitrogen dynamics and the impact of land-derived nitrogen in this region. During our expedition in fall 2020, concentrations of nitrate, nitrite, ammonium, and dissolved organic nitrogen in surface waters increased towards the mouths of large rivers such as Ob and Lena. Concentrations of N_2O were only weakly correlated with dissolved nitrogen, and not substantially enhanced towards rivers. Sediment-water fluxes of ammonium, nitrite and phosphate, but not nitrate, increased with sediment organic carbon content, reflecting organic matter remineralization. Low sediment-water N_2O fluxes, together with constant N_2O concentrations through the water column do not support a strong role of sediments for controlling shelf water N_2O concentrations, suggesting that water column production and consumption processes are more important in the study region. Our observations suggest that nitrogen availability in the Siberian Arctic Ocean might be enhanced in the future by increased transfer of land-derived nitrogen, and to some extent also through re-mineralization of organic matter in shelf sediments. Both could stimulate primary production, but effects on N_2O emissions in the region are expected to be minor.

Particulate and dissolved organic carbon in the Lena Delta – the Arctic Ocean interface

Olga Ogneva (Alfred Wegener Institute for Polar and Marine Research), Gesine Mollenhauer (Alfred Wegener Institute for Polar and Marine Research), Tina Sanders (Institute for Carbon Cycles, Helmholtz Centre Hereon), Juri Palmtag (Department of Geography and Environmental Sciences, Northumbria University), Matthias Fuchs (Alfred Wegener Institute for Polar and Marine Research), Hendrik Grotheer (Alfred Wegener Institute for Polar and Marine Research), Paul J. Mann (Department of Geography and Environmental Sciences, Northumbria University) and Jens Strauss (Alfred Wegener Institute for Polar and Marine Research).

Abstract

Rapid Arctic warming accelerates permafrost thaw releasing aged organic matter (OM) to inland aquatic ecosystems and ultimately, after transport via estuaries or deltas, to the Arctic Ocean nearshore. Despite the importance of Arctic deltas, their functioning is still poorly studied. Here, we examined seasonal fluctuations and spatial differences in the quantity and composition of OM in the Lena Delta, measuring dissolved and particulate organic carbon (DOC and POC) concentrations, carbon isotopes ($\delta^{13}C$ and $\Delta^{14}C$), and total suspended matter (TSM). We compared deltaic POC to the POC in the Lena River main stem over a ~1600 km transect, from Yakutsk to the Lena Delta. We further examined and compared dynamics of DOC and POC in summer and winter across a ~140 km transect in the Lena Delta. TSM and POC concentrations decreased by 75 % during transit from Yakutsk to the Lena Delta. 18 % of deltaic and 5 % of river main stem POC originated from Yedoma deposits. Thus, despite lower concentrations of POC in the delta, amount of POC from Yedoma deposits in deltaic waters were almost twice as large as in the main stem (0.07 ±0.02 and 0.04 ±0.02 mg L^{-1}, respectively). Deltaic POC was strongly depleted in ^{13}C due to significant phytoplankton contributions (~-68 ±6 %). Strong differences between winter and summer samples in DOC and POC concentrations and their properties in the Lena Delta were also found. Combined analyses of DOC and POC revealed that Pleistocene-aged Yedoma deposits were still actively degrading in winter influencing the quantity and composition of OM of the Lena Delta and exported OC loads. Deltaic processes control the type and amount of OM exported to the Arctic Ocean and require deeper investigations as crucial processes for the riverine and oceans pathways in a warming Arctic.

Land-ocean transport of permafrost derived organic matter from continental Europe during the last deglaciation

Gesine Mollenhauer (Alfred Wegener Institute; Departmen of Geosicences and MARUM, University of Bremen), Eduardo Queiroz Alves (Alfred Wegener Institute), Hendrik Grotheer (Alfred Wegener Institute), Jens Hefter (Alfred Wegener Institute) and Yunyie Wang (Alfred Wegener Institute; now at NORCE).

Abstract

The last deglaciation is the most recent relatively well-documented period of pronounced and fast climate warming and, as such, it holds important information for our understanding of the impacts of warming on the land-sea export of permafrost-derived organic matter. While most studies into these processes focus on the Arctic, the last deglaciation was also the period over which permafrost disappeared from most of Europe, and records of its retreat can be found in marine sediments off the outlets of major rivers draining the late glacial landscape of continental Europe. Here we investigate the mobilization of organic matter via two major river systems. We present records from the Bay of Biscay at the mouth of the Channel River, and from the Black Sea, where the Dniepr-Dniestr river system discharges its particulate load. Both locations have previously been studied and revealed distinct periods of high terrigenous organic matter (terrOM) accumulation. Using biomarkers and their compound-specific ages we investigate the possible sources of the terrOM and suggest that ancient peat deposits were a major contributor. We also investigate the relative timing of terrOM accumulation maxima, which have to be interpreted in context of meltwater routing from the retreating ice sheets. Our results point to the possibility of permafrost carbon export to the ocean as one of the factors contributing to changes in atmospheric carbon dioxide.

Organic matter degradation and dissolved inorganic carbon production in Siberian Arctic Ocean shelf sediments

Lewis Sauerland (Department of Environmental Science, Stockholm University), Nicholas Ray (Department of Ecology and Evolutionary Biology, Cornell University), Tommaso Tesi (Institute of Polar Sciences, National Research Council), Oleg Dudarev (Il'ichov Pacific Oceanological Institute (POI), Far-East Branch of the Russian Academy of Sciences), Örjan Gustafsson (Department of Environmental Science, Stockholm University,), Igor Semiletov (Tomsk State University) and Birgit Wild (Department of Environmental Science, Stockholm University).

Abstract

Arctic amplification is causing strong changes in the marine Arctic environment. Increased river discharge and coastal erosion may lead to a higher input of terrestrial organic matter into shelf sediments. In addition, rising water temperatures and nutrient influxes into the Arctic Ocean stimulate phytoplankton blooms, potentially increasing the export of marine particulate organic matter to ocean shelf sediments. Decomposition of especially land-derived organic matter to dissolved inorganic carbon (DIC) has been suggested to lie behind the strong acidification observed in the Arctic Ocean shelf seas north of Siberia, adding to the effect of increasing atmospheric carbon dioxide (CO_2) concentrations and low surface water temperatures. Yet, rates of organic matter cycling and DIC production in shallow Arctic Ocean sediments, as well as the environmental factors controlling them, are poorly understood to date. Here, organic matter mineralization rates to DIC and factors driving their variability were investigated for 16 surface sediments from the Kara Sea, Laptev Sea and the East Siberian Sea. Water column to sediment oxygen (O2) fluxes were determined during on-ship incubations of intact sediment-cores and combined with respiratory quotients ($\sum CO_2/O_2$ flux) measured in aerobic laboratory incubations to derive in-situ DIC fluxes. Sediment and organic matter properties were investigated with molecular biomarkers, stable & radioactive carbon isotopes and physical sediment properties. DIC production rates and their relation to oxygen consumption will be compared with sediment properties to assess drivers of variability. It is hypothesised that 1) sediment organic matter content explains a large amount of DIC flux variability, whereas 2) the amount of terrestrial organic matter and 3) the degradation state of the terrestrial material might also influence DIC production rates significantly. The findings of this study will further the understanding of how organic matter is mineralized in Arctic Ocean surface shelf sediments and what factors may induce changes in the future.

Permafrost organic matter mobilization since the last deglaciation recorded in Laptev Sea sediments

Tsai-Wen Lin (Alfred Wegener Institute), Jens Hefter (Alfred Wegener Institute), Tommaso Tesi (National Research Council, Institute of Polar Sciences) and Gesine Mollenhauer (Alfred Wegener Institute).

Abstract

Arctic permafrost contains about twice as much carbon as the pre-industrial atmosphere and is one of the most sensitive carbon pools on Earth, as the Arctic reacts faster to global warming than other areas. It is important to understand how permafrost thawing responds to global warming, and to quantify the amount of potentially released carbon. Here we present multi-proxy biogeochemical results using a suite of biomarkers reflecting terrigenous organic matter (OM) input, including n-alkanes, glycerol dialkyl glycerol tetraether lipids (GDGTs), and fatty acids. We used two marine sediment cores (PS51/154 and PS51/159) from the Laptev sea covering the last 18 ka. Three peak periods of organic matter mobilization were recorded in the cores at 13.3-14.1 ka, 11.1-11.3 ka, and 10-10.5 ka, respectively. These periods coincide with increasing numbers of lake basal ages in Eurasia, reflecting thermokarst lake formation induced by hinterland warming. The hinterland warming during 10-12 ka was also reflected in a maximum of the Paq index in our core records, which indicates wetlands developing during this period. The relative abundances of GDGTs during 13.3-14.1 ka was different than during the later two peaks, implying that the source of carbon transported to Laptev Sea might have shifted between 13.3 and 11.3 ka. The decreasing BIT index in the last 6 ka indicates the increasing marine input, which corresponds with the rising sea level in the Laptev Sea in the mid Holocene. Our results may offer a better understanding of the pathways and the timing of permafrost carbon mobilization in the Laptev Sea region.

Calibrating estimates of modern carbon burial on the Canadian Beaufort Shelf

Matt O'Regan (Department of Geological Sciencces, Stockholm University), Julie Lattaud (Swiss Federal Institute of Technology), Thomas Bosse-Demers (Université Laval), Michael Fritz (Alfred Wegener Institute), Negar Haghipour (Swiss Federal Institute of Technology), Bennet Juhls (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Atsushi Matsuoka (University of New Hampshire), Paul Overduin (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Andre Pellerin (Université du Québec à Rimouski), Taylor Priest (Max-Planck-Institute for Marine Microbiology), Daniel Rudback (Department of Geological Sciencces, Stockholm University), Jorien Vonk (Vrije Universiteit Amsterdam), Dustin Whalen (Geological Sruvey of Canada/Natural Recources) and Lisa Bröder (ETH Zürich).

Abstract

Large quantities of sediment and organic carbon (OC) are delivered to the Beaufort Sea by the Mackenzie River and erosion of coastal permafrost. Knowledge on offshore burial rates of OC is a pre-requisite for determining the fate of this carbon, and quantifying the amount that is mineralized in either the water column or sediments. Canadian Beaufort Shelf estimates of OC accumulation rates are based on data compiled over 25 years ago when no direct measurements on sedimentation rates were available. Instead, they were derived from the seismically imaged thickness of sediments deposited since post-glacial transgression. Potential errors in this approach are large, particularly the assumption that sediment accumulation has remained constant throughout the Holocene. The aim of this study is to test the accuracy and applicability of these long-term OC burial estimates for studying modern carbon cycling on the shelf. We use marine sediment cores and geophysical data collected from the CCGS Amundsen in 2021 during the Permafrost Carbon on the Beaufort Shelf (PeCaBeau) expedition. We compare estimates from the approximated thickness of post-transgression sediments with ^{210}Pb, ^{137}Cs, and ^{14}C dating (foraminifera and mollusc shells). Preliminary data from two sites (western shelf break, 74 mbsl; eastern middle shelf, 50 mbsl) indicate that modern sedimentation rates are 40-60% higher than maximum estimates from post-transgression sediment thicknesses. However, due to higher porosity in surface sediments, mass accumulation rates are only 5-40% higher. Here we will present data from additional sites to assess the magnitude and origin of these differences across the shelf.

Fluvial versus coastal input of permafrost organic carbon - insights from the Canadian Beaufort Sea

Lina Madaj (Department of Earth Sciences, Vrije Universiteit Amsterdam), Fleur van Crimpen (Department of Earth Sciences, Vrije Universiteit Amsterdam), Dustin Whalen (Geological Survey of Canada Atlantic, Natural Resources Canada), Lisa Bröder (Geological Institute, Swiss Federal Institute of Technology (ETH), Thomas Bosse-Demers (Department of Chemistry, Université Laval) and Jorien Vonk (Department of Earth Sciences, Vrije Universiteit Amsterdam).

Abstract

Increased atmospheric warming leads to changes in Arctic coastlines through permafrost thaw and erosion. Simultaneously, it also impacts Arctic rivers that deliver sediments, nutrients, and organic carbon (OC) into the Arctic Ocean. The Canadian Beaufort Sea coast has some of the highest recorded erosion rates along the Arctic Ocean and additionally receives input from the Mackenzie River delta, the largest fluvial sediment supplier to the Arctic Ocean. Here, current estimates of annual OC release exceed those of OC discharged through coastal erosion. Upon coastal release, this OC is either degraded within the water column and released as CO_2 into the atmosphere, or it settles onto the sea floor where it is further degraded or buried. Enhanced warming will increase permafrost thaw and loss of sea ice, which will likely increase both coastal and fluvial OC release. Currently we lack a proper method to distinguish between coastal and fluvial OC after its release into the ocean, which limits our ability to reliably estimate relative degradation and burial rates for those two fluxes. Here we present our approach to differentiate fluvial from coastal OC input by characterising suspended sediments in the water column and underlying seafloor surface sediments, from both the Mackenzie delta and the adjacent Beaufort Sea shelf. Analyses of the sediment's OC, transport and provenance-specific parameters (TSS, TOC, $\delta^{13}C$, mineral surface area, XRF, isotope signatures, grain size and shape) will improve our understanding of the origin, amount and fate of permafrost-derived OC. With ongoing Arctic change which will further influence fluvial and coastal OC fluxes, differentiation of OC contributions from these sources will become increasingly important with regards to improving Arctic coastal carbon budgets.

Remineralization of permafrost-derived dissolved organic matter in Longyeardalen, Spitsbergen

Izabela Pałka (Institute of Oceanology Polish Academy of Sciences), Katarzyna Koziorowska-Makuch (Institute of Oceanology Polish Academy of Sciences), Laura Bromboszcz (Institute of Oceanology Polish Academy of Sciences), Magdalena Diak (Institute of Oceanology Polish Academy of Sciences), Fernando Aguado Gonzalo (Institute of Oceanology Polish Academy of Sciences), Przemysław Makuch (Institute of Oceanology Polish Academy of Sciences), Piotr Prusiński (Institute of Oceanology Polish Academy of Sciences), Beata Szymczycha (Institute of Oceanology Polish Academy of Sciences), Aleksandra Winogradow (Institute of Oceanology Polish Academy of Sciences) and Karol Kuliński (Institute of Oceanology Polish Academy of Sciences).

Abstract

Permafrost areas are a large reservoir of organic carbon. The permafrost occurs as ice in pores or as ice lenses and can function as a stabilizer in sediments. When this ice melts, precipitation, meltwater, and other erosional processes can easily erode sediments. As a consequence organic matter previously trapped in the frozen ground is released. Although there are several studies characterizing the quantity of DOM (Dissolved Organic Matter) released from thawing permafrost, it's still unclear how fast and to what extent it undergoes remineralization. Therefore, we have set the following goals in our study: 1) to assess the bioavailability of permafrost-derived DOM and related CO_2 production 2) to determine the DOM composition changes during remineralization via optical measurements (e.g. humification and freshness index). For the study site, we have selected Longyeardalen located in Isfjorden-Adventfjorden (Spitsbergen) as the high-Arctic areas are particularly vulnerable to warming and thus are of prime interest to investigate the quality of permafrost-derived DOM. Most of the valley floor is taken up by the braided river – Longyearelva, whose catchment covers 22,9 km^2. Permafrost thickness in this area varies between 150m and 450 m. Our study was done through 180-day-lasting incubation experiments of leachates obtained by extracting the permafrost active layer samples with MiliQ water (to reflect precipitation influence). Samples for DOC (Dissolved Organic Carbon), DIC (Dissolved Inorganic Carbon), nutrients, and optical measurements were taken so far at the beginning of incubations and after 1, 2, 3, 5, 9, 21, and 40 days, and will continue after 60, 90, and 180 days. Preliminary results show that a significant part of DOM is bioavailable and its climate-driven enhanced supply may significantly contribute to CO_2 release already on land but also in rivers, streams and coastal fjord waters affecting their acid-base balance.

Composition and Transport of Organic Carbon in the Nearshore Zone of Herschel Island, Qikiqtaruk

Pia Petzold (Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research), Hugues Lantuit (Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research) and Michael Fritz (Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research).

Abstract

Arctic permafrost coasts are greatly impacted by global climate change. Warming permafrost, decreasing sea ice extent and increasing sea temperature lead to greater coastal erosion. The carbon stored in the permafrost is then released into the nearshore zone, where it degrades, potentially leading to the release of greenhouse gas emissions (GHG) into the atmosphere. Yet, the exact pathways of organic carbon (OC) in the nearshore zone are not completely understood. In order to fill this gap, we collected dissolved and particulate OC (DOC, POC) samples in the nearshore zone of Herschel Island, Qikiqtaruk. The sampling was repeatedly carried out along a transect over a period of two weeks during the open water season in summer 2022. Water samples were collected at the surface and at several water depths. Subsequently, water samples were filtered through 47 µm fiberglass filters and examined in the laboratory for suspended particulate matter, DOC, and POC. When possible, Van Veen Grab samples and short cores were taken at each sample location. The upper six centimeters of the short cores as well as the grab samples were analyzed for grain size, mercury, carbon and nitrogen content. In addition to the water sampling, temperature, conductivity, salinity, and turbidity were measured at each sampling location with CTD and turbidity meter. Initial data shows a gradient in temperature and turbidity in the water column, especially at the beginning of the sampling period, which coincided with the sea ice breakup. Hereby, values for Turbidity range from 3.81 to 205.00 FNU. The amount of DOC and POC in the water samples will give an indication on the variability of geochemical properties in the water column over time. This will allow us to determine and quantify the link between these properties and environmental forcing.

Mercury (Hg) distribution and its relation to organic carbon in marine surface sediments on the Canadian Beaufort Sea Shelf

Michael Fritz (Alfred Wegener Institute Potsdam), Katharina Schwarzkopf (Alfred Wegener Institute Potsdam), Lisa Bröder (Eidgenössische Technische Hochschule Zürich), Matt O'Regan (Stockholm University), Bennet Juhls (Alfred Wegener Institute Potsdam), Taylor Priest (Max-Planck-Institute for Marine Microbiology, Bremen), Julie Lattaud (Eidgenössische Technische Hochschule Zürich), Dustin Whalen (Geological Survey of Canada, Halifax), Atsushi Matsuoka (University of New Hampshire, Durham), André Pellerin (Université du Québec à Rimouski), Thomas Bossé-Demers (Université Laval, Québec City), Daniel Rudbäck (Stockholm University), Maria-Emilia Rodriquez-Cuicas (Université du Québec à Rimouski), Paul Overduin (Alfred Wegener Institute Potsdam), Jorien Vonk (Vrije Universiteit Amsterdam) and Hugues Lantuit (Alfred Wegener Institute Potsdam).

Abstract

Mercury (Hg) is a naturally occurring but neurotoxic legacy contaminant that accumulates in the food web and poses significant threats to both the ecosystem and human health. Despite limited local emissions, Arctic regions have elevated levels of Hg in fish, marine mammals, and seabirds, putting Arctic communities relying on these resources at a disproportionate risk. Currently, Hg in Arctic ecosystems largely originates from geological sources and distant anthropogenic emissions, yet it is expected that enhanced permafrost degradation will increase the concentrations, export rates, and potential for Hg methylation. For example, we expect an uptick of Hg fluxes into the Arctic nearshore zone due to increasing coastal erosion caused by the combined effects of declining summer sea-ice cover on the Arctic Ocean, longer and warmer thawing seasons, and rising sea level. In this study, we analyzed total mercury concentrations in 30 surface sediment cores (upper 1 m) taken from the southern Canadian Beaufort Sea Shelf, where water depths ranged from 7.5 to 75 m. Mercury concentrations increased with water depth from 9.4 to 100.5 ng/g. As Hg is typically bound to organic matter we calculated Hg/TOC ratios (µg Hg/g C) for upscaling and to calculate marine sedimentary Hg pools and burial rates across the shelf. Hg/TOC ratios ranged between 1.0 in shallow waters close to shore and 6.9 in deeper locations further offshore. This indicates a relative enrichment of Hg over TOC and an effective Hg burial in marine deposits further offshore. Quantifying the magnitudes of Hg mobilization, transport and burial will improve assessments on the potential production and exposure to bioavailable Hg, which could inform strategies to mitigate this environmental and public health risk.

Nitrogen-Cycling Genes in stream sediments across the Arctic

Cecilie M Holmboe (Aarhus University), Xingguo Han (Swiss Federal Institute for Forest, Snow and Landscape Research WSL), Pau Giménez Grau (Aarhus University), Núria Catalán (Institute of Environmental Assessment and Water Research, IDAEA-CSIC), Anna M Romaní (Universitat de Girona), Jennifer Tank (University of Notre Dame), Aline Frossard (Swiss Federal Institute for Forest, Snow and Landscape Research WSL), Tenna Riis (Aarhus University) and Ada Pastor (Universitat de Girona).

Abstract

Nitrogen (N) is essential for life, however is often available in low amounts of reactive forms, limiting productivity across Arctic ecosystems. In freshwaters, microbial biofilms are a hotspot for biogeochemical cycling, but there is limited information on their role in N processing in the Arctic. We explored potential N pathways across 25 small Arctic streams (Alaska, Canada, Greenland and Svalbard) by quantifying the abundances of sediment N-functional genes involved in biological N fixation (nifH), nitrification (amoA of bacteria and archea, nrxB), and denitrification (nirS, cnorB qnorB and nosZ), as well as the microbial abundance (16S rRNA). We then determined the main environmental variables driving N-functional pathways, both on a habitat scale (river water and sediment characteristics) and catchment scale. Sampled streams displayed a high variability in stream environmental variables, e.g. dissolved inorganic N ranged from 10 to 337 µg N/L, dissolved organic carbon from 0.4 to 10 mg C L/1, as well as in sediment, e.g. organic matter (OM) content ranged from 0.6 to 12.9%. Accordingly, we found a high variability in microbial abundance (from $9.95\times10^{\wedge5}$ to $3.09\times10^{\wedge9}$ 16S rRNA gene copies /g sediment dry weight) and N-functional genes. The sum of N-genes copies per dry weight of sediment increased with sediment OM. Individual N gene abundances were positively correlated among each other, except for amoA genes of ammonia-oxidising archaea and bacteria. Dissolved stream iron concentration was one of the main variables explaining nifH gene abundance. Denitrification genes abundance was associated with the sediment granulometry and the contribution of nosZ gene (encoding nitrous oxide reductase) among the measured denitrification genes was responsive to dissolved organic carbon concentration. This study contributes substantially to understanding the role of freshwater microbial biofilms in N processing across the Arctic, which is key to assess land to ocean connectivity.

Water extracts from Siberian thawing permafrost - from land to ocean

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Abstract

To better understand and quantify fluxes of dissolved elements upon permafrost thaw, water-soluble elements from Siberian permafrost samples covering a wide geographic range were determined by extraction. We measured the pH- and EC-values as well as the total dissolved major and secondary cation concentrations and anion concentrations for 270 water extracts from 12 different sites around the Laptev Sea. Cation concentrations were analyzed using inductively coupled plasma-optical emission spectrometry and anion concentrations by ion chromatography. Hydrogen carbonate concentrations were measured by potentiometric pH-value titration using an automatic titrator. Electrical conductivity and pH values were measured using a WTW MultiLab 540 multi-parameter device. As ground ice melts throughout Siberia with continued climate warming, drainage of the soils in many locations is improving and exposing mineral surfaces that were previously largely inert by their perennially frozen condition and unaffected by active weathering through seasonal wetting and drying cycles. Chemical analyses of water extracts allow an assessment of the potential interactions between mineral surfaces and pore melt water and the characteristics and biogeochemical and ecological consequences of the export of melt water from thawing permafrost. The (hydro-)chemical flux from permafrost sources into the riverine and marine realms is mainly defined by its source signatures and concentrations, which will be addressed in the present study. We compare our values with water data from lakes, rivers and the Arctic Ocean. The influence of terrestrial input from thawing permafrost including ground ice is expected to increase as coastal and river shore erosion as well as other permafrost degradation processes accelerate under Arctic warming and mobilize previously freeze-locked material. The increasing influx of dissolved elements influences transport and deposition processes in aquatic environments as well as nutrient supply, food chains and life cycles with largely understudied consequences for aquatic and coastal ecosystems in the Arctic.

Coastal permafrost erosion reduces the Arctic Ocean's CO_2 uptake from the atmosphere

David Nielsen (Max Planck Institute for Meteorology), Fatemeh Chegini (Max Planck Institute for Meteorology), Joeran Maerz (Bjerknes Centre for Climate Research), Sebastian Brune (University of Hamburg), Mikhail Dobrynin (Deutscher Wetterdienst), Victor Brovkin (Max Planck Institute for Meteorology), Johanna Baehr (University of Hamburg) and Tatiana Ilyina (Max Planck Institute for Meteorology).

Abstract

Coastal erosion releases organic matter (OM) from the permafrost into the Arctic Ocean, transporting about 5 to 15 Tg (mega tons) of organic carbon every year. Recent projections show that such rates could increase by a factor of 2 to 3 by the end of the century due to anthropogenic climate change. However, the impact of the increasing coastal permafrost erosion on the Arctic Ocean's uptake of atmospheric CO_2 is unknown. Once eroded, the OM may take different pathways. It could 1) be remineralized onshore or in the ocean, producing CO_2, 2) boost primary production, consuming CO_2, or 3) sink and be buried in the ocean bottom sediment, having little immediate effect on surface CO_2. Here, we represent OM fluxes from coastal erosion into the Arctic Ocean in the Max Planck Institute Earth System Model (MPI-ESM) and investigate the ocean's biogeochemistry response. We run a set of 8 sensitivity simulations varying permafrost OM characteristics, covering the historical period (1850-2014) and 3 future scenarios (2015-2100) from the Coupled Model Intercomparison Project (CMIP) phase 6. In all scenarios and sensitivity simulations, coastal permafrost erosion reduces the Arctic Ocean's atmospheric CO_2 uptake by 1 to 2 TgC/year per degree of increase in global mean surface temperature. The yearly sink of atmospheric CO_2 into the Arctic Ocean could thus be reduced by about 10% to 20%, depending on scenario and, mostly, on OM characteristics. While all simulations robustly show a decrease in the oceanic CO_2 uptake, the magnitude of such decrease is highly sensitive to the representation of OM in our model (i.e. C/N ratio and particulate-dissolved fractions). Despite large uncertainties, our work highlights the relevance of coastal permafrost erosion to the Arctic carbon cycle, and thereby the need for considering such fluxes in Earth system model simulations.

Permafrost thawing provides more reactive nitrogen in the transition from soil to river and ocean – an isotopic perspective on the Lena Delta

Tina Sanders (Helmholtz-Zentrum Hereon), Claudia Fiencke (Universität Hamburg), Bennet Juhls (Alfred Wegener Institute), Olga Ogneva (Alfred Wegener Institute), Jens Strauss (Alfred Wegener Institute), Gesa Schulz (Helmholtz-Zentrum Hereon), Robyn Tuerena (Scottish Association for Marine Science), Sebastian Wetterich (Technische Universität Dresden) and Kirstin Dähnke (Helmholtz-Zentrum Hereon).

Abstract

Permafrost-affected soils around the Arctic Ocean contain a large reservoir of organic matter including nitrogen, which partly reaches the riverine system after thawing, degradation and erosion of permafrost. After mobilization, reactive nitrogen in form of dissolved organic nitrogen (DON) or dissolved inorganic nitrogen (DIN: ammonium and nitrate) is either used for primary production, microbial turnover and/or is transported to coastal waters where it serves as a key source of nutrition for the marine food web. In this study, we have followed the nitrogen released from permafrost soil via the Lena River into the Laptev Sea and used the natural abundance of 15N stable isotopes to identify sources, sinks and processes. Therefore, we have investigated different soil. We present a comprehensive data set from two transect cruises (03/08 2019) through the delta, and the outcome of a monitoring program (2018 - 2021) at Samoylov Island in the central delta. High-frequency monitoring and cruise data shows that the nitrogen transported from the river to the Laptev Sea was dominated by DON and nitrate, which occurred in similar amounts of approx. 10 µmol L–1 in the river water. The nitrate concentration decreased during the early summer and increased from late summer throughout the winter until the spring flood. During the spring flood, the nitrogen concentration was up to ten times higher. Thus, spring floods transport approx. 20 % of the annual load of reactive nitrogen into the Laptev Sea just at the onset of the growing season. The nitrogen stable isotope values of the different nitrogen components ranged mainly between 0.5 and 4.5‰, and were subsequently enriched from the permafrost soils via suspended particulate matter/sediment and DON to nitrate, which indicate an oligotrophic ecosystem. Using a Bayesian mixing model, the stable isotope signature of nitrate suggested a strong source of atmospheric deposition during the spring flood. During the rest of the year, soils are the main source of the reactive nitrogen, which is transported to the marine realm.

Organic carbon in subsea permafrost: a globally significant but inert carbon pool

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Abstract

Subsea permafrost underlays 2.4 million km^2 of the Arctic Shelf, an area equaling ~18% of the terrestrial permafrost region. Most of it was inundated at some point after the last glacial maximum and is in an advanced state of warming. How much organic carbon (OC) accumulated, how this carbon pool was affected by permafrost presence and degradation over time, how much carbon still remains today and how much of it may be mobilized are major unknowns in the global carbon cycle. Recent estimates of OC decomposition from thawing submarine permafrost were as high as 8 Tg OC per year in methane alone.

Here, we combine a numerical model of sedimentation and permafrost evolution with simplified carbon turnover to estimate accumulation and microbial decomposition of organic matter on the pan-Arctic shelf over the past four glacial cycles (450 kyr). Organic carbon decomposition is modeled with a reactivity continuum model using inversely determined parameters from incubation experiments and liquid water content within the permafrost as the limiting factor rather than temperature alone. We find that Arctic shelf permafrost is a long-term carbon sink storing 2822 (1518 - 4982) Pg OC, two to four times the amount stored in lowland permafrost. Although subsea permafrost is currently thawing, prior microbial decomposition and organic matter aging would limit decomposition rates to less than 48 Tg OC per year even if all frozen sediment deposited in the past 450 kyr thawed immediately. Since actual thaw rates are orders of magnitude lower, true emissions due to subsea permafrost thaw are also orders of magnitude lower than this. The OC pool in shelf permafrost is therefore largely immobilized.

Compared to the organic matter in thawing permafrost large emissions are more likely derived from older and deeper sources as shelf's frozen lid, the permafrost, becomes more permeable.

Utilization, release, and long-term fate of ancient carbon from eroding permafrost coastlines

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Abstract

About 34% of global coast lines are underlain by permafrost. Rising temperatures cause an acceleration in erosion rates of up to 10s of meters annually, exporting increasing amounts of carbon and nutrients to the coastal ocean. The degradation of ancient organic carbon (OC) from permafrost is an important potential feedback mechanism in a warming climate. However, little is known about permafrost OC degradation after entering the ocean and its long term-fate after redeposition on the sea floor. Some recent studies have revealed CO_2 release to occur when ancient permafrost materials are incubated with sea water. However, despite its importance for carbon feedback mechanisms, no study has directly assessed whether this CO_2 release is indeed derived from respiration of ancient permafrost OC. We used a multi-disciplinary approach incubating Yedoma permafrost from the Lena Delta in natural coastal seawater from the south-eastern Kara Sea. By combining biogeochemical analyses, DNA-sequencing, ramped oxidation, pyrolysis and stable and radiocarbon isotope analysis we were able to: 1) quantify CO_2 emissions from permafrost utilization; 2) for the first time demonstrate the amount of ancient OC contributing to CO_2 emissions; 3) link the processes to specific microbial communities; and 4) characterize and assess lability of permafrost OC after redeposition on the sea floor. Our data clearly indicate high bioavailability of permafrost OC and rapid utilization after thawed material has entered the water column, while observing only minor changes in permafrost OC composition over time. Microbial communities are distinctly different in suspended Yedoma particles and water. Overall, our results suggest that under anthropogenic Arctic warming, enhanced coastal erosion will result in increased greenhouse gas emissions, as formerly freeze-locked ancient permafrost OC is remineralized by microbial communities when released to the coastal ocean.

Organic matter distribution and origin in marine surface sediments on the Canadian Beaufort Sea Shelf

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Abstract

The continental shelves of the Arctic Ocean are undergoing profound changes because of climate warming. Large amounts of previously freeze-locked carbon and nutrients are released towards the shelves due to increasing river discharge, deeper permafrost thaw and accelerated coastal erosion. Still, their interactions and their effects on carbon turnover and greenhouse gas fluxes between sediment, ocean, and atmosphere are poorly understood. This study aims to investigate the origin and depositional patterns of organic matter in the Canadian Beaufort Sea. To address this, long and short sediment cores were taken in fall 2021 from twenty-five positions along five major transects that spanned the Beaufort Sea Shelf. We discuss the concentration and regional distribution of organic carbon, nitrogen, mercury, and grain size in surface sediments (upper 2 cm). In addition, bulk ^{14}C radiocarbon ages and stable isotope ratios ($\delta^{13}C$ and $\delta^{15}N$) are used to help distinguish sources and degradation status of terrigenous organic matter. Preliminary results show that the material is predominantly fine-grained clayey silt, and the bulk surface ages vary between 5500 and 10000 years before present. We found specific spatial distribution patterns of carbon, nitrogen, and mercury, which highlight the influence of bathymetry, currents, and distance to the Mackenzie River delta on transport and degradation mechanisms of organic matter. The Permafrost Carbon in the Beaufort Shelf (PeCaBeau) project took place on the Research Vessel CCGS Amundsen in September and October 2021 on the Canadian Beaufort Sea Shelf. This project was funded by the EU Horizon 2020 Arctic Research Icebreaker Consortium (ARICE, grant no. 730965).

Enhanced river runoff and permafrost thaw affect Arctic shelf processes

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Abstract

Enhanced river runoff and coastal erosion are causing greater amounts of terrestrial material supply to Arctic shelf waters. Increasing freshwater export of carbon and nutrient loads from land (terr-OM) together with compositional shifts - due to changing hydrologic flow paths and permafrost thaw, can modify shelf water chemistry and biogeochemical processes. Here, we examine how shifts in land-ocean terr-OM supply may alter shelf primary productivity, respiration and ultimately net regional CO_2 air–sea fluxes. Unique insights into terr-OM dynamics and composition during transit through riverine, deltaic and shelf waters were collected through multiple field campaigns on the Lena River and Laptev Sea shelf region. Harnessing these field data, we examine the effects of contemporary and future terr-OM supply to shelf waters using newly developed 1-D and 3-D regional biogeochemical models specifically capable of parameterising terr-OM, composition and degradation.
In agreement with prior studies, we find that land-derived nutrients could strengthen coastal production sustaining up to ~50% of primary productivity under current terr-OM conditions. However, we also found that additional terr-OM supply caused increased light limitation in coastal waters, offsetting nutrient fertilization effects and stimulating zooplankton grazing. Model experiments indicate that future increases in terr-OM of between 25-50% and/ or shifts to more biologically reactive coastal OM -such as to be expected with permafrost thaw, will reduce net CO_2 uptake and lead to positive CO_2 feedback from Arctic shelf waters.

Our results question the capacity of the coastal Arctic Ocean to serve as a net sink for atmospheric CO_2 with future increasing land-ocean connectivity and terr-OM supply.

Release and transport of organic carbon from permafrost coasts along the Canadian Beaufort Sea

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Abstract

The Arctic is rapidly warming, thawing permafrost, increasing storm activity and wave action accelerating the erosion of the coast. The large stocks of organic carbon (OC) in permafrost soils are released into the marine system where this material will be decomposed in the water column or buried in shelf sediments depending on the hydrodynamic properties of the material. To improve our estimates on coastal OC storage and its potential marine fate we sampled eight locations on the Canadian Beaufort Sea Coast from McKinley Bay in the East to King Point in the West. Additionally to the parent material, sediment and water samples have been collected (n=5 at each location) in two parallel zones along the coast, the resuspension zone (RZ) and the deposition zone (DZ), both defined by a combination of distance from shore, water depth, and turbidity. To mimic the sorting process in the marine system all samples were hydrodynamically fractionated based on grainsize and density (cut off 1.8 g/ml), and subsequently analysed for their OC, TN, $_{13}$C and $_{14}$C content. This enables us to estimate (i) the total coastal OC that enters the nearshore, but also (ii) the fraction of coastal material that is likely to be transported offshore. We found that lighter and finer fractions tend to have a higher OC percentage and hence more OC will stay in suspension where it is prone to degradation. The heavier particles, which are generally lower in OC, will sink and settle on the sea floor. The geochemical, fraction-specific data from eight locations will be upscaled using coastal classification based on geomorphology, cliff hight and ice content. By classifying the coast we can provide better estimates of coastal OC release and its degradation potential within the marine system.

Sedimentary organic matter composition across the Canadian Beaufort Sea – a molecular biomarker approach

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Abstract

The Beaufort Sea receives large quantities of sediment, organic carbon and nutrients from coastal erosion and riverine transport by e.g. the Mackenzie River. Increases in these fluxes in response to the rapidly warming climate have uncertain consequences for the carbon budget of the shelf and the deep ocean. To investigate the movement and composition of organic matter delivered from land, we collected surface sediment samples during the 2021 expedition of the Canadian coast guard ice-breaker Amundsen along five transects across the Beaufort Sea spanning from shallow, coastal sites at water depths of ≤ 20 m to shelf-break and deep-water settings on the continental slope with water depths of ≥ 1000 m. We use molecular biomarkers (plant wax and membrane lipids, lignin phenols) to trace land-derived organic matter and assess the extent of degradation of this material. In order to constrain transport times of sedimentary organic matter across the Beaufort shelf, we employ compound-specific radiocarbon dating of long-chain fatty acids (source-specific biomarkers for terrestrial plants). Furthermore, we apply pyrolysis-gas chromatography-mass spectrometry to investigate the relative contributions of major groups of macromolecular components to the organic matter pool (such as terrestrial phenols, carbohydrates, aromatics, etc.). These compound groups can be broadly classified as either intrinsically "labile" or "recalcitrant" and their relative proportions can inform about the organic matter's overall susceptibility to microbial degradation. These results will be placed in context with bulk organic matter and sediment characteristics to improve our understanding of the fate of permafrost organic matter in the marine environment and thereby help to assess the trajectory of the Canadian Beaufort Sea shelf as a carbon source or sink.

LNAPL migration in frozen and thawed heterogenous sands using physical modelling techniques

Alex Lefebvre (Canadian Armed Forces), Kevin Mumford (Queen's University) and Ryley Beddoe (Royal Military College of Canada).

Abstract

Permafrost strongly affects the movement, storage, and exchange of surface and subsurface fluids, including light non-aqueous phase liquids (LNAPLs) such as gasoline and other petroleum fuels. As a result of climate warming, thaw-activated groundwater flow will create new transport pathways for contaminants, including LNAPLs. Previous laboratory studies of LNAPL migration in frozen soils have been conducted in homogenous soils, and were focused on the isolated effects of pore ice and low temperatures. This study investigated LNAPL migration in heterogeneous, variably-saturated soils, and adapted a light transmission method to track LNAPL migration in both frozen and thawed conditions. Results demonstrated that while LNAPL's response to heterogeneity in frozen soils differs, heterogeneity remains a critical component for accurate predictions of the horizontal and vertical extent of a spill. LNAPL was found to be very sensitive to such ground features and results suggest that the heterogeneity effect seen in thawed soils may be enhanced in frozen soils at high ice saturation, including due to thin layers of fine grains which may become impermeable once frozen. This was most evident when the LNAPL reached the top of the frozen capillary fringe and was completely contained above the ice. Moreover, results highlighted that viscous forces need to be considered to account for differences at colder temperatures. Spills in these experiments were observed to migrate as wider masses in frozen conditions than thawed soils. LNAPL penetration rates also diminished in frozen soils, attributed to an increase in the LNAPL viscosity at low temperatures and lateral migration due to partial blockage of pore space by ice. Overall, this study demonstrated that light transmission is a useful technique for the detailed investigation of LNAPL migration in frozen soils and additional studies are underway investigating the impact of freeze-thaw cycles on long term LNAPL migration.

Arctic nearshore CO_2 outgassing driven by the Mackenzie River terrestrial dissolved carbon runoff

Clément Bertin (LIttoral ENvironnement et Sociétés (UMR 7266), La Rochelle Université), Dustin Carroll (Moss Landing Marine Laboratories, San José State University), Dimitris Menemenlis (NASA Jet Propulsion Laboratory-California Institute of Technology), Stephanie Dutkiewicz (Massachusetts Institute of Technology (MIT)), Hong Zhang (NASA Jet Propulsion Laboratory-California Institute of Technology) and Vincent Le Fouest (LIttoral ENvironnement et Sociétés (UMR 7266), La Rochelle Université).

Abstract

Five of the world's largest rivers discharge into the Arctic Ocean (AO) conveying massive amount of terrestrial organic matter into its coastal waters. In the context of global warming and accelerating permafrost thaw, the response of coastal AO to terrestrial dissolved organic carbon (tDOC) supply remains widely uncertain, which makes the assessment of air-sea CO_2 flux highly challenging in this region. To better understand the impact of terrestrial carbon release on the AO air-sea CO_2 flux, we use an innovative ocean-sea ice-biogeochemical model (ECCO-Darwin) configured on a coastal area exposed to strong environmental pressures: the southeastern Beaufort Sea (SBS; Western AO). The model includes the very first daily interannual riverine tDOC runoff estimated in the region, which forces two DOC pools of different microbial degradation rates. We first quantify the effects of tDOC inputs on coastal CO_2 flux from synoptic to interannual scales. Then, we assess the sensitivity of the model to bacterial remineralization according to conditions observed in situ. We find that tDOC river runoff is responsible for a CO_2 outgassing of 0.23 TgC/yr over the 2000-2019 period with a strong variability in localized air-sea CO_2 fluxes driven by the river discharge. Our numerical study is particularly relevant and timely as the intensified land-to-sea coupling strongly responds to climate change and drives the carbon cycling above Arctic Ocean shelves.

This abstract participates in the Outstanding PYRN Oral Communication / Poster Award

Deglacial compound-specific radiocarbon age records of lignin phenols and lipids from rivers draining Arctic and sub-Arctic permafrost regions

Mengli Cao (Alfred Wegener Institute For Polar And Marine Research), Jens Hefter (Alfred Wegener Institute For Polar And Marine Research), Hendrik Grotheer (Alfred Wegener Institute For Polar And Marine Research), Ralf Tiedemann (Alfred Wegener Institute For Polar And Marine Research), Lester Lembke-Jene (Alfred Wegener Institute For Polar And Marine Research) and Gesine Mollenhauer (Alfred Wegener Institute For Polar And Marine Research).

Abstract

Since the last deglaciation, the thawing of permafrost caused by the warming climate has resulted in the formation of thermokarst lakes and wetland expansion, as well as in enhanced export of terrestrial organic matter (OM) to marine sediments. Permafrost-derived OM exported to the ocean may be delivered either via near-surface conduits or following deep erosion of river banks and coastal bluffs. The relative contribution of materials delivered by these contrasting pathways depends on the thermal state of permafrost. Because the age difference between co-occurring lipids and lignin phenols in recent sediments off modern-day Arctic rivers varies with the thermal state of the permafrost in the hinterland, paired compound-specific radiocarbon analyses (CSRA) of individual terrigenous compounds is potentially a powerful tool to reconstruct permafrost-thawing history. Previous studies on the delivery of aged carbon were based on CSRA of lipids from the Yukon and Amur river catchments, and radiocarbon ages of lignin in these records have so far not been obtained. Here, we provide the first downcore CSRA records of lignin from sediment cores retrieved off the Yukon and Amur Basins, covering the early deglaciation to the Holocene, to study the contribution of different carbon pools to OM in marine sediments, and thereby test whether the age difference between the two compound groups (lignin vs. lipids) reveals the thaw dynamics. Mass accumulation rates of lipids and lignin in these sediments, however, suggest that both types of terrestrial biomarkers have been delivered to the ocean by identical processes during deglacial maxima of permafrost mobilization, i.e., runoff and erosion, in contrast to findings from the modern-day Arctic river systems. CSRA thus helps to clarify the delivery mechanisms responsible for the export of terrigenous OM.

SESSION 4
Structure and function of freshwater ecosystems on lowland permafrost landscapes

Conveners:

- **Ada Pastor**, *Universitat de Girona*; ada.pastor@udg.edu
- **Cecilie M. Holmboe**, *Aarhus University*, cecilie.holmboe@bio.au.dk
- **Tenna Riis**, *Aarhus University*, tenna.riis@bio.au.dk

Summary:

Lakes, rivers and wetlands are predominant features across permafrost landscapes. They host valuable biodiversity and play an important role in biogeochemical cycling. The observed warming across the Arctic region is responsible for the rapid melting of glaciers, ice sheets, and permafrost, while changing precipitation patterns have drastically altered freshwater run-off on land. Moreover, terrestrial vegetation is also responding to climate change, with the "greening" and "browning" of the ecosystems. It is well established that catchment properties -including vegetation, geology and geomorphology and soil characteristics- strongly influence the structure and function of freshwater ecosystems. Therefore, climate-driven changes are expected to severely impact on the structure and function of freshwater ecosystems, also resulting with impacts to marine ecosystems. This session aims at offering an overview of the structure and function of freshwater water ecosystems on permafrost areas. In particularly, focusing in the terrestrial-aquatic linkages and effects of climate change. Contributions are welcome on topics such as biogeochemical cycling, ecosystem function, biodiversity, biogeography, food web ecology on aquatic ecosystems.

Influence of geology, permafrost thaw and wildfires on recent and Holocene thermokarst lakes in Yukon (Canada)

Sarah Ollivier (Laboratoire GEOPS, Université Paris-Saclay), Antoine Sejourne (Laboratoire Géosciences Paris-Saclay (GEOPS), Université Paris-Saclay), Laure Gandois (Laboratoire d'Ecologie Fonctionnelle et Environnement (LEFE), ENSAT), Frédéric Bouchard (Département de géomatique appliquée, CARTEL, Université de Sherbrooke), Aurélie Noret (Laboratoire Géosciences Paris-Saclay (GEOPS), Université Paris-Saclay), Christine Hatté (Laboratoire des Sciences du Climat et de l'Environnement (LSCE), CEA-CNRS-UVSQ, Université Paris-Saclay), Nic Jelinski (University of Minnesota-Twin Cities), Irfan Ainuddin (University of Minnesota-Twin Cities), Megan Andersen (University of Minnesota-Twin Cities) and Arthur Szylit (Laboratoire d'océanologie et de géosciences, Université ULCO).

Abstract

Widespread ice-rich Yedoma permafrost is known to store an important amount of carbon whose liberation will have a positive feedback on climate. Even though it covers only 1% of the permafrost area, its characteristics are diverse and studying its impacts due to thermokarst in different regions is needed. Our study site is located in Yukon, Canada, in the vicinity of Beaver Creek, in a discontinuous extensive permafrost region. This area is characterized by a complex glacial and periglacial history. Pleistocene ice-rich sediment overlies late Wisconsinian moraine. Formation of thermokarst lakes occurred during the Holocene and is developing recently with climate change. Moreover, a massive wildfire occurred in May 2019. This study is part of the PRISMARCTYC project and aims at identifying the biogeochemical composition of Holocene and recent thermokarst lakes in relation to the different geocryolithological characteristics, thermokarst type and wildfires. In August 2022, lakes and springwater have been sampled during field campaign, in various geological and soil backgrounds. Porewater was extracted from shallow permafrost cores. Physico-chemical in situ parameters, water stable isotopes, major and trace element concentrations, dissolved inorganic (DIC), organic (DOC) and particulate organic (POC) carbon forms have been analyzed. Lake water chemical composition reflects geomorphology background, and is impacted by wildfires and permafrost thaw. Lakes present different biogeochemical signatures. In the morainic zone, lakes show higher values for DIC concentrations, electrical conductivity and pH, but lower DOC concentrations compared to lakes in non-morainic zones. Lakes impacted by fire in the morainic area show a decrease in conductivity and DIC concentration, and an increase in DOC concentrations. For active thermokarst lakes, the vertical profile of water stable isotopes indicates input from thawing permafrost at intermediate levels. In the morainic area, where permafrost is thawing, recent thermokarst lakes show lower pH and higher DOC concentrations than Holocene lakes.

This abstract participates in the Outstanding PYRN Oral Communication / Poster Award

Suprapermafrost groundwater transfers high concentrations of aged dissolved organic carbon to Greenlandic rivers

Julien Fouche (LISAH, Université Montpellier, INRAE, IRD, Institut Agro, Montpellier, France), Camille Bouchez (Univ Rennes, CNRS, Géosciences Rennes), Negar Haghipour (Geological Institute, ETH Zürich) and Lisa Bröder (ETH Zürich).

Abstract

Climate change is rapidly altering northern watersheds by disrupting large amounts of water and materials stored in glaciers, snow cover and permafrost. Permafrost thaw enhances the connectivity between surface and deeper water pathways and increases the suprapermafrost groundwater (SPGW) contribution to Arctic river discharge. SPGW, which can originate from permafrost thaw or infiltrated rain waters, participates to the transfer of water and carbon in Arctic catchments. However, the coupling of the water and carbon cycles in SPGW are not quantified, while it can modulate the permafrost climate feedback. Here, we investigate the origin and water transit time of SPGW and quantify and characterize dissolved organic matter (DOM) in the Zackenberg valley (Northeastern Greenland). We aim to quantify SPGW fluxes contribution to river water and carbon exports. In August 2021, we collected water samples from the glacio-nival Zackenberg river, its tributaries and a small nival headwater stream (Graense). SPGW was sampled from wells along transects from soils to river channels. Water samples were analysed for water isotopes (^{2}H, ^{18}O), dissolved gases (222-Rn, SF6, CFCs), dissolved organic carbon (DOC) concentration, radiocarbon ages ($\Delta^{14}C$), and DOM optical properties. A significant contribution of young-SPGW to rivers is estimated from dissolved gases. Contrasted DOC concentrations, DOM properties and $\Delta^{14}C$ are observed between SPGW, hyporheic and river waters, with consistently higher concentrations and older DOC in subsurface flows. DOM optical properties evolve significantly from soils to rivers and along stream channels. Hyporheic waters displayed an enrichment in proteinaceous organic compounds illustrating their role as hotspots for microbial activity where intense DOM processing occurs. This dataset provides unique insights into SPGW role in hydrological and biogeochemical cycles in Arctic permafrost ecosystems.

Vulnerability of organic matter to enhanced enzymatic degradation in terrestrial and aquatic tundra ecosystems

Liam Heffernan (Uppsala University), Elisabeth J Cooper (UiT The Arctic University of Norway), Johan Olofsson (Umeå University) and Lars Tranvik (Uppsala University).

Abstract

Increasing temperatures at northern latitudes will have important implications for biogeochemical cycling and the magnitude of their climate feedback. Warmer winters can cause increased mineralization of soil carbon (C) and shifts in vegetation and below-ground nutrient dynamics. The enzymatic degradation of organic matter in tundra ecosystems is sensitive to temperature and nutrient availability. The objective of this study was to assess how increasing temperatures and shifts in vegetation dynamics in tundra ecosystems impacts the enzymatic degradation and mineralization of organic matter in terrestrial soils and upon export to the aquatic network. The study took place in Adventdalen, Svalbard (78°10'N, 16°04'E) and Abisko, Sweden (68°25' N, 18°19' E) at snow cover manipulation experimental plots (i.e., snow fences) established in 2006 and 2003, respectively. Both locations have experienced increased snow depths and shifts in vegetation. In September 2022, surface soil cores were taken from heath and meadow vegetation snow fence plots, and their associated ambient controls, at both sites. We also took 40 L of water from a first order stream draining the catchment at Adventdalen and froze it. Soils were analyzed for their oxidation state and nutrients, and stream water was analyzed for carbon and nutrients. The kinetics of enzyme degradation in both soils and stream water were assessed. Soils were incubated for 3 months at 2 temperatures (4 and 20 C°). The water extractable fraction of soil organic matter was extracted from each sample and added to thawed first order stream water in a ratio of 1:4 and then incubated for 1 month. Changes in headspace CO_2 and oxygen concentrations were measured in soil and water incubations and used to calculate mineralization rates and respiratory quotients. The results from this study will provide insights into how a rapidly changing arctic climate will impact biogeochemical cycling within tundra catchments.

Impact of permafrost thaw on the geochemistry of thermokarst lakes in Central Yakutia (Eastern Siberia)

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Abstract

Permafrost thaw and subsequent soil erosion and weathering significantly alter surface water chemistry by releasing suspended sediments and solutes to aquatic systems such as rivers and lakes. The type of permafrost thaw may control the flow paths of water transfer, thus impacting differently surface water composition. Small watersheds, where localized and rapid thermokarst occurs, remain understudied. This study aimed at investigating the hydrological and geochemical impacts of current thermokarst dynamics to surface water chemistry in Central Yakutia, a region of ice-rich permafrost undergoing intense thermokarst. During summer 2017-2018-2019, we sampled different components of the hydrosystem (lake, river, groundwater) and analyzed major elements, water stable isotopes (^{2}H, ^{18}O) and DIC (^{13}C, ^{14}C) to characterize their geochemical signature. There are 4 lake types: actively developing thermokarst lakes, ancient thermokarst lakes (alases) formed in the Holocene, alases that are connected to a river and, other alases that are modified by thaw slumps. Lake types have distinct geochemical signatures in relation to thermokarst processes. Recent thermokarst lakes have high solute concentration with a HCO_3–Mg–Na chemical facies and old ^{14}C-DIC due to high evaporation and input of meltwater from thermokarst. There seems to be a correlation between the ^{14}C activities and the year of formation of the recent lakes. Alases have also high content but with a HCO_3–Na facies and modern ^{14}C-DIC mainly due to evaporation and equilibration with atmosphere. However, alases with thaw slumps show a similar chemical facies as recent lakes but rather modern ^{14}C-DIC. At the inverse, alases connected to a small river in a watershed have low solute content with HCO–Mg–Ca facies and relatively old modern ^{14}C-DIC. This shows the influence of groundwater and thermokarst inputs. This study extends the knowledge of the surface water geochemistry in ice-rich Yedoma permafrost zone within a taiga landscape.

New model simulations reveal high sensitivity of arctic pond CH_4 emissions to warming

Zoé Rehder (MPI for Meteorology), Thomas Kleinen (MPI for Meteorology), Lars Kutzbach (University of Hamburg), Victor Stepanenko (Lomonosov Moscow State University,), Moritz Langer (VU Amsterdam) and Victor Brovkin (MPI for Meteorology).

Abstract

We employ a new, process-based model for methane emissions from ponds (MeEP) to investigate the methane-emission response of polygonal-tundra ponds in Northeast Siberia to warming. Small and shallow water bodies such as ponds are vulnerable to warming due to their low thermal inertia compared to larger lakes, and the Arctic is warming at an above-average rate. While ponds are a relevant landscape-scale source of methane under the current climate, the response of pond methane emissions to warming is uncertain. MeEP differentiates between the three main pond types of the polygonal tundra, ice-wedge, polygonal-center, and merged polygonal ponds. The model resolves the three main pathways of methane emissions - diffusion, ebullition, and plant-mediated transport - at the temporal resolution of one hour, thus capturing daily and seasonal variability of the methane emissions. The model was tuned using chamber measurements resolving the three methane pathways. We perform idealized warming experiments, with increases in the mean annual temperature of 2.5, 5, and 7.5 °C on top of a historical simulation. The simulations reveal an overall increase of 1.33 g CH_4 year-1 °C-1 per square meter of pond area. Under annual temperatures 5 °C above present temperatures pond methane emissions are more than three times higher than now. Most of this emission increase is due to the additional substrate provided by the increased net productivity of the vascular plants. Furthermore, plant-mediated transport is the dominating pathway of methane emissions in all simulations. We conclude that vascular plants as a substrate source and efficient methane pathway should be included in future pan-Arctic assessments of pond methane emissions.

DOM molecular composition among Arctic ecosystems, and influence of the vegetation cover composition

Alienor Allain (Sorbonne Université), Marie A. Alexis (Sorbonne-Université), Maxime C. Bridoux (CEA DAM) and Maryse Rouelle (Sorbonne Université).

Abstract

Dissolved organic matter (DOM) is a small but very reactive pool of organic matter in environments. Its composition reflects its sources of production, and the processes it has been exposed to. In terrestrial environments, vegetation is one of the main source of DOM, before it is processed. Therefore, it is a challenge to correlate vegetation OM to DOM properties. This study aims to link the composition of the vegetation cover of contrasted environments (i.e.: tundras and peatlands) to the molecular composition of DOM. DOM samples of supra permafrost, peatlands, wetlands, rivers and lakes were collected from contrasted Arctic environments in summer (n = 13). Their molecular composition were assessed through high resolution mass spectrometry. The molecular composition of DOM samples were compared to each other and to previously acquired molecular composition of fresh and degraded vegetation-derived water extractable organic matter (WEOM). The results of this study highlighted that a major (51-75 %) proportion of the attributed molecular formulas was ubiquitous. However, despite these similarities, significant differences of molecular composition were observed between contrasted environments, and between ecosystems. The comparison to vegetation-derived WEOM molecular signatures enabled to conclude that DOM composition was similar to (1) degraded vegetation WEOM (rather than fresh), and (2) shrubs (rather than highly degradable lichens and graminoids). Lastly, the contributions of each species to the vegetation cover were compared to the contributions of their WEOM to the molecular signature of DOM. These comparisons highlighted that the WEOM molecular composition was positively correlated with the proportions of B. nana, but not with other studied species. In conclusion, DOM molecular composition is influenced by the vegetation cover composition. Therefore, the ongoing vegetation shifts induced by global warming are expected to result in a significant change in the molecular composition of DOM, and the biogeochemical cycles it is involved in.

Coupling hydrology and biogeochemistry to evaluate the impact of groundwater inflows on CH_4 cycling and food chains in thaw ponds

Carolina Olid (University of Barcelona), Alberto Zannella (Swedish University of Agricultural Sciences) and Danny C.P. Lau (Swedish University of Agricultural Sciences).

Abstract

Groundwater inflow from the seasonally thawed active layer is increasingly recognized as an important pathway for delivering methane (CH_4) into Arctic surface waters. Groundwater flows traditionally are regarded as inactive pipes through which terrestrial CH_4 can reach the water bodies without altering water chemistry nor biological processes in receiving waters. However, this approach may underestimate the role of groundwater inflows in CH_4 cycling because it disregards complex interactions between groundwater and biogeochemical processes. Potential effects on the aquatic food chain are also ignored. In this study, we aimed to evaluate the effects of CH_4 inputs through active layer groundwater flows on internal CH_4 cycling and the food chains in sub-Arctic thaw ponds in northern Sweden. We used a radon mass balance approach to quantify CH_4 transport from the active layer into the ponds. We also analysed stable isotopes and fatty acids of pond macroinvertebrates. Our results indicated that CH_4 fluxes from the active layer can sustain CH_4 emissions from the ponds. Consumers in ponds receiving greater CH_4 inputs from the active layer had lower stable carbon isotope signatures that indicate a greater trophic reliance on methane oxidizing bacteria (MOB). These consumers also had lower nutritional quality as indicated by their lower tissue concentrations of polyunsaturated fatty acids. Accurate predictions of CH_4 release from small thaw ponds will thus require improved knowledge of the contributions from various processes including the interaction between internal production, groundwater flow paths, and CH_4 oxidation by MOB.

Hydrologic control on soil-, ground-, and surface water chemistry in a small catchment in the continuous permafrost zone

Johan Rydberg (Umeå University), Emma Lindborg (Danish Hydrologic Institute Sweden), Benjamin Fischer (Uppsala University), Christian Ellekilde Bonde (University of Copenhagen), Mikkel Toft Hornum (Department of Geosciences and Natural Resource Management, University of Copenhagen) and Ylva Sjöberg (University of Copenhagen).

Abstract

Studies of the hydrologic control on fluxes of water and elements in the terrestrial landscape in permafrost areas have long been restricted by a general shortage of relevant long-term data series and limitations in modeling capabilities. We combine ten years of monitoring data (e.g. groundwater table, ground temperatures, on-site meteorology, water isotopes, water chemistry) with numerical hydrologic modeling to investigate the impact of near-surface water flow on element transport in a catchment underlain by continuous permafrost in west Greenland. The catchment is dominated by dry dwarf-shrub tundra vegetation and silty soils in the active layer (<0.8 m). There are no permanent surface streams, but a network of intermittent overland flow channels appears during the snowmelt period. We find considerable and increasing interactions with very shallow soil layers during the snowmelt season, indicated by changes in isotopic compositions and chemistry in surface waters and active layer groundwater. This suggest that elements from shallow soil layers in wetter areas are efficiently flushed during the snowmelt period. However, numerical modeling indicates that dryer areas – which make up a substantial part of the catchment – do not contribute to groundwater and surface water flow during the non-snowmelt period when the active layer is at its thickest.

Understanding thaw pond characteristics, diversity and environmental controls (Nunavik, Northern Quebec, Canada)

Pedro Freitas (CEG, Laboratório Associado TERRA, IGOT, Universidade de Lisboa; CEN, Université Laval), Gonçalo Vieira (CEG, Laboratório Associado TERRA, IGOT, Universidade de Lisboa; CEN, Université Laval), Carla Mora (CEG, Laboratório Associado TERRA, IGOT, Universidade de Lisboa), Diana Martins (CEG, Laboratório Associado TERRA, IGOT, Universidade de Lisboa), João Canário (CQE, Institute of Molecular Sciences and Department of Chemical Engineering, IST-UL; CEN, Université Laval) and Warwick Vincent (Département de biologie, Université Laval; CEN, Université Laval).

Abstract

Thaw ponds are one of the main results of abrupt permafrost thaw, originating from the collapse, erosion and subsidence of ice-rich permafrost under warming conditions. It is estimated that they have a significant biogeochemical role when it comes to processing and degrading old permafrost carbon through microbial and photochemical transformations, making them highly effective as a positive feedback mechanism for climate warming. However, there is a hiatus on the understanding of the biogeochemical significance and variability of permafrost thaw ponds. Showing great abundance and diversity in the Arctic and Subarctic, they cannot be tracked and monitored using traditional surveying and sampling methods. New remote sensing platforms (e.g., Landsat-9, Sentinel-2, PlanetScope and Unmanned Aerial Vehicles) along with in-situ observations may be used synergistically for revealing the importance of these highly productive aquatic ecosystems, from local scale to wide regional sectors. Here, using in-situ data on conductivity, pH, redox potential, dissolved organic matter, suspended particulate matter, chlorophyll, and metals from over 150 ponds in the sporadic and discontinuous permafrost zones of Subarctic Canada, Nunavik/Northern Quebec (Kuujjuarapik, Umiujaq, and Kangiqsualujjuaq) and ultra-high resolution drone imagery and digital surface models, we assess the different optical and physicochemical characteristics of thaw ponds and discuss the environmental controls (e.g., climatic, geomorphological, lithological, biophysical), that can be linked to those differences. We then feed a geographic model based on satellite remote sensing that upscales these observations and reveals very dense and diverse thaw pond hotspots in the Eastern Hudson Bay region. This research is developed under the PERMAMERC and THAWPOND projects goals, funded by the Foundation for Science and Technology (FCT), Portugal. Pedro Freitas is funded by an FCT PhD grant (SFRH/BD/145278/2019).

Characterizing periglacial catchment hydrology through seasonal and yearly variations in catchment hydrology

Cansu Culha (Environmental System Science Department, ETH, CHN, Universitätstrasse 16) and James Kirchner (Environmental System Science Department, ETH, CHN, Universitätstrasse 16).

Abstract

Permafrost, the frozen layer beneath a freezing and thawing active layer, is an impermeable frozen soil that persists for multiple years. The gradual thawing of permafrost and thickening of the active layer allows a glimpse into the evolution of the hydraulic processes that shape the periglacial landscape. One question in understanding the governing mechanics within the rapidly evolving periglacial landscape is how water retains within or segregates through the active layer to eventually feed rivers.

In this exploratory study, we analyze data from multiple periglacial hydraulic catchments over time and characterize their hydraulic response rate to stressors. We test whether deconvolution and demixing of noisy time series can isolate precipitation from thawing permafrost signals in river discharge. We use the Ensemble Rainfall-Runoff (ERRA) script, which is effective in inferring nonstationary and nonlinear responses to precipitation using Runoff Response Distribution (RRD), to further test temperature signatures. Using this tool, we measure the RRD for the same catchments both over the years and over the summer months. We hypothesize that an increase in active layer thickness over years and over summer months will delay the RRD due to an increase in water storage.

By analyzing the parameters that change the RRD of periglacial systems with time, soil moisture content, average seasonal and yearly temperatures, and precipitation, we can begin a systematic understanding of how the active layer modulates hydraulic responses and how the responses may be different from other hydraulic systems.

Impact of permafrost degradation on organic matter origin and composition in modern and Holocene thermokarst lakes in Central Yakutia

Sarah Ollivier (Laboratoire Géosciences Paris-Saclay (GEOPS), Université Paris-Saclay), Laure Gandois (Laboratoire d'Ecologie Fonctionnelle et Environnement (LEFE), ENSAT), Antoine Séjourné (Laboratoire Géosciences Paris-Saclay (GEOPS), Université Paris-Saclay), Christine Hatté (Laboratoire des Sciences du Climat et de l'Environnement (LSCE), CEA-CNRS-UVSQ, Université Paris-Saclay), Frédéric Bouchard (Département de géomatique appliquée, CARTEL, Université de Sherbrooke), François Costard (Laboratoire Géosciences Paris-Saclay (GEOPS), Université Paris-Saclay), Aurélie Noret (Laboratoire Géosciences Paris-Saclay (GEOPS), Université Paris-Saclay) and Damien Calmels (Laboratoire Géosciences Paris-Saclay (GEOPS), Université Paris-Saclay).

Abstract

In the Arctic, thawing of ice-rich Yedoma permafrost has geomorphological and geochemical consequences. Carbon initially stored in permafrost, could be reintroduced in the active carbon cycle. This study aimed at identifying the origin of dissolved organic carbon (DOC) and particulate organic carbon (POC) of thermokarst lakes in Central Yakutia (Eastern Siberia), to better understand the impact of permafrost thawing on carbon cycle. Central Yakutia shows 4 lake types: actively developing thermokarst lakes since 1990s, and ancient lakes (alases) formed in the early Holocene. Some alases are connected to the river and other alases are modified by retrogressive thaw slumps. Concentrations and isotopic signatures in ^{13}C and ^{14}C of DOC and POC, DOC/DON ratio and optical properties of dissolved organic matter such as specific ultraviolet absorbance (SUVA) have been analysed in these lakes sampled in 2018 and 2019. Lake types have distinct biogeochemical signatures. Connected alases had low concentrations of DOC and POC, modern ^{14}C signatures, and high SUVA. Recent lakes and alases with retrogressive thaw slump showed the highest DOC concentrations, lowest SUVA index values and ancient ^{14}C signatures for DOC and POC. Alases had intermediate DOC concentrations between those of recent lakes and connected alases, and a wide range of value for ^{14}C signatures depending on carbon type and SUVA, while DOC/DON ratio was lower compared to other lakes. When all lakes were considered, ^{14}C of DOM was significantly correlated to DOC concentrations and SUVA index, indicating that higher DOC concentrations were associated with less aromatic, older DOM. Our results show that DOM composition and origin are related to lake types. Permafrost thaw led to an important transfer of old OC to lakes, mostly in the DOM's form with a specific composition. Even alases, supposedly inactive, can be considered active when retrogressive thaw slumps are active along their banks.

This abstract participates in the Outstanding PYRN Oral Communication / Poster Award

Winter nitrogen cycling in sediments of large boreal lakes affected by browning and mining

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Abstract

The ice-covered period of boreal lakes has contrasting environmental conditions respect to the ice-free, with cold temperatures, absence of light, and minor gas exchange between water and atmosphere. Focusing on the nitrogen (N) cycle, winter seems a suitable period for N-transforming prokaryotes with a high availability of reactive N due to minor assimilation by photoautotrophs. However, there is limited data about winter N cycling rates and the microbes involved on, and about the role of organic matter quality on N cycling processes. We studied two oligotrophic large boreal lakes in North Karelia, Finland, Lake Viinijärvi and Lake Höytiäinen, each lake with clear-water and brown-water sides. Viinijärvi has an additional side affected by mining activities in the catchment showing higher nitrate and sulphate levels in the hypolimnion. During winter of 2021 we sampled five sites at the beginning (January-February) and at the end (March-April) of the ice-covered period. Using the Isotope Pairing Technique we incubated sediment cores with $15NO_3$- and quantified the products of 1) complete denitrification (N_2), 2) truncated denitrification (N_2O), and 3) dissimilatory nitrate reduction to ammonium (DNRA, NH_{4+}) to infer the process rates. In addition, to see the role of organic matter, we perform anoxic slurry incubations of the top sediment layer with $15NO_{3-}$ and 1) lake water, 2) miliQ water, 3) algal dissolved organic matter (DOM) extract, or 4) peatland DOM extract. We characterised the DOM using FT-ICR MS. We also explore the genetic potential (DNA) of the sediment microbiome by using several sequencing techniques: 1) amplicon (16S rRNA), 2) targeted, using probe captures for the main N and CH_4 functional genes, and 3) shotgun. Preliminary results identify the N-transforming microbes and point to changing nitrate consuming activities and N genetic potentials between the clear-water, the brown-water, and the mining affected sites.

SESSION 5
Water in Mountain Permafrost Environments

Conveners:

- **Stefano Brighenti**. *Faculty of Science and Technology, Free University of Bozen/Bolzano*; stefano.brighenti@unibz.it
- **Cassandra Koenig**. *Department of Geosciences, University of Fribourg;* Cassandra.koenig@unifr.ch
- **Dr. Masaki Hayashi**. *Department of Geoscience, University of Calgary;* hayashi@ucalgary.ca
- **Nicola Colombo**. *Water Research Institute, Italian National Research Council, Montelibretti*; nicola.colombo@irsa.cnr.it
- **Monica Tolotti**. *Research and Innovation Centre, Istituto Agrario di S. Michele all'Adige, Fondazione Edmund Mach;* monica.tolotti@fmach.it

Summary:

Climate change affects the quantity and quality of mountain freshwaters. In glacierized and glacier-free areas,surface waters have been experiencing a rapid change of physical and chemical conditions, including runoff modifications, and shifts in water temperature and solute content due to degrading permafrost. Altered thermal conditions of the subsurface may affect water pathways, resulting in modified hydrological regimes associated with changesto recharge/discharge, or release of water from melting ground-ice. Numerical modelsseeking to predict effects of future warming must account for the complexity of mountain terrains, bringing a heterogeneous distribution of permafrost and ground-ice, unique from polar permafrost zones. Observed changes associated with permafrost degradation include solutes increase (including nutrients, ions and heavy metals) in mountain waters, with potential effects on aquatic ecology. Yet, ice-rich landforms such as intact rock glaciers, are emerging as potential climate refugia because the slow loss of their subsurface ice enables the persistence of cold habitats and related biodiversity. In this session, we encourage presentations about the physical hydrology and hydroecology of mountain headwaters that are influenced by degrading permafrost. Suggested topics include: observed and predicted changes to hydrology and hydrochemistry in mountain watersheds with degrading permafrost, numerical modelling of these systems under ongoing climate change, biodiversity and adaptations of ecological communities dwelling in these particular and rapidly shifting aquatic habitats.

Water origin and chemistry of different stream types in three Alpine catchments

Stefano Brighenti (Faculty of Science and Technology - Free University of Bozen/Bolzano), Francesca Bearzot (Faculty of Science and Technology - Free University of Bozen/Bolzano), Matteo Delpero (Faculty of Science and Technology - Free University of Bozen/Bolzano), Monica Tolotti (Research and Innovation Centre, Fondazione Edmund Mach), Maria Cristina Bruno (Research and Innovation Centre, Fondazione Edmund Mach), Leonardo Cerasino (Research and Innovation Centre, Fondazione Edmund Mach), Maria Vittoria Tenci (Research and Innovation Centre, Fondazione Edmund Mach; DICAM, University of Trento), Alfredo Maule (Research and Innovation Centre, Fondazione Edmund Mach), Bertolotti Giulia (Institute for Interdisciplinary Mountain Research, Austrian Academy of Sciences), Andrina Janicke (Institute for Interdisciplinary Mountain Research, Austrian Academy of Sciences), Anna Klara Stang (Institute for Interdisciplinary Mountain Research, Austrian Academy of Sciences), Andrea Fischer (Institute for Interdisciplinary Mountain Research, Austrian Academy of Sciences), Werner Tirler (Eco-Research Srl), Lorenzo Brusetti (Faculty of Science and Technology, Free University of Bozen/Bolzano, Bolzano) and Francesco Comiti (Faculty of Science and Technology - Free University of Bozen/Bolzano).

Abstract

Ongoing climatic changes are rapidly transforming the hydrology of mountain areas, where the fading influence from glaciers and snow is paralleled by an increasing relative contribution from rainfall, groundwater resources and permafrost ice melt. Within the Euregio project “ROCK-ME”, we are studying the isotopic and hydrochemical conditions of 15 streams from three catchments of the Eastern European Alps with low (Lazaun, Futschöl) to absent (Madritsch) glacier cover. Based on fortnightly campaigns conducted during summer 2022, we measured concentrations of stable water isotopes (δ^2H, $\delta^{18}O$), major ions and minor/trace elements in streams with different origin (glaciers, intact and relict rock glaciers, moraine slopes, and catchment outlets), rainfall, snowmelt, glacier and rock glacier ice melts. End-member mixing analyses based on δ^2H, d-excess and electrical conductivity allowed us to build up site – specific estimates of the relative contribution to runoff from different water resources. Springs from relict rock glaciers and from moraine slopes, composed of season- and site-specific mixture of snowmelt and rainwater, had very low concentration of heavy metals. Rock glacier ice melt and springs of intact rock glaciers (where the ice melt accounted up to 20 % of discharge during late summer) had high major ions and metals concentrations, with catchment-specific combinations of enriched elements (e.g., Ni, Sr, Ti, Ba, Mn, Y). At Lazaun, high concentrations of major ions, Al, Ni, Zn, Cu, Co, and Mn were also detected in the glacier ice melt and at the glacier outlet during late summer, when discharge was mostly composed of the ice melt component. At all catchments, high concentrations of different heavy metals remained high even at the catchment outlets. Our work confirms the hydrological and chemical significance of rock glaciers in alpine areas, and opens up a new perspective for hydrograph separation in rock glacier springs.

The core nature within the Clot de la Menera rock glacier, radioactive tracers and stable isotopes (NE-Andorra, SE Pyrenees)

Valentí Turu (Marcel Chevalier Earth Science Foundation).

Abstract

Warned by the extremely low water temperature of a particular spring (1.3 – 1.8 ºC in September) located at the foothill of a rock glacier (N42º31’10.84”–E01º42’42.08”–2414 m a.s.l.) within the Clot de la Menera north faced glacier cirque, this study aims to shed light on the presence of an ice core within the rock glacier by using groundwater tracers. * Method: A hydrogeochemical study was conducted based on groundwater tracers, allowing for the water travel time, among other options. The most frequent radioisotope used are Tritium and ^{14}C, while the most widely used stable isotopes are deuterium (^{2}H) and ^{18}O. The Grandvalira ski resort uses a second spring downstream as a water supply (N42º31’36.33”–E01º42’09.52”–2208 m a.s.l.) was included in the study. * Results: The Tritium units (TU) and the per ^{14}C age were measured in the rock glacier spring (6.38 ± 0.43 TU; 1,110 ± 40 yrs. BP) and in the ski resort catchment (6.64 ± 0.44 TU; 450 ± 40 yrs BP). The same was for deuterium (∂D), and $\partial^{18}O$ were -65.3 ‰ and -10.2 ‰ respectively for the catchment, and -65.2 ‰ / -10.26 ‰ in the spring, the excess of deuterium (ΔD) was 16.3 in the catchment and 16.88 in the spring. * Interpretation: The contribution of the old and modern water follows an exponential model, having 4 % of old water at the ski resort catchment and a higher portion for the rock glacier spring (9 %). Thus, applying the same proportion to the stable isotopes, 18O concentration for the rock glacier spring (-10.2 ‰) and the ski resort catchment (-10.26 ‰) for modern infiltration meteoric water, solving the isotopic dilution, the corresponding recharge altitudes were 2930 m a.s.l. for the rock glacier spring and the ski resort catchment, 350 m higher than the current recharge area. The last corresponds to a former temperature of 1.68ºC lesser than the nowadays temperature, using a pre-climate change temperature ratio of -0.48 ºC/100 m. * Discussion: The construction of a “3H/^{14}C” diagram allows reporting a Younger Dryas age for the groundwaters. * Conclusions: The core of the Clot de la Menera rock glacier benefit from the presence of melting ice from the end of the last glacial cycle.

How the ice within rock glaciers can influence the hydrology of high Mountain areas: the example of the Central Italian Alps

Silvia Picone (Ca Foscari University - Insubria University), Dario Battistel (Ca' Foscari University), Marco Roman (Ca' Foscari University) and Mauro Guglielmin (Insubria University).

Abstract

The rock glaciers springs may have major ions concentrations strongly influenced by permafrost degradation and melting of internal ice, showing a strong summer increase. The chemical enrichment driven by the melting ice is related to the release of a high concentration of solutes, although the dynamics of the process are not well established yet. To evaluate the impact of internal ice melting on rock glaciers springs chemical enrichment, water springs were sampled both at the beginning and at the end of the summer season in three different active rock glaciers with different geological settings in the Central Italian Alps. The springs were taken both in the proximity of rock glaciers and, for comparison, in the surroundings included some permafrost free areas. The chemistry of the springs reflects quite well the difference of geological composition. Rock glacier springs are characterized by very low water temperatures and an enrichment in high concentrations of major ions and solutes in late summer. On the contrary, external springs exhibit a different trend with a general elemental loss and a little enrichment both in terms of the amount of elements involved and in their concentration increase. Snow melt is the dominant water source in early summer, showing a dilution effect in all rock glaciers springs, while in late summer the main water contribution becomes the melting of the internal rock glaciers ice. The high major ions and solutes concentrations in streams emerging from rock glaciers are attributed to the melting and refreezing fractionation process which may occur near the internal ice body.

Quantifying the meltwater released from rock glaciers with an energy approach: Insights on seasonal ground ice formation and melting in rock glacier Murtèl (Engadine, Switzerland) from in-situ measurements

Dominik Amschwand (University of Fribourg), Seraina Tschan (University of Fribourg), Martin Scherler (University of Fribourg), Martin Hoelzle (University of Fribourg), Anna Haberkorn (GEOTEST AG), Bernhard Krummenacher (GEOTEST AG), Lukas Aschwanden (University of Bern) and Hansueli Gubler (ALPUG GmbH).

Abstract

In arid and rapidly deglacierizing mountain regions, meltwater released from degrading ice-rich permafrost landforms like rock glaciers is hoped to attenuate late-summer water scarcity. However, quantifying the meltwater contribution from ground ice is challenging and still unresolved: First, the most established fingerprinting parameter with stable isotopes ($\delta^{18}O$, $\delta^{2}H$) can often not distinguish between snow, ground ice or glacier ice meltwater. Second, the contribution of ground-ice melt to total rock glacier runoff is so small that hydrological approaches via the water balance are difficult, because uncertainties exceed the ground ice melt rates. Here, we approach the ground ice melt from the energy perspective: The melt rate is determined by the available energy. By parametrizing the subsurface energy fluxes towards the ground ice table and accounting for sensible heat storage changes in the thick debris mantle, the latent storage changes associated with water phase changes – melting and refreezing – can be isolated. The estimates of net heat fluxes and storage changes are derived from our extensive sensor network that we installed above ground as well as in natural cavities of the active rock glacier Murtèl (Engadine, eastern Swiss Alps), including hygrometers, heat flux plates and wind speed sensors distributed at depth. The sensor array complements the weather station and instrumented boreholes operated by the Swiss permafrost monitoring network (PERMOS). The calculated melt rates are compared with an empirical melt model derived from independent "ablation" measurements at a ground-ice exposure in a nearby furrow and related to discharge and stable isotope measurements of the rock-glacier outflow. Our work contributes to the quantitative understanding of heat transfer and seasonal refreezing-melting processes in the coarse debris mantle of cold rocky landforms.

Hydrological significance of rock glaciers in the Ozernaya river basin, northern Tien Shan region

Liudmila Lebedeva (Melnikov Permafrost Institute SB RAS).

Abstract

Rock glaciers are climatically less sensitive than glaciers and potentially significantly contribute to the mountainous rivers. The overall aim of the research was to study rock glacier streams in the Ozernaya river basin in the northern Tien Shan to evaluate potential hydrological significance of the three rock glaciers – Gorodetsky's, Morenny and Tourist. Hydrochemical and temperature monitoring of rock glaciers streams showed that Gorodetsky's rock glacier could not have ground ice near the streams, while Morenny and Tourist rock glaciers have internal ice. Rock glacier streams significantly differ from the glacier streams in the region. Rock glacier streams are stable in terms of water level, temperature and electrical conductivity without any intraday fluctuations, while glacier streams have pronounced diurnal cycles of water quantity and quality. The streams of the three studied rock glaciers differ in TDS, temperature, and dominant major ions due to different lithology, rock glacier structure and varying time of water-rock interaction. Rain, snow, rock glaciers streams, groundwater springs, glacier ice and two rivers in the Ozernaya river basin belong to ultra-fresh bicarbonate-calcium or bicarbonate-sodium types. The dynamics of the water isotopic composition suggests that periglacial lakes contribute to the streams in the second half of the warm season.

This abstract participates in the Outstanding PYRN Oral Communication / Poster Award.

Improved Permafrost Modeling in Mountain Environments Using Convective-Enhanced GeoTOP Model

Gerardo Zegers (University of Calgary), Rodrigo Perez (Universitat Politècnica de Catalunya) and Masaki Hayashi (University of Calgary).

Abstract

Permafrost is a critical cryosphere component through its influence on energy exchanges, hydrological processes, and natural hazards. In mountainous regions, permafrost occurrence is affected by complex topography and surficial geology, resulting in significant spatial heterogeneity. Gravel-size sediments can create a special thermal regime that allows permafrost to persist even under positive mean annual air temperatures due to lower ground temperatures caused by natural convection. Several authors have described this; however, there is still the need for quantitative assessments of the impact of natural convection on ground temperature. In order to improve the prediction of the permafrost occurrence in surficial sediments, we present a modified version of the GeoTOP model, a widely-used distributed hydrological model for permafrost. Our convective-enhanced GeoTOP model includes the airflow through Darcy's equation and the Oberbeck-Boussinesq approximation to account for the density-driven buoyancy effects, as well as an advection-diffusion heat transport for the air phase without assuming local thermal equilibrium between the air and the other phases. We validate our model against known natural convection solutions in inclined porous media and demonstrate its effectiveness in a synthetic catchment using climate data from the Lake O'Hara basin in the Canadian Rockies. Our model shows that the presence of gravel-size sediments can lead to ground temperatures four to seven degrees lower when natural convection is considered. This new tool will improve our understanding of permafrost dynamics in mountain environments and aid in developing effective adaptation and mitigation strategies in the face of climate change. Additionally, by including this process in a distributed hydrological model, we can study the direct effect of permafrost thaw on groundwater discharges, which is crucial for understanding and predicting the consequences of permafrost thaw in these environments.

The project "ROCK-ME: Geochemical response of Alpine Rock Glaciers to global warming: hydroecological consequences of trace element Export"

Monica Tolotti (Research and Innovartion Centre, Fondazione Edmund Mach), Stefano Brighenti (Free University of Bozen/Bolzano), Lorenzo Brusetti (Free University of Bozen/Bolzano), Francesco Comiti (Free University of Bozen/Bolzano), Andrea Fischer (Institute for Interdisciplinary Mountain Research, Austrian Academy of Science) and Maria Cristina Bruno (Research and Innovartion Centre, Fondazione Edmund Mach).

Abstract

ROCK-ME is a 3-year project funded by the 4th Call of the EUREGIO Interregional Project Networks framework, including the Alpine regions North Tyrol (A), South Tyrol and Trentino (I). The project, started in April 2022, addresses the effects of climate warming on the degradation of mountain permafrost. Thawing rock glaciers (RG) are becoming key hydroecological drivers in numerous deglaciating Alpine catchments, as they export cold waters often enriched in trace elements (TE). However, both the hydrological dynamics and the ecological effects of TE enrichment on water quality and ecology of RG and the downstream river networks are almost entirely unknown. The research questions investigated by ROCK-ME are: 1) Do thawing RGs export higher loads of TE than glaciers, relict RGs and groundwater springs? 2) Do TE in RG-streams mainly originate from bedrock weathering, while only a smaller amount derives from past/present atmospheric deposition? 3) Do TE export and its ecological effects vary at multiple timescales in relation to seasonal and long-term dynamics of permafrost thawing; 4) Do TE bioaccumulate in the stream foodweb? 5) Do RG microbial communities modulate TE bioavailability? 6) Do thawing RGs release trace metal resistance genes? Three Alpine catchments with different proportions of glaciers and RG cover - Futschöl in Jamtal (North Tyrol, A), Lazaun in Schnalstal/Val Senales and Madritsch in Martelltal/Val Martello (South Tyrol, I) - have been investigated during the Alpine summer 2022 following an integrated approach combining geomorphological/geochemical analysis, hydrological monitoring and modelling, ecological and genomic characterization. Field activities are going to be completed within autumn 2023.

Water Management in Glacial / Periglacial Watersheds in the Dry Andes – A New Cryo-Hydro Modelling Approach

Pablo Wainstein (BGC Engineering Inc.), Alan Edmunds (BGC Ingeniería Ltda.) and Lukas Arenson (BGC Engineering Inc.).

Abstract

High mountain catchments in the Chilean and Argentine Andes, which are of interest for various project developments, including transportation, mining and energy, are often located in environments controlled by the local cryosphere. Snowmelt and glacier ice melt runoff estimates are critical for water management, environmental assessments, geohazard management and project planning. Certain characteristics of the cryosphere produce specific challenges to the development of reliable and representative tools for the synthetic generation of runoff estimates for past, present, and projected future conditions at a project scale under the effects of climate change. Among these characteristics are hydrological contributions from glacial and periglacial cryoforms, and the role of permafrost in the local hydrographs. We present a novel, watershed scale cryo-hydrological model where such cryoforms are present. In this model, the characteristics of the various elements of the cryosphere are first conceptualized with respect to their hydrological role, such as their spatial distribution. They are then incorporated into the stochastic modelling platform Goldsim by migrating the HSPF-SNOW energy balance model to estimate the snowmelt and glacier melt and using the Australian Water Balance Model (AWBM) to perform runoff estimations. The integrated Goldsim HSPF-SNOW and AWBM models have been applied successfully to projects in the Arid Andes to produce daily average runoff estimates. Applying this novel model is particularly interesting for project closure and hydrological projections under the effects of climate change, using locally downscaled temperature and precipitation trends derived from CMIP6 climate projections. This presentation demonstrates the benefits of cryo-hydrological considerations in the conceptual model and shows an example of the results generated using a Monte Carlo simulation. Limitations and data requirements for further calibration and validation of this new cryo-hydrological modelling approach are also discussed.

Discovery of groundwater springs in Isortoq Valley, Western Greenland

Mikkel Toft Hornum (Department of Geosciences and Natural Resource Management, University of Copenhagen), Søren Jessen (Department of Geosciences and Natural Resource Management, University of Copenhagen), Andy Hodson (Department of Arctic Geology, The University Centre in Svalbard, Longyearbyen) and Ylva Sjöberg (Department of Geosciences and Natural Resource Management, University of Copenhagen).

Abstract

Accelerating mass loss from the Greenland Ice Sheet (GIS) contributes significantly to sea level rise with meltwater runoff as the dominant driver. Even so, fundamental understanding of meltwater routing from the GIS to the ocean, especially during the cold season, yet remains elusive. In areas with continuous permafrost, the surface hydrology is normally assumed to shut down and liquid water is a rare phenomenon and commonly only observed in front of glacial termini where subglacial meltwater can discharge to the surface. However, distributed frequently along the margins of Isortoq Valley that stretches ~100 km from the GIS to the sea, more than 40 icings discovered on satellite imagery indicate cold-season hydrological activity. Three of the icings located ~5 km from the GIS were subject to field investigations and identified as groundwater springs that all carry considerable amounts of methane. The spring waters are calcium-bicarbonate dominated and with low chloride concentrations. The relative concentration of these major ions is distinct from potential fluvial and meteorological sources, while the stable water isotope composition is close to that of the Isortoq River. On this basis, we suggest that the spring water originates from glacial meltwater recharging an artesian aquifer system within the valley sediments. This explanation is in line with the unusually deep and sediment-filled valley incision that stretches under the GIS as documented in other studies. The thick layer of sediments beneath the valley bottom likely reaches below the permafrost layer and could thus forms a considerable aquifer that act as pathway for groundwater recharge produced at the base of the GIS. The groundwater springs in Isortoq Valley represent a previously unknown mechanism of meltwater routing from the GIS, which importance for GIS mass loss and transport of solutes and dissolved gasses to the oceans and atmosphere is yet to be resolved.

This abstract participates in the Outstanding PYRN Oral Communication / Poster Award

Rock glacier cryo-hydrology in the Central Andes

Jordan Harrington (BGC Engineering), Cassandra Koenig (BGC Engineering, University of Fribourg), Alan Edmunds (BGC Engineering), Lukas Arenson (BGC Engineering) and Pablo Wainstein (BGC Engineering).

Abstract

Many semi-arid areas downstream of mountain ranges around the world are experiencing water stress and uncertainty in future water availability due to changing water use and shifting hydrological regimes. Some of these cold, dry mountain headwaters contain rock glaciers, which can store water in the form of permafrost ground ice. Various studies have reported on the distribution of rock glaciers and have attempted to constrain ranges of water volume stored as ground ice. However, the understanding of rock glacier hydrological processes and functions in watershed hydrology remains limited by the relative scarcity of subsurface geological, thermal, and hydrological data in these or other periglacial landforms.

Towards addressing these gaps, we present a case study from the Central Andes of South America with some of the relatively few instrumented boreholes in rock glaciers worldwide, complemented with geophysical surveys. Up to six years of monitoring data were used to develop conceptual thermal and hydrological models. Numerical thermal models were used to evaluate permafrost thaw and the potential contribution of associated ground ice melt to streamflow. Key findings to date are: i) stratigraphy and ground ice content were heterogeneous within individual rock glaciers and also compared to other rock glaciers within the same watershed; ii) water flow can occur year-round in rock glaciers via supra-permafrost taliks and sub-permafrost fractured rock and/or basal sediments; and iii) modelled permafrost thaw was relatively slow, and, when considered at either the sub-watershed or watershed scale, associated ground ice melt was a minor contributor to the water budget.

These results, based on unique in-situ subsurface data, contribute to the understanding of hydrological processes in rock glaciers under climate change. The observed variability highlights the need to develop a site-specific conceptual understanding of thermal and hydrological processes affecting individual rock glaciers when considering their functions in watershed hydrology.

Glacier and rock glacier streams host microbial communities with distinct taxonomy, diversity, and seasonality.

Monica Tolotti (Research and Innovation Centre, Fondazione Edmund Mach), Stefano Brighenti (Free University of Bozen/Bolzano), Maria Cristina Bruno (Research and Innovartion Centre, Fondazione Edmund Mach), Leonardo Cerasino (Research and Innovation Centre, Fondazione Edmund Mach), Claudio Donati (Research and Innovation Centre, Fondazione Edmund Mach), Massimo Pindo (Research and Innovation Centre, Fondazione Edmund Mach), Michela Rogora (CNR Water Research Institute), Roberto Seppi (Department of Earth and Environmental Sciences, University of Pavia), Werner Tirler (Eco Research) and Davide Albanese (Research and Innovation Centre, Fondazione Edmund Mach).

Abstract

Alpine headwaters are threatened by global warming which is accelerating glacier and permafrost thawing. Diversity and seasonal dynamics of aquatic communities are expected to shift in response to increased seasonal variability of temperature, hydrology, and chemical regime, with potentially great implications for future integrity and functionality of Alpine freshwaters. Despite the growing literature on the impacts of climate change on glacier hydrology and periglacial environments, the chemical and biological features of waters emerging from Alpine rock glaciers (RG) have been poorly investigated so far. In particular, microbial communities have remained largely unexplored until recently, despite the recognition that they can play a disproportionate role in driving Alpine stream biodiversity, hydrochemistry, and metabolism. From 2016 to 2018 we investigated the prokaryotic assemblages of epilithic and sediment biofilm in glacier- (kryal), rock glacier- and groundwater-fed streams (krenal) in four deglaciating catchments of the Central Italian Alps using metagenomic approach. The 2016 late summer survey outlined that RG-fed headwaters represent chemically and biologically unique ecosystems, as they are characterized by high solute concentrations, including trace elements, and by highly diverse bacterial assemblages that significantly differ from those of glacier-fed streams. The 2017-2018 seasonal investigation (June-September) outlined that the high prokaryotic biodiversity of RGs is characterized by intermediated seasonal variability in comparison with glacial and krenal streams, the latter being characterized by larger seasonal changes. Prokaryotic biodiversity appears to be related to the different physical and chemical settings of the three water types, although physical variables (e.g., water temperature, turbidity) and solute concentrations play a key role in all the surveyed water types. These findings suggest that the chemical, biological and seasonal characteristics of Alpine headwaters fed by thawing permafrost, may contribute to set the future microbial diversity of Alpine headwaters in combined with the progressive glacier retreat.

Modelling Ground-Ice Degradation within the Bermejo Rock Glacier, Central Argentina

Cassandra Koenig (University of Fribourg), Christin Hilbich (University of Fribourg), Christian Hauck (University of Fribourg), Pablo Wainstein (BGC Engineering Inc.), Silvio Pastore (Universidad de San Juan) and Lukas U Arenson (BGC Engineering).

Abstract

The hydrological contribution from degrading mountain permafrost under climate change in the Central Andes is poorly understood. However, knowledge on thermal and hydrologic feedbacks that influence water availability in this region can be facilitated using numerical cryo-hydrogeology models capable of simulating complex permafrost degradation processes. Such models are often restricted to hypothetical environments due to scarce ground-based data from high altitudes and from periglacial regions of South America in general. The resultant lack of physically representative case studies consequently limits the ability of such models to quantitatively assess possible impacts of climate warming on hydrology, such as contributions to runoff from thawing ground-ice.

We present a conceptual model and numerical build for the Bermejo Rock Glacier, located in the Argentinian Andes at approximately El. 4,500 m. The presented model is a refinement of an existing regional numerical model previously developed for a hypothetical mountain slope in the High Andes (up to El. 6,000 m) using characteristic topo-climatic boundaries and bulk geologic properties. The refined model incorporates results from geophysical investigations completed across the 0.5 km^2 rock glacier and water flow measurements collected at its front. Electrical resistivity tomography and refraction seismic tomography surveys on the landform informed initial permafrost distribution and ground-ice contents in the model, which varied from ice-free to potentially ice-rich conditions. Discharge measured in front of the landform ranged between 30-155 L/s and represents the combined runoff of upstream meltwater and potential contribution from ground-ice thaw. Future model simulations will investigate the possible contribution to this observed runoff from degrading ground-ice, considering the current distribution of permafrost and possible degradation scenarios.

Evolving Permafrost-groundwater interactions in arid Trans-Himalayan landscapes of Spiti region, NW India

Soumik Das (Centre for the Study of Regional Development, Jawaharlal Nehru University), Elora Chakraborty (Centre for the Study of Regional Development, Jawaharlal Nehru University) and Milap Chand Sharma (Centre for the Study of Regional Development, Jawaharlal Nehru University).

Abstract

This study examines the periglacial landscapes of the arid Trans-Himalayan region of Spiti in the mountainous state of Himachal Pradesh, India. The Spiti river basin, with an average elevation of ~ 3500 m asl on the leeward side of the Pir Panjal, is barely fed by Indian Summer Monsoon (ISM), making it largely arid. The great altitudes help preserve pieces of evidence of permafrost in the landscape; its geomorphic expressions abound in the valley. Our inquiry into the socioeconomic canvas of the villages indicates the importance of permafrost features in providing necessary water for all livelihood purposes. The permafrost meltwater system follows the local gradient from source to sink, supplying water to peat bogs and thermokarst lakes, which the local populace uses in agricultural fields. The locals have used their traditional knowledge to identify sustainable meltwater sources and, through the ages, have engaged in rudimentary yet functional conservation methods (e.g. check dams, small reservoirs) along the ephemeral drainage lines. These methods are aimed at storing additional solid winter precipitation from the Mid-Latitude Westerlies (MLW), providing a sustained water supply through the dry and short summer cropping season. The study draws its conclusions from field realities alongside Focussed Group Discussions (FGD) and Participatory Rural Appraisal (PRA) with the local inhabitants to validate permafrost as the primary source of accessible water for livelihood activities in the study area. Strangely enough, no previous studies on similar lines exist for this basin which is reasonably accessible by a network of highways. Three target villages have been identified in the Upper Spiti catchment for our enquiry into their permafrost-induced hydro-ecological and socioeconomic characteristics. The study delves into the local perception, which reports a steady depletion of spring waters, pointing towards an imbalance in the system and ongoing degradation in the permafrost due to environmental factors.

This abstract participates in the Outstanding PYRN Oral Communication / Poster Award

Hydrological, thermal and chemical influence of an intact rock glacier discharge on a mountain stream (NW Italy)

Francecsca Bearzot (Free University of Bozen-Bolzano), Nicola Colombo (University of Turin), Edoardo Cremonese (Environmental Protection Agency of Valle d'Aosta), Umberto Morra Di Cella (Environmental Protection Agency of Valle d'Aosta), Elisabetta Drigo (Environmental Protection Agency of Valle d'Aosta), Mariachiara Caschetto (University of Milano-Bicocca), Stefano Basiricò (University of Milano-Bicocca), Giovanni Crosta (University of Milano-Bicocca), Paolo Frattini (University of Milano-Bicocca), Paolo Pogliotti (Environmental Protection Agency of Valle d'Aosta), Michele Freppaz (University of Turin), Franco Salerno (National Research Council of Italy), Alessandra Brunier (Environmental Protection Agency of Valle d'Aosta) and Micol Rossini (University of Milano-Bicocca).

Abstract

Rock glaciers are the most prominent permafrost-related mountain landforms, capable of storing water in solid (ice) and liquid (groundwater) form. Under future climate warming conditions, they might constitute a relevant water resource. Here, we aimed at quantifying the hydrological, thermal and chemical influence of an intact rock glacier discharge on a high-elevation mountain stream, located in the NW Italian Alps (Aosta Valley). To do this, we performed discharge rate and water temperature measurements, dye tracer injections, volumetric variation measurements, and chemical/isotopic analyses during the summer-autumn 2019-2020-2021. Despite draining only 39 % of the watershed area, the rock glacier sourced a disproportionately large amount of discharge to the stream, with the highest, relative hydrological contribution occurring in late summer-early autumn (63 %). However, we estimated that only a minor contribution to the overall discharge originated from ice melt (<3.5 %). Moreover, we found that the cold and solute-enriched discharge significantly lowered the stream water temperature (up to −2.9 °C) and increased the concentrations of most solutes in the stream (e.g., SO^{42-}, Mg^{2+}, Ca^{2+}, Ba, and NO^{3-}). We also found contrasting hydrological and chemical behaviors at the springs sourcing from the two lobes composing the rock glacier. This evidence agreed with a discrepancy in the internal hydrological systems of the lobes, likely caused by different permafrost and ice contents. Indeed, the lobe with higher permafrost and ice content was characterised by higher hydrological contributions and significant seasonal trends in solute concentrations. Here, we demonstrated the relevance of rock glaciers as (ground) water resources, and as thermal and hydrochemical hot-spots, despite the estimated reduced water fluxes originated from ice melt. Our results also suggest an effective, increasingly relevant hydrological role of rock glaciers as a valuable water resource to account on in the view of future climate changes.

Springs from cold rocky landforms: icy seeps in warming mountains

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Abstract

The decline of cold environments is among the major effects of climate change. In mountain areas, freshwater habitats have been warming as a result of increasing air temperature, reduction of the snowmelt period, and glacier recession. However, most high-mountain regions contain landforms composed of coarse rocky materials and often containing ice, that are thermally buffered, and sustain cold/cool habitats in otherwise unfavourable climatic conditions. These cold rocky landforms, often originate very cold springs (< 2 °C), termed icy seeps, that might represent climate refugia for cold-adapted aquatic organisms. Rock glaciers appear to be the most common source of icy seeps, but other mountain landforms including debris-covered glaciers, morainal deposits, talus slopes, and protalus ramparts can support similarly cold springs. Collectively, icy seeps have been understudied, and little is known about how their thermal regimes vary among types of icy seep and across major mountain ranges. We monitored summer water temperature (mostly 2021/2022) of 152 springs across 14 mountain areas of the Eastern and Western European Alps, Rocky Mountains, Great Basin Mountains, and Patagonian Andes. The monitored springs represented icy seeps from rock glaciers, morainal deposits, talus slopes, protalus ramparts, and debris-covered glaciers, plus reference springs originating from slopes composed of fine materials with diverse origins. Thermal conditions at the same spring types differed among mountain ranges, but icy seeps were consistently colder (by 0.5 – 6.0 °C) than reference springs located within the same catchments, and at comparable elevations. This thermal offset was positively correlated with spring elevation, slope aspect, and average clast size of the landform debris. Our results highlight that major geomorphological drivers are useful for identifying some mountain features as cold rocky landforms for aquatic habitats. Hydroecological research on these environments is needed to address management strategies for climate change adaptation.

Active Rock Glaciers as Dynamic Water Storage: The Case Study of Rock Glacier Lazaun (South Tyrol, Italy)

Giulia Bertolotti (Institute for Interdisciplinary Mountain Research - Austrian Academy of Science), Gerfried Winkler (Institute of Earth Sciences, NAWI Graz Geocenter, University of Graz) and Karl Krainer (Institute of Geology, University of Innsbruck).

Abstract

Rock glaciers are able to store water both as permafrost ice (solid form) and as groundwater (liquid form). The aim of the present study is the characterization of the runoff pattern of the active rock glacier Lazaun and its relationship to different flow components including permafrost ice in the rock glacier and glacial ice in the upper catchment. For this purpose, a recession analysis and a lumped-parameter rainfall-runoff model have been implemented on a multi-year dataset. Preliminary results show a typical discharge pattern for active rock glaciers, with maximum discharge during the snowmelt period (June-July) and a gradual decrease towards the fall season, interrupted by rainfall-induced runoff peaks. Discharge and water temperatures around 1.2-1.4 °C during winter support the hypothesis of a groundwater dominated baseflow. In addition, stable isotope and electrical conductivity (EC) values have been implemented as natural tracers for flow component separation. The collected data suggest at least 3 sources of discharge components: i) low EC, low $\delta^{18}O$ values during spring and early summer indicate high amounts of snow melt water, ii) a baseflow component with high EC and enriched in $\delta^{18}O$ mainly during autumn and winter indicates most probably groundwater, and iii) rainwater of summer precipitation with lower EC and slightly higher $\delta^{18}O$ values. A fourth source (melt water of permafrost or glacial ice) is assumed. EC increases from the beginning of the melt season until autumn/winter and $\delta^{18}O$ of the stream water becomes more and more positive. The recession analysis also shows 2 to 3 components ("fast flow" and "baseflow", plus an intermediate flow component), characterized by different recession coefficients. These indicate also at least two different storage units. The model shows a first estimate of the future development of the active rock glacier discharge and its role in the local catchment.

Future groundwater/permafrost feedbacks in the High Andes (5,800 m a.s.l., 27 °S).

Sebastián Ruiz-Pereira (Dep. Ing. Hidráulica y Ambiental (DIHA), PUC, Chile & PermaChile network) and Sarah Leray (Dep. Ing. Hidráulica y Ambiental (DIHA)).

Abstract

Under future surface temperature rise, permafrost degradation may impact groundwater dynamic and headwater hydrological responses. Such impacts could lead to increasing aquifer active depth and cooling of recharge volume but also enact upwelling groundwater flow and eventually lead to different groundwater mixing and hydrological connectivity patterns affecting both streamflow and water chemistry. At 27 °S, and at the border between Argentina and Chile, we assessed a headwater hydrological source area under permafrost conditions above 5,000 m ASL. We combined regional temperature models (CORDEX), the modeling of subsurface thawing and thickening of the active layer and groundwater flow. The analysis integrated surface temperature increase assumed permafrost thickness and bottom temperatures within the next 80 years. Projections substantiate the premise of structural and hydrodynamic variations in both the unconfined aquifer and confined layer. The implications for high-altitude permafrost landscapes consider important transformations both by the cooling of the shallow runoff, recharge and residence times. The hydrological connectivity in subsurface would suffer an important change [beyond the year 2,100] as the aquifer system shows a 'resilience' to surface warming under RCP scenarios in the high Andes.

**This abstract participates in the Outstanding PYRN Oral Communication / Poster Award*

SESSION 6
Advances in the observation and simulation of the snowpack: Implications and applications for permafrost monitoring

Conveners:

- **Jesús Revuelto**, *Instituto Pirenaico de Ecología CSIC*; jrevuelto@ipe.csic.es
- **Esteban Alonso González**, *Centre d'Etudes Spatiales de la Biosphère, CESBIO, Univ. Toulouse, CNES/CNRS/INRAE/IRD/UPS*; esteban.alonso-gonzalez@univtlse3.fr
- **Franziska Koch**, *Institute for Hydrology and Water Management. University of Natural Resources and Life Sciences;* franziska.koch@boku.ac.at

Summary:

The snowpack is the element of the cryosphere with the highest spatial and temporal variations. Additionally to the major importance that the snowpack has to isolate frozen soils and glaciers from the atmosphere, it has manifold impacts on water availability, vegetation patterns, and ecosystems. In the last years important advances on monitoring snow dynamics have been done, comprising remote sensing techniques, detailed simulation system or the combination of these through data assimilation routines. There exists a wide variety of approaches but also on the spatial and temporal scales and on the variables monitored. A deeper comprehension of snow dynamics in remote areas will allow an improved understanding of permafrost evolution in these areas, together with an enhanced monitoring. This session will focus on novel studies applying state of the art models, remote sensing or in-situ techniques and also the combination of these to monitor and understand snow dynamics. We encourage contributions with special focus on the snowpack in polar and mountain areas.

An investigation of Australian semi-perennial snowpatches using satellite imagery

Philip Campbell (University of Canberra, Australian Capital Territory).

Abstract

The Kosciuszko National Park in southern New South Wales contains Australia's longest lasting semi-perennial snowpatches, lying on south to southeast facing slopes between 1,900 and 2,200 metres where they receive the lowest insolation and greatest accumulation from snow- bearing winds. Since 1954, the duration of the winter snowpack has declined by three days per decade, and depth by 0.48 cm year (Sanchez-Bayo and Green 2013), with an observed reduction in snowpatch longevity (Green and Pickering, 2009). As semi-perennial snowpatches supress the growth of shrubby tall alpine species in favour of short alpine herbfield, and nurture downslope areas with meltwater during summer months, a reduction in extent and duration is expected to significantly effect local vegetation dynamics (Edmonds et al 2006, Venn et al 2011, Wharen et al 2001), and is likely to also impact associated physical processes recorded in the patches such as nivation (Costin et al 1964). Satellite images acquired through the Planet Education and Research Program and the Sentinel EO Browser are being used to identify any long-term trend in the melt date of 24 key snowpatches since the early 1980s. Using higher resolution satellite data available from 2006, changes in snowpatch area and volume will be calculated, and Australian Bureau of Meteorology data for ENSO, iOD and SAM climate cycles assessed for their role in snowpatch interannual variability. The data collected will be used to build a model of future changes in snowpatch duration and extent and expected effects on associated plant communities and geomorphological processes to help inform better decision making by ecologists and land mangers within the Kosciuszko UNESCO World Heritage alpine area.

Future snowpack evolution in Disko Island, Greenland

Josep Bonsoms (University of Barcelona), Marc Oliva (Department of Geography, Universitat de Barcelona) and Juan Ignacio López-Moreno (Instituto Pirenaico de Ecología (IPE-CSIC), Campus de Aula Dei).

Abstract

Greenland's permafrost and ground thermal regime is governed by topographical, climatological, and snowpack dynamics. Climate warming, however, is changing the high-latitude snow patterns, with relevant impacts in permafrost environments. Therefore, a better understanding of snow evolution within a warming climate is crucial. In this work, we forced a physical-based snow model with 21st century climate projections to analyze the snow sensitivity to the anticipated increase of temperature. Snowpack analysis is performed in Qeqertarsuaq Arctic Station (69º15'N, 53º 31'W; Disko Island, Western Greenland), where instrumental records are available since the 1990s. Results highlight the high sensitivity of Arctic snow to climate change. Seasonal snow accumulation and duration are clearly reduced due to warming. During snow accumulation season, the increase of temperature leads to decreases in the snowfall ratio, leading to rain-on-snow events. On the other hand, during snow ablation season, the peak seasonal snowpack is anticipated by around 10 days per ºC, triggering earlier snow ablation during the cold season and faster snow cover depletion. The positive air temperature trend of 1ºC expected before 2050 results into an increase of around 0.5ºC in surface temperature, suggesting that snow plays a key role controlling the ground thermal regime and soil stability.

Effect of snow on simulated pan-arctic ALT with a new version of the Arctic Crocus snow model

Alain Royer (Université de Sherbrooke), Ghislain Picard (Institut de géophysique de l'environnement), Marie Dumont (Météo-France) and Alexandre Langlois (Université de Sherbrooke).

Abstract

Snow cover duration as well snow microstructure modify the soil thermal regime and thus the Active Layer Thickness (ALT). An increase of snow density increases its thermal conductivity and thus cools the soil surface during winter while the increase in summer air temperatures, which also reduces snow cover duration, increases the ALT. In this study, we modified a version of the French snow Crocus model for a better adaptation to Arctic conditions. A typical Arctic snowpack is characterized by a vertical density profile decreasing from the top to the bottom (opposite to Alpine snow) and by a dense surface wind slab layer overlaying a depth hoar layer. Using 'Arctic Crocus' driven by ERA_Interim, we analyzed the trend of ALT over the last 4 decades (1979-2018) over the circumpolar Arctic land above treeline. Results show that the 'Arctic Crocus' simulates a significant increase of ALT with a mean trend of +4 cm/decade (16 %), while the standard Alpine Crocus shows no trend along the same period. We will discuss this finding, more consistent with what is generally observed.

Model evaluation for blowing snow impacts on permafrost and greenhouse gas fluxes

Hotaek Park (JAMSTEC), Alexander Fedorov (MPI) and Tetsuya Hiyama (Nagoya University).

Abstract

Snow strongly affects permafrost and hydrothermal processes, and the associated feedbacks to climate. The snow distribution covering over soil surface is closely related to topography, vegetation, and climatic conditions. The strong winter wind leads to frequent blowing snow and thus heterogeneous snow cover, which is majorly identified in the Arctic tundra. In recent decades, observational records captured the amplified warming magnitude of permafrost in the tundra regions, due to the combined impacts of increasing air temperature and higher snow insulation. Most land surface models do not consider the blowing snow, and thus tend to overestimate snow depth against the observations. A land surface model CHANGE, improved the blowing snow component, is used to assess the influences of the blowing snow on permafrost temperatures and the associated greenhouse gases, based on two experiments that included or excluded the blowing snow for an observational site in the northeastern Siberia and over the pan-Arctic scale for 1979–2016. The differences between the two experiments indicated that the blowing snow-caused thinner snow depth with higher density and the resultant cooler permafrost temperature linked to lower both vegetation photosynthesis and decomposition of soil organic carbon, relating to the increased soil moisture stress in terms of the increased soil ice portion. These results suggest that the land surface models without the blowing snow component likely overestimate the simulated greenhouse budget over the tundra regions. There is a strong need to improve land surface models for better simulations and future projections of the northern environmental changes. These results are further upgraded from the outcome of 2019 AGU Fall Meeting.

Spatio-temporal evaluation of extreme snow melting in Greenland (1990 – 2020)

Josep Bonsoms (Department of Geography, Universitat de Barcelona), Marc Oliva (Department of Geography, Universitat de Barcelonaa) and Juan Ignacio López-Moreno (Instituto Pirenaico de Ecología (IPE-CSIC), Campus de Aula Dei).

Abstract

Climate warming is altering the Greenland snow melting rates, duration, and spatial patterns, with important soil implications on permafrost environments. Here, we examine the summer (June, July and August) extreme (percentile 90th) snow melting events for the 1990 to 2021 period. Spatial and temporal snow melting is linked with the atmospheric circulation patterns that rule the synoptic variability across Greenland. Different snow melting patterns are found depending on the Greenland sector. The largest extreme snow melting frequency and magnitude, as well as relative contribution to the accumulated snow melting per season, is generally observed in western Greenland. On the contrary, minimum values are observed in the northern sectors. The average extreme snow melting during summer is non-statistically significant increasing in the entire Greenland. Similarly, snow melting is also increasing within Greenland, although non-statistically significant decreases are observed within the central area. Extreme snow melting days as well as the contribution of extreme snow melting to the total snow melting per season show an upward trend. The largest and statistically significant (< 0.05) increases are observed in NW (R^2 = 0.19) and NE (R^2 = 0.11). The synoptic characterization of Greenland snow melting show that only a few atmospheric circulation weather types trigger the majority of the average daily snow melting. The largest snow reductions are observed when an anticyclonic system is located across southern and central Greenland, which leads to positive sublimation and shortwave radiation anomalies. Our results are important for a better characterization of snow melting across Greenland in a warmer world.

Spatio-temporal variability of snow distribution at mountain range scale from novel high-resolution satellite-derived snow data: The Pyrenees Mountains, Spain

Sophie Biskop (Friedrich Schiller University Jena), Bernhard Sassik (ExoLabs) and Hendrik Wulf (ExoLabs).

Abstract

Seasonal snowpack has significant implications on the periglacial environment in high altitude regions. Changes in snow distribution, its timing, duration and thickness can considerably affect permafrost thermal conditions such as the freeze/thaw cycles on the ground. A deeper understanding of the spatio-temporal variability and seasonal dynamics of snow distribution is critical for predicting climate change impacts on periglacial processes and landforms related to permafrost, the active layer or seasonally frozen ground. In this study, we analyse the spatio-temporal distribution of the seasonal snowpack in the Pyrenees based on novel satellite-derived snow products with an unprecedented temporal (daily) and spatial (20 m) resolution. The high-resolution snow products include different variables such as snow-covered area, snow depth and snow water equivalent. To assess spatio-temporal variation characteristics of the snowpack in the Pyrenees various snow metrics describing properties of the accumulation-ablation season are derived for the winter seasons 2020/21, 2021/22 and 2022/23. Moreover, the influence of the topography on spatio-temporal snow patterns in the Pyrenees is analysed considering specific topographic variables (e.g. elevation, slope, aspect, etc.). The outcomes of this study provide a useful basis for future regionally focused investigations on the thermo-insulation effect of the seasonal snow-cover in the Pyrenean periglacial land system.

Evolution of the properties of the snowpack at Crater Lake from 2017 to 2021 (Deception Island, Antarctica).

Miguel Ángel de Pablo (Departamento de Geología, Geografía y Medio Ambiente. Universidad de Alcalá), Miguel Ramos (Departamento de Física y Matemáticas. Universidad de Alcalá) and Gonçalo Vieira (Centro de Estudos Geográficos, Instituto de Geografia e Ordenamento do Território. Universidade de Lisboa).

Abstract

Deception Island, at the South Shetlands Archipelago in Antarctica, is close to the northern limit of permafrost in the region, with mean annual air temperatures about -3 °C. In those conditions, small changes in air temperature result on permafrost degradation. To detect it, active layer and permafrost thermal regimes are permanently monitored at Crater Lake in Deception Island since 2005. Air and ground surface temperatures, as well as ground temperatures at different depths, down to 5 m are recorded. Masts with temperature sensors at different heights and time-lapse cameras were later added to monitor changes on snow cover. Interannual changes on the active layer thickness and temperatures have been reported in various papers. The snow cover regime was pointed as the main controlling factor in the interannual variability of soil temperatures, mainly controlled by changes on snow thickness, as well as on the onset and offset dates of the snowpack. A snowpack analyzer (Sommer Gmbh) has been installed in early 2017 close to one of the permafrost monitoring stations, to record multiple snowpack parameters, including: thickness, weight, density, water content, ice content, temperature, and snow water equivalent, among others, as well as environmental variables, such as air temperature and moisture, and the radiation budget. Here we present the station and the data acquired from 2017 to 2021, and its contribution to understanding the dynamics of the active layer and permafrost thermal regimes.

Real-time monitoring of snowmelt infiltration in steep permafrost affected rock slopes using fluorescent dyes

Matan Ben-Asher (EDYTEM, Université Savoie Mont Blanc, CNRS), Florence Magnin (EDYTEM, Université Savoie Mont Blanc, CNRS), Jean-Yves Josnin (EDYTEM, Université Savoie Mont Blanc, CNRS), Josue Bock (EDYTEM, Université Savoie Mont Blanc, CNRS), Emmanuel Malet (EDYTEM, Université Savoie Mont Blanc, CNRS) and Yves Perrette (EDYTEM, Université Savoie Mont Blanc, CNRS).

Abstract

The increased rockfall activity observed in high mountainous regions has been linked to permafrost degradation and water infiltration into rock fractures. However, little is known about the connectivity between surface water and subsurface fractures in steep permafrost-affected rock slopes. Here we present a novel high-elevation field experiment, to monitor real-time infiltration in rock fractures at Aiguille du Midi (3842 m a.s.l), in the Mont-Blanc massif. A tunnel that was carved for access to visitors, allows the collection of water directly from fractures that cross the tunnel walls. We monitored flow rate, temperature, and electrical conductivity of water in two adjutant fractures. We installed a fluorescence probe and inserted two different fluorescent dyes: amino-acid-G and sulphorhodamine-B, into snow patches at the surface, in two locations directly above the fractures (5-15 m) to track the water source. We sampled water from the monitored fractures and other locations in the tunnel. Results show that the peak flow rate occurred as early as June and is likely the result of a heat wave that accelerated melting. Flow rate showed sub-daily fluctuations, between <1 L/hour in the morning to >10 L/hour in the late afternoon, that correlate with oscillations in surface temperatures, with a 1-2 hours lag time. The two adjacent fractures showed different flow regimes. The amino-acid-G tracer was continuously detected in the water, from the first flow events in mid-May, until all the visible snow cover was gone in July. Substantial flow continued after the amino-acid-G tracer was no longer detected. The second tracer (Sulphorhodamine-B) was not detected. Samples from other locations in the tunnel did not show any of the two dyes. Water samples were also analyzed for composition of stable isotopes to study their source. Our results show evidence of high connectivity between surface water and sub-surface pathways in permafrost rocks.

Impact of snow cover on soil surface temperature in a permafrost dominated catchment of Central Siberia: model comparison and climate change projection.

Thibault Xavier (Géosciences Environnement Toulouse), Esteban Alonso-González (Centre National d'Etudes Spatiales), Anatoly Prokushkin (V.N. Sukachev Institute of forest SB RAS), Oleg Pokrovski (Géosciences Environnement Toulouse), Laurent Orgogozo (Géosciences Environnement Toulouse) and Simon Gascoin (Centre d'Etudes Spatiales de la Biosphère).

Abstract

The Kulingdakan watershed is located in East Siberian region and has been studied and monitored for about two decades. It is located 5 km away from Tura city (64°17' N, 100°13'E), where daily meteorological data (temperatures, snow height and precipitations) are available from 1999 to 2014. The 40 - 65 cm (depending on the year) thick snow layer provides insulation between the soil and the air, together with the moss layer located above the soil.
Soil surface temperature is a key input data for permafrost modeling, although generally the available temperature information is air temperature. The aim of the present study is to take into account the snow layer and also of the moss layer when deriving the temperature at the soil surface from daily meteorological data, in both present conditions and future scenarios.
For this purpose, we use a degree-day snow model, together with a transfer function approach for estimating soil surface temperature. Snow water equivalent is derived from snow heights measurements using a snowpack model and a data assimilation algorithm, and then used as input data in the transfer function model. The 16 years of daily meteorological and snow data are used to assess the precision of the predictive capabilities of this modelling chain, and inter-annual variation effects is discussed. We finally quantify the effect of future climatic conditions on the snow layer and the temperature of the soil surface underneath according to different climate scenarios built on CMIP6 simulations. The obtained results may be used to build top boundary conditions for permafrost dynamics modelling of the considered site.

Automated snow cover observations from two Arctic permafrost sites

Julia Boike (Alfred Wegener Institute), Inge Gruenberg (Alfred Wegener Institute), Niko Bornemann (Alfred Wegener Institute), William Cable (Alfred Wegener Institute), Frederieke Miesner (Alfred Wegener Institute), Brian Groenke (Alfred Wegener Institute), Moritz Langer (Vrije Universiteit Amsterdam, Department of Earth Sciences, Amsterdam) and Julia Martin (Alfred Wegener Institute).

Abstract

From the soil pore space to continental spatial scales, permafrost in the Arctic is undergoing warming and degradation. Shifts in winter air temperatures are mitigated by the snowpack in a complex fashion, as snowpack height and snow thermal properties evolve. Complex snow phenomena such as depth hoar formation, refreezing of melt water and wind compaction change how the soil cools in winter. We report on the spatial and temporal scales of snow cover and physical properties from two Arctic permafrost observatories located in Spitsbergen (Bayelva) and Siberia (Samoylov). Our hypothesis is that the snow cover properties, especially the collapse (thaw) of the snow cover due to winter warming events (Bayelva) and the formation of the depth hoar (Samoylov) affect (decrease/ increase) the ground temperatures. We present time series of snow properties such as such as snow height, water equivalent / snow density measurements. A basal ice layer was typically observed in the Bayelva snowpack, indicative of winter warming events. The snow on Siberia had a depth hoar layer of several centimeters located at the ground-snow interface. The automated snow density data from this site showed differences in the onset, formation and extent of the depth hoar layer between years. For both sites, the complexity of the snowpack and its inter-annual variability had a strong influence on the ground thermal regime. In the case for the Bayelva site, the snowpack collapsed due to a strong winter rainfall. The water froze subsequently, forming a thick ice cover which led to cooling of the ground. At the Siberian site, the effect of depth hoar formation was different between two consecutive years. Tying these observations to larger-scale models of permafrost response is an ongoing challenge due to the small-scale complexities and lack of snow models which accurately represent depth hoar formation in Arctic snow.

Progress and limitations in simulating arctic snow cover: implications in understating soil winter temperatures

Alexandre Langlois (Universite de Sherbrooke), Frédéric Bouchard (Universite de Sherbrooke), Alexandre Roy (Université du Québec à Trois-Rivières), Vincent Sasseville (Universite de Sherbrooke) and Élise Groulx-Maurer (Universite de Sherbrooke).

Abstract

Patterns in the spatial extent and mass balance of snow have shown a statistically significant trend towards negative anomalies over the past few decades. More specifically, spring snow cover extent (SCE) and duration (SCD) have decreased significantly in permafrost-rich regions of Eurasia where the duration of the spring snow-free period was 30-50 % longer than normal. Changes in spatial and temporal patterns of SCD and SCE will have strong impacts of permafrost thermal regime and stability and yet, accurately simulating snow geophysical properties governing energy exchange across the air-snow-soil interface remains an open challenge. Here we present results of recent work on improving arctic snow simulations using the SNOWPACK model. Several studies have highlighted problems with using SNOWPACK in open tundra environments where problems on microstructure and thermal conductivity were highlighted. In this paper, we present recent improvements on snow density simulations by empirically adjusting the wind speed threshold for densification using in-situ observations from our main study site in Cambridge Bay, Nunavut. Results suggest an improvement in density simulation of 15-38 % between depth hoar and wind slab respectively. Moreover, using snowpit data collected across 2015-2022 (>200 pits) we evaluated the model's performance in simulating snow depth, SCE and SCD at 1-km resolution, forced with the Global Environmental Multiscale – Limited Area Model (GEM-LAM) at 2.5 km resolution for the 2017-2022 period. Such work will allow notable improvements in characterizing the interactions between snow cover dynamics and freeze-thaw cycles across permafrost landscapes.

Modelling and measurement of carbon emissions under Arctic snow

Nick Rutter (Northumbria University), Victoria Dutch (Northumbria University), Paul Mann (Northumbria University), Leanne Wake (Northumbria University), Chris Derksen (Environment and Climate Change Canada), Branden Walker (Wilfrid Laurier University), Gabriel Hould Gosselin (Université de Montreal), Oliver Sonnentag (Université de Montreal), Alexandre Roy (Université du Québec à Trois-Rivières), Alex Mavrovic (Université du Québec à Trois-Rivières), Richard Essery (University of Edinburgh), Carolina Voigt (University of Eastern Finland), Phillip Marsh (Wilfrid Laurier University) and Julia Boike (Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research).

Abstract

Arctic carbon dioxide emissions during the winter months are frequently omitted from global carbon budgets, due to prior assumptions that their contribution is largely insignificant compared to other sources and seasons. This paradigm has recently been challenged, amid a growing awareness of the importance of winter fluxes on overall carbon budgets. Through field measurements at Trail Valley Creek, NWT, Canada, and simulations using the Community Land Model 5.0, here we: 1) consider how the representation of snow thermal conductivity in an Earth System Model impacts simulated near-surface soil temperatures and net ecosystem exchange, 2) report on new low-cost in-situ measurement techniques that aim to quantify carbon dioxide concentrations and fluxes within Arctic snowpacks.

We anticipate new measurement techniques will help evaluate rates of production of carbon dioxide from frozen soils during winter months and address discrepancies between observed and simulated carbon dioxide emissions. Increased confidence in future simulations is important in a region susceptible to permafrost thaw, which is warming two to three times as fast as the global average since the late twentieth century.

Detection of movements in the basal layer of the seasonal snow cover by means of inclination data loggers, Cuiña Cirque (Ancares Mountains, NW Iberia).

Marcos Valcarcel (Departamento de Xeografía. Universidade de Santiago de Compostela), Juan López-Bedoya (Departamento de Xeografía. Universidade de Santiago de Compostela) and Pedro Carrera-Gómez (Departamento de Xeografía. Universidade de Santiago de Compostela).

Abstract

On the northeastern slope of the Cuiña Peak (Ancares Mountain, NW Iberia) the seasonal snowpack undergoes basal movements that give rise to intense geomorphological activity, characterized by the plucking of the rock substrate, the transport of clasts and the abrasion of exposed rock surfaces. Basal movement of the snow cover occurs as snow slide and avalanches. Sliding is a slow and continuous movement, by which the snow mantle slides on the substrate. The displacements due to avalanches are rapid movements, in which the entire snowy mantle is displaced from its base, breaking up into large blocks. To detect the nature of subnival glide caused by snow push a monitoring program was designed. Two miniature "Onset Hobo UA-004-64©" data loggers with a built-in inclination sensor were mounted inside protective steel boxes 80 x 80 x 55 mm in outer dimensions. The sensor measures inclination values in x-, y- and z-axis. The main objective of this research was to develop and test an automatic and continuous procedure for the detection of the basal snow movements and resistance to the thrust forces and collisions with clasts which would be cost effective and permit monitoring at several points. The recorded data allowed identification of several periods of variable duration (days to weeks) characterized by smooth and continuous changes in the inclination of the dataloggers, attributed to slow basal sliding events. Those episodes occurred in spring and winter, with periods of stability evidenced by the absence of changes in the inclination values. In most of the records there are events of sudden activity with marked changes in the inclination values during the spring, attributed to avalanches. The methodology employed permitted the recording of movements in the base of the snow cover, and permits distinction between sliding and full depth avalanches.

Quantifying drivers of snow thickness variation across a discontinuous permafrost watershed

Ian Shirley (UC Berkeley), Sebastian Uhlemann (Lawrence Berkeley National Lab), John Peterson (Lawrence Berkeley National Lab) and Baptiste Dafflon (Lawrence Berkeley National Laboratory).

Abstract

Spatial variation in snowpack thickness is a primary driver of landscape heterogeneity in discontinuous permafrost landscapes, exerting a strong control on watershed–scale variation in thermal and hydrological processes, vegetation dynamics, and carbon cycling. At the landscape scale, topography and vegetation are understood to play an important role in driving variation in snow thickness, but the complex morphology of these landscapes impedes efforts to disentangle these drivers.

Using an Unmanned Aerial Vehicle (UAV), we collected maps of ground, vegetation and snow surface elevation over multiple years across a watershed on the Seward Peninsula in Alaska. We use the inferred maps of snow thickness during peak snow accumulation in 2019 and 2022 and collocated ground surface elevation and vegetation height to quantify drivers of snow thickness variation at landscape scale. We first present a novel approach to extract microtopographic features from complex landscape morphologies. We uncover relationships between microtopography and snow thickness in these environments, and show that these relationships vary for different microtopographic features (e.g. drainage paths, risers and terraces, thermokarst terrain). Then, using machine learning predictions of snow thickness based on topographic information alone, we are able to quantify snow accumulation by shrub canopies in these landscapes. Finally, we demonstrate that these relationships between microtopography, vegetation height, and snow thickness hold across years, even though the watershed was covered by a deep snowpack in 2019 and a shallow snowpack in 2022.

Modeling land use effects on the soil thermal state in Mongolia

Matvey Debolskiy (NORCE Research Centre AS), Hanna Lee (Department of Biology, Norwegian University of Science and Technology), Sebastian Westermann (Department of Geosciences, University of Oslo), Avirmed Dashtseren (Institute of Geography and Geoecology, Mongolian Academy of Sciences), Anarmaa Sharkhuu (Department of Biology, School of Arts and Sciences, National University of Mongolia) and Khurelbaatar Temuujin (Institute of Geography and Geoecology, Mongolian Academy of Sciences).

Abstract

Land use and land cover change (LULCC) significantly modify surface and near-surface mass and energy balance through biogeophysical feedbacks and play an important role in global climate change. Permafrost, as a component of the cryosphere, plays an important role in Earth's climate system. In the southern permafrost regions such as Mongolia, where the thermal state of the soil greatly depends on surface characteristics, the dynamic interaction between land cover and subsurface requires improved prognostic parameterizations for biogeophysical processes for planning more efficient and sustainable land use within the regions. Moreover, the effects land use induces on the subsurface thermal state can affect existing local infrastructure and should be considered for future planning. Observational data suggest that the ground surface temperature difference between grazed and ungrazed grassland in Mongolia can reach several degrees C and can be a determining factor for the existence of permafrost underneath. In addition, the differences in surface temperature between the forest-covered and logged sites can be even higher. In this work, we estimate ecosystem dynamics under different future LULCC scenarios in Mongolia with Community Terrestrial Systems Model (CTSM). We improve CTSM's ability to reflect the biogeophysical state of human-affected ecosystems by adding CENTURY parameterization for grazing. The advanced model version is calibrated and validated with observational data obtained from fencing experiments from different sites in Mongolia. Though pasture is the most common land use type in Mongolia, we also consider forest management effects on permafrost state and surface mass and energy fluxes.

Estimating surface water availability in high mountain rock slopes using a numerical energy balance model

Matan Ben-Asher (EDYTEM, Université Savoie Mont Blanc, CNRS), Florence Magnin (EDYTEM, Université Savoie Mont Blanc, CNRS), Sebastian Westermann (Department of Geosciences, University of Oslo), Emmanuel Malet (EDYTEM, Université Savoie Mont Blanc, CNRS), Johan Berthet (Styx 4D), Josué Bock (EDYTEM, Université Savoie Mont Blanc, CNRS), Ludovic Ravanel (EDYTEM, Université Savoie Mont Blanc, CNRS) and Philip Deline (EDYTEM, Université Savoie Mont Blanc, CNRS).

Abstract

Snowmelt is a major source of water that infiltrates into rock fractures in high mountains and can strongly influence the thermal and mechanical properties of steep rock slopes. However, there is very little knowledge of the quantity and timing of water availability for infiltration in steep rock slopes. This knowledge gap originates from the complex meteorological, hydrological, and thermal processes that control snowmelt, and also the challenging access and data acquisition in extreme alpine environments. Here we utilize field measurements and meteorological datasets (S2M-SAFRAN) in a numerical energy and mass balance model (CryoGrid) coupled with a state-of-the-art snowpack scheme (CROCUS) to simulate the heat and water fluxes in a steep high elevation permafrost affected rock slope at Aiguille du Midi (3842 m a.s.l), in the Mont-Blanc massif. Our results provide new information about water balance at the surface of steep rock slopes. Model results suggest that only ~25 % of the snowfall accumulates in our study site, and the remaining ~75 % is redistributed by wind and gravity. Snow accumulation depth is inversely correlated with surface slopes between 40° to 70°, without accumulation on slopes> 70°. Most snowmelt water does not reach the rock surface due to an impermeable ice layer at the base of the snowpack. The annual effective snowmelt water, that is available for infiltration, is highly variable and ranges over a factor of six with values between 0.05-0.3 m in the years 1959-2021. The onset of the effective snowmelt occurs between May and August and ends before October. It precedes the first rainfall by one month on average. Sublimation is the main process of snowpack mass loss in our study site. Model simulations at varying elevations show that effective snowmelt is the main source of water for infiltration above 3600 m a.s.l.; below, direct rainfall is the dominant source.

SESSION 7
Recent advances in modelling permafrost dynamics, interactions, and feedbacks across scales

Conveners:

- **Jan Nitzbon**, *Alfred Wegener Institute*; jan.nitzbon@awi.de
- **Simone Stünzi**, *Alfred Wegener Institute*; simone.stuenzi@awi.de
- **Léo C. P. Martin**, U*trecht University*; l.c.p.martin@uu.nl
- **Sarah Chadburn**, *University of Exeter*; S.E.Chadburn@exeter.ac.uk

Summary:

Quantifying permafrost thaw and itsfar-reaching impactsis a major challenge in polar and climate research. As a widespread subsurface phenomenon, instrumented monitoring of permafrost conditions is challenging and direct observation through remote sensing is often very limited. Mathematical and physics-based models are therefore an important tool to assess the current state of permafrost and to investigate itsinteractions with the climate in the past, present, and future. In thissession, we invite contributions that highlight recent developments and trendsrelated to the modelling of the dynamics, interactions, and feedbacks involving permafrost. We are particularly inviting contributions addressing improved modelling of the thermal regime, thaw processes, permafrost hydrology, ground ice dynamics, mass transport, and how these processes are affected by and interact with surface conditions such as snow, drainage, or vegetation covers, and, to a larger extent, with the atmosphere, and the overall climate system. We aim to cover a broad range of spatiotemporal scales, from the site to the catchment and global scales, as well as high-latitude, high-altitude, and subsea permafrost. Approaches towards bridging these spatial and temporal scales are of particular interest. We also invite contributions aiming at the exploitation of observational data such as remote sensing and field measurements within numerical models, for example through data assimilation, scientific machine learning, or other statistical modelling techniques

An examination of near-surface permafrost modelling techniques for boreal wetland environments, Whatì, NT, Canada

Philip Bonnaventure (University of Lethbridge), Seamus Daly (Wilfrid Laurier University), Scott Vegter (University of Lethbridge) and Will Kochtitzky (University of New England).

Abstract

In the discontinuous permafrost zones of boreal wetlands, generalized permafrost products are inadequate for local scale planning. These environments are homogenous with respect to air temperature yet display a complex and heterogeneous pattern of permafrost distribution. This is highly dependent on ecosystem structure and the prominence of topographic hollows influencing drainage. Permafrost presence is thus regarded as ecosystem derived or ecosystem protected despite cold mean annual air temperatures (-5.5°C). These environments are also prone to frequent forest fires, further augmenting the delicate balance between climate, ecosystem structure, permafrost distribution and thermal state. Thus, generating permafrost distribution maps for hazard assessment presents a considerable challenge. In this study we apply two established analytical models in the community of Whatì, NT. The aim is to assess these models for suitability determining potential pitfalls and best practices for the boreal wetlands. The first approach ran a binary logistic regression (BLR) model using a combination of field data, digital surface model-derived variables and remotely sensed products. Independent variables included vegetation, topographic position index and elevation. The dependent variable is sourced from 139 physical checks of near-surface permafrost presence/absence. Utilizing this approach 50 % of the terrain was underlain by permafrost which was highly corelated to vegetation and disturbance (burn) presence. Approach two utilized a Temperature at the Top of Permafrost (TTOP) model. This climate-based approached used field collected data from in-situ air temperature sensors and Ground Temperature Nodes (GTN) to spatially model surface variability. As in the first approach vegetation was highly corelated to the presence of permafrost however, this model only showed 30 % of the surface underlain by permafrost. The discrepancies in modeled permafrost coverage illustrates how critical assumptions in model structure influence outcome. It appears in environments prone to disturbance or complex ecosystem structure, climate-based approaches likely underpredict the presence of permafrost.

Addressing watershed scale, centennial permafrost simulation in a permafrost-dominated catchment of Central Siberia with permaFoam

Thibault Xavier (Geosciences Environment Toulouse), Anatoly Prokushkin (V.N. Sukachev Institute of forest SB RAS), Oleg Pokrovski (Géosciences Environnement Toulouse) and Laurent Orgogozo (Géosciences Environnement Toulouse).

Abstract

Permafrost dynamic involves non-linear processes and strong coupling between thermal and hydrological transfers. A mechanistic approach to solve this stiff problem requires the use of High Performance Computing resources and adapted methodologies. For these reason the free, open-source solver permaFoam dedicated to permafrost simulation has been developed within the OpenFOAM framework.
Using this solver, a numerical study is conducted on the Kulingdakan watershed, which is located in East Siberian region (64°17′ N, 100°13′ E) and has been studied and monitored for about two decades. Sub-surface temperature as well as active layer thickness are being discussed and compared to in-situ measurements. The effect of hydrological properties such as litter hydraulic conductivity on permafrost dynamics and water fluxes are quantified and discussed.
Different future climate scenarios are then applied to explore their potential effects on the watershed permafrost dynamics. To this aim, CMIP6 simulations are used to provide with the meteorological forcing. Snowpack dynamics under climate change is taken into account by a dedicated degree-day model, calibrated on the experimental data. A transfer function model is used to derive the surface temperature from the external conditions by taking into account both snow and moss insulation effect. For each scenario, discussion on active layer thicknesses evolution is conducted. Peculiar attention is driven to numerical methodologies designed to perform and efficiently analyze century-scale simulations at watershed scale.

Exploring the relationship between boreal forests and thermokarst development in ice-rich permafrost

Simone Maria Stuenzi (Alfred Wegener Institut), Julia Boike (Alfred Wegener Institut), Sebastian Westermann (University of Oslo) and Moritz Langer (Vrije Universiteit Amsterdam).

Abstract

Boreal forests cover ~55 % of the total global permafrost area and protect it through shading, suppression of below-canopy turbulent fluxes, and interception of liquid and solid precipitation, giving rise to a sensitive interplay between vegetation, climate, and the hydrothermal regime of the ground. In light of ongoing climatic changes and shifts in boreal forest covers, ecosystem changes have become more frequent and threaten the vulnerable thermal equilibrium between the atmosphere, vegetation, and permafrost. Specifically, in ice-rich areas, melting of ground ice can lead to permafrost degradation, forest loss, and thermokarst formation in the form of thaw lakes. The development of such thaw lakes is tightly coupled to local conditions like snow accumulation, topography, and vegetation cover. We aim to understand when and under which hydrothermal and climatic conditions thermokarst-inducing processes occur in boreal permafrost. We simulate the underlying physical processes in boreal permafrost by applying a one-dimensional, numerical permafrost model (CryoGrid) coupled to a detailed multilayer canopy model (CLM-ml v0). Intensive validation of the model setup has allowed for the precise quantification of the heat- and water-transfer processes responsible for the complex permafrost dynamics under boreal forest covers. At various study sites throughout eastern Siberia, the simulations revealed that the forest cover has a net stabilizing effect on the permafrost ground below by changing the radiation balance and modifying the snow cover phenology. Here, we implement excess ice layers and lateral water- and energy fluxes to analyze the initial and further development of thaw lakes. We run simulations to understand the timing of thermokarst development under different boreal forest covers and climate warming scenarios. This gives us insights into the relationship between initial thermokarst-inducing processes, the pooling of water in thaw lakes, and the related possible water stress for surrounding forests, potentially leading to additional forest changes and permafrost degradation.

Explaining uncertainty in the thermal state of permafrost with Bayesian inversion of hydrothermal dynamics

Brian Groenke (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research; Technical University of Berlin), Moritz Langer (Vrije Universiteit Amsterdam; Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Jan Nitzbon (Alfred Wegener Institute Helmholtz Center for Polar and Marine Research), Sebastian Westermann (University of Oslo), Guillermo Gallego (Technical University of Berlin) and Julia Boike (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research; Humboldt Universität zu Berlin).

Abstract

Rapid climate warming in the Arctic is changing the thermal state of permafrost at a global scale. However, large-scale monitoring of ground temperatures, active layer thickness, and hydrological conditions remains difficult due to the sparse availability of subsurface temperature and soil moisture measurements. Models play a crucial role in bridging this gap to help us understand how permafrost is responding to a rapidly changing climate. All but the simplest models, however, carry with them a substantial amount of uncertainty due to a wide range of unknown variables such as soil properties and boundary conditions that must be specified in order to carry out numerical simulations of geophysical processes. Quantifying this uncertainty is crucial to being able to effectively use models to draw inferences about the state of permafrost at meso and macro scales. Bayesian inference provides a natural framework for probabilistically quantifying and constraining this uncertainty using available data. We present recent work where we applied Bayesian ensemble inversion methods with a 1D transient, two-phase heat conduction model to investigate the relationship between freeze-thaw processes and observed changes in ground temperature. We conducted this study using borehole temperature data from four sites located in northeastern Siberia, northern Alaska, northwestern Canada, and the Brøgger peninsula of Svalbard. In this work, we demonstrated that ground temperature measurements alone do not serve as a reliable measure of the thermal state of permafrost due to the nonlinear effects of soil freezing characteristics and historical climatology. Furthermore, we highlight current challenges in ensemble modeling of permafrost processes at large spatiotemporal scales along with possible strategies for overcoming these obstacles using physics-informed machine learning.

This abstract participates in the Outstanding PYRN Oral Communication / Poster Award.

Model and field data comparison for assessing the drivers of watershed-scale heterogeneity in soil thermal regimes and carbon fluxes

Baptiste Dafflon (Lawrence Berkeley National Lab), Chen Wang (Lawrence Berkeley National Lab), Ian Shirley (Lawrence Berkeley National Lab), Stijn Wielandt (Lawrence Berkeley National Lab), Sebastian Uhlemann (Lawrence Berkeley National Lab), Jack Lamb (Stanford University), Zelalem Mekonnen (Lawrence Berkeley National Lab), Robert Grant (University of Alberta), Bill Riley (Lawrence Berkeley National Lab) and Susan Hubbard (Oak Ridge National Lab).

Abstract

Discontinuous permafrost environments exhibit strong spatial heterogeneity in subsurface thermal states, vegetation cover, and carbon fluxes, with sharp transitions that occur at scales too small to be driven by weather forcing or to be captured by Earth System Models. Here we analyze – using field observations and an ecosystem model – the effects of observed spatial heterogeneity in terrain, soil and vegetation properties on heat, water and carbon dynamics in a watershed on the Seward Peninsula in Alaska. First, we quantify the controls on soil thermal regimes across the watershed using a dense network of distributed temperature profiling systems (DTP) to capture soil temperature and thermal parameters, and an Unmanned Aerial Vehicle (UAV) to map terrain elevation, snow depth and vegetation height. In addition, we evaluate the mechanisms driving heterogeneity in heat, water and carbon dynamics by applying a Morris global sensitivity analysis (GSA) to a process-rich ecosystem model, ecosys. The GSA outputs cover the observed ranges of soil temperatures, soil moisture, and surface CO_2 fluxes observed in the watershed. The DTP and UAV data indicate that the heterogeneity in soil thermal regimes is primarily driven by spatial variability in snow depth and frozen soil thermal properties, and co-vary with vegetation type, with near-surface permafrost and talik present under graminoid and tall shrub covered area, respectively. The GSA outputs indicate that the snow depth, O-horizon thickness and soil water content control the soil thermal regime more than an air temperature gradient corresponding to a 140 km north-south distance. The field and model data consistently show that heterogeneity in surface and subsurface hydrological processes is impacting the talik distribution, and that high shrub productivity is only present in talik soil with high nitrogen availability. Our results highlight the complexity inherent in discontinuous permafrost environments and demonstrate that missing representation of landscape heterogeneity could bias predictions of carbon budget.

Investigating spatial variability in the ground thermal regime across divergent ecosystems in Labrador, northeastern Canada

Victoria Colyn (Queen's University), Robert Way (Queen's University), Yifeng Wang (Queen's University), Jordan Beet (Queen's University), Anika Forget (Queen's University), Rosy Tutton (Global Water Futures), Antoni Lewkowicz (University of Ottawa) and Caitlin Lapalme.

Abstract

Across the circumpolar North, recent atmospheric warming has directly accelerated permafrost thaw, while associated ecosystem change has been shown to either amplify or suppress the effects of climate warming. Our incomplete understanding of the interactions between local site conditions and permafrost introduces challenges for understanding future environmental change in regions like Labrador, northeast Canada, where there is a paucity of long-term permafrost data. Regional permafrost-affected habitats support various land-based practices and cultural keystone species for Labrador Inuit and Innu, such as caribou (Inuttitut: tuttuk; Innu-aimun: atikuat) and cloudberries (Inuttitut: appik; Innu-aimun: shikuteu). Recent research in the region has documented rapid environmental change including shrub expansion in the tundra and thermokarst development in peatlands. Expansion of tall shrubs will likely increase ground temperatures through enhanced snow capture, which has implications for regional permafrost thaw. Until recently, there was limited information about the distribution, thermal state, and vulnerability of permafrost in Labrador. However, in 2013, a network of monitoring stations was established in the region as a first step towards characterizing permafrost conditions across coastal-continental and ecosystem gradients. Using data from these stations, this study assesses patterns in ground thermal conditions (temperature at ground surface and ~1 m depth), microclimates (air temperature, relative humidity, snow depth), and local ecosystem properties (e.g., soil, geomorphology, vegetation). Together with numerical modelling and machine learning techniques, the influence of ecosystem properties on spatial variations in the ground thermal regime will be explored across this ten year-old network. Preliminary results at a subset of monitoring locations show divergent responses of ground temperatures to vegetation, soil, and snow conditions, suggesting coastal-continental differences in ecosystem responses to change. This research will help disentangle drivers of near-surface permafrost conditions and contribute to the next generation of permafrost distribution mapping for Labrador in support of northern climate change adaptation.

Globsim v.3 Improvements to an open-source software library for utilizing atmospheric reanalyses in point-scale land surface simulation

Nicholas Brown (Carleton University / NSERC PermafrostNet), Bin Cao (National Tibetan Plateau Data Center, Institute of Tibetan Plateau Research, Chinese Academy of Sciences) and Stephan Gruber (Carleton University).

Abstract

Permafrost simulation is limited in remote areas by a lack of long-term and consistent meteorological observations. Consequently, models that describe permafrost change over time cannot be driven or spun-up for comparison with observations or for impact studies. Reanalysis-derived time series are valuable because they are available with global coverage, for a long time period, and for a broad set of physically consistent variables. Multiple reanalyses are available and can be used together to provide estimates of uncertainty. Practically, however, this data is difficult to use for several reasons: large volumes of data need to be managed, differences in variables, units, and delivery between reanalyses must be reconciled, and grid-scale reanalyses must be downscaled and interpolated horizontally (and vertically within the atmospheric column for mountains regions) to the site-scale. Globsim is an open-source python library (available via GitHub) developed to handle these challenges and to facilitate a simulation workflow using multiple reanalysis products. It outputs sub-daily meteorological time series for any location that resemble meteorological stations. Since the release of the first version of Globsim, we have improved usability, refactored code for maintainability and speed, and fixed several bugs. We also added support for ERA5 ensemble data, and added more sophisticated heuristic downscaling algorithms, including TOPOscale for elevation-adjusted radiative fluxes. We use Globsim as a core tool in a multi-model permafrost simulation workflow. In some cases, model-specific representations of site-scale microclimatic phenomena (such scaling snow accumulation) have also been implemented in Globsim. This makes it possible to increase the similarity of input data between individual models when running simulation ensembles. We expect this tool to be broadly applicable to other permafrost modelers working in remote locations.

Statistical modeling of thermokarst lakes

Constanze Reinken (Max Planck Institute for Meteorology), Victor Brovkin (Max Planck Institute for Meteorology) and Ingmar Nitze (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research).

Abstract

Surface waterbodies are a common landscape feature in permafrost regions. They alter the energy and water exchange between land surface and atmosphere and are sources or sinks of carbon dioxide and methane. Especially ice-rich regions exhibit a large abundance of thermokarst lakes, which form as a consequence of ground ice melting. Due to thermal and mechanical erosion, these lakes can expand quickly while amplifying the thaw of surrounding permafrost. They often have life spans of only a few centuries or millennia and drain when surface or sub-surface drainage channels have formed. Despite their role in the climate system, dynamics of thermokarst lakes in high latitudes are only rudimentarily or not at all represented in Earth system models. Because involved hydrological processes depend on small-scale sub-surface heterogeneities that are difficult to measure, we develop a statistical model of thermokarst lake dynamics (formation, expansion and drainage) by utilizing common stochastic approaches (such as the Poisson process) as tools to simulate changes in lake density and sizes. Recent progress in remote sensing provides an opportunity to use high-resolution satellite data for parameterizations of natural and/or climate-induced thermokarst lake dynamics. Temporal sets of these data will be used to derive the dependence of the statistical parameters on time and changing climate variables, such as near-surface air temperature. We expect our approach and the results of our simulations to contribute to a better representation of permafrost dynamics in Earth system models.

Digital mapping of permafrost in the Yamal-Nenets autonomic district (YaNAD) of Russia

Vladislav Isaev (Scientific Center of arctic research, Salehard), Artemy Antypov (Scientific Center of arctic research, Salehard) and Ekaterina Koroleva (Scientific Center of arctic research, Salehard).

Abstract

Modern ratio of arctic exploration has required new ways for collection, analyses and visualization of natural and technogenic data in implementation to the research objects as natural as well artificial. Complex survey of permafrost is including satellites data analyses, light detection and rangering system (LiDAR) data, permafrost state parameters measurements (temperature, ice content, mineral content et ctr.) throw-out engineering drilling in combination with rank of geophysics studies (Electric Resistivity Tomography (ERT), Ground-Penetration Radar (GPR), Induced Polarisation (IP) and ElectroMagnetic Conductivity (EMC). These methods overlay get to researchers following ability: - to make step from dot data to spatial one; - to find the main reason of changing in natural or technogenic ground system; - to prepare next step of monitoring - the prediction of future changing by modelling on the base of long-term observation data. In our study we have an aim to renovate the analog linear maps of permafrost, engineer-geologist maps, map of quaternary deposits, hydrology, geology and topographic maps in 1:1 000 000 scale. This aim requires to solve following tasks: - formation of new topographic basement on the base of satellites data (Sentinel 1-2 and Maxar); - transfer of linear maps from archives to vector (digital) ones with actualization of its content on the base of remote sensing data; - adding validation areas maps with more detail scale - 1:100 000 to the main scale project; - adding the validation dot data from permafrost monitoring net of YaNAD (Scientific Center of Arctic research data base; Fuel and Energy Complex data base; The Russian Federal Service for Hydrometeorology and Environmental Monitoring (RosHydroMet) data base) to the main project; All these stages lets to prepared digital permafrost map as the first step to digital twin of YaNAD with modelling of city agglomeration and industrial objects on the base of Building Information Modelling (BIM) technology and natural areas on the base of analytic-modelling mechanism. In the result we will recieve Open Data project with dynamic data bases for all fields of YaNAD activities from industrial tasks to the indigenous people requires.

Uncovering Ground-Temperature Model Accuracy in Permafrost Environments

Hannah Macdonell (Carleton Unviersity) and Stephan Gruber (Carleton University).

Abstract

Permafrost thaw has implications for people, ecosystems, and the global climate. If modelling results are to help inform adaptation, it must be demonstrated that they can accurately characterize permafrost environments. There are a variety of statistical methods available to gauge accuracy by comparing simulated outputs to observational data, yet there is no single agreed-upon approach to model evaluation. Establishing a consensus around which measures to use faces a number of challenges: (a) model performance varies over time and by location, (b) differing statistical approaches exist for comparing simulated output to observational data and produce differing results, (c) numbers summarizing model accuracy are difficult to interpret or compare, and (d) ground temperature data is limited in its availability and quality and may thus bias measures of model accuracy. The aim of this study is to enable more meaningful comparison of two simulation products or to assess improvement in permafrost modelling software. Through review and experimental testing, we select accordance measures that we apply to daily data, for differing terrain types, and differing temporal subsets. From the results, we develop a ranking of simulation quality that accounts for the specific characteristics of ground temperature in permafrost areas as well as for the uncertainty introduced by small observation data sets. We demonstrate the method using three clusters of ground-surface temperature (GST) sites in the Northwest Territories, Canada. For those, we simulate GST using the model GEOtop and three driving meteorological point-scale reanalysis datasets (MERRA-2, JRA-55, and ERA5) derived via GlobSim. We evaluate each simulation as well as the ensemble mean and rank their performance.

Analysis of resolution-induced differences in soil - hydrology - vegetation interactions in the Arctic using state-of-the-art land surface model

Meike Schickhoff (Max-Planck-Institut für Meteorologie), Philipp de Vrese (Max-Planck-Institut für Meteorologie) and Victor Brovkin (Max-Planck-Institut für Meteorologie).

Abstract

Arctic permafrost degradation and carbon decomposition do not occur homogeneously across Arctic ecosystems due to the rich landscape diversity and the high amount of small-scale heterogeneities. Traditionally, Earth system models (ESM) are deployed to investigate future climate change in the northern permafrost areas. The typical heterogeneous landscape characteristics of the Arctic are however in scale well below the usual ESM resolutions of several hundred kilometers. To take in-depth account of small-scale heterogeneous landscapes, a higher land surface model resolution is advantageous. To investigate whether and why resolution matters in simulating the interactions of soil physics, hydrology, and vegetation in the Arctic, we develop a high-resolution version of the land surface model (LSM) JSBACH3 on the scale of 5 km for a case study in the Chersky region in eastern Siberia. We then compare the results with the output of the same model in a low ESM resolution of about 200 km. The LSM simulations are performed in standalone mode (without feedbacks to climate) using the same climate forcing for both, high- and low- resolution setups. Our analysis shows that small-scale soil characteristics are more relevant regarding resolution than vegetation properties. We found that the formulation of supercooled water processes in the soil has a major impact on the differences between low and fine resolutions, as well as soil organic matter fractions. Other soil parameters such as hydraulic conductivity, soil porosity or heat conductivity have relatively minor effects on differences between model resolutions. We show the relevance of model resolution in the simulation of Arctic land physical and biogeochemical interactions and thus argue that the development of a high-resolution pan-Arctic LSM would be a major advancement in modelling future Arctic permafrost and carbon projections.

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Modeling shoreline thermodynamics of lakes in the Arctic permafrost region

Mehriban Aliyeva (Alfred Wegener Institute Helmholtz centre for polar and marine research), Ngai-Ham Chan (Alfred Wegener Institute Helmholtz centre for polar and marine research), Rui Chen (Alfred Wegener Institute Helmholtz centre for polar and marine research), Jan Nitzbon (Alfred Wegener Institute Helmholtz centre for polar and marine research), Thomas Schneider von Deimling (Alfred Wegener Institute Helmholtz centre for polar and marine research), Simone Stuenzi (Alfred Wegener Institute Helmholtz centre for polar and marine research) and Moritz Langer (Vrije Universiteit Amsterdam).

Abstract

Lakes are an important element of Arctic and Sub-arctic landscapes. According to estimates there are over 8 million lakes of various origins there, of which a significant share belongs to the lakes formed due to permafrost degradation (thermokarst). The climate warming of the last decades has led to more lakes that do not freeze along the whole depth profile in winter and stay unfrozen at the bottom where thaw pouches (taliks) form. This process is further accelerating the thawing of permafrost as well as exposing thawed organic matter to microbial decomposition. Another important component is shoreline erosion processes controlling the expansion and drainage of lakes. These processes have been observed and studied before using satellite methods, but there is not yet a satisfactory modeling approach that would allow lake shoreline erosion under transient climate conditions We use the numerical permafrost model CryoGridLite to simulate the freeze-thaw dynamics of arctic and subarctic lakes and present a first conceptual framework to represent lake expansion and drainage under different cryolithological and climate conditions.

Data assimilation of Sentinel-2-retrieved fractional snow-covered area and InSAR-retrieved seasonal ground subsidence on Brøgger peninsula, Svalbard

Clarissa Willmes (University of Norway), Sebastian Westermann (University of Oslo), Line Rouyet (NORCE), Kristoffer Aalstad (University of Oslo), Désirée Treichler (University of Oslo), Juditha Aga (University of Oslo) and Lotte Wendt (NORCE).

Abstract

Increases in permafrost temperatures are observed globally and models project this increase to continue with climate change, imposing economic, societal and environmental consequences. The timing and magnitude of projected changes in permafrost nonetheless varies considerably between different models and climate scenarios. For well-informed future projections of permafrost evolution, accurate representations of current ground states are needed, but the models typically suffer from the spatial and temporal sparsity of in-situ measurements. Satellite remote sensing offers great opportunities to fill these spatial and temporal gaps, but can not provide direct information on the permafrost subsurface state. In this study, we combine the CryoGrid community model and satellite retrievals of fractional snow-covered area and seasonal surface subsidence in a data assimilation framework to infer ground parameters. Local conditions of snow cover strongly modify the ground thermal state. With the assimilation of Sentinel-2-derived fractional snow-covered area, the timing of snow melt and the overall depth of the winter snow cover can be constrained. The assimilation of InSAR-retrieved seasonal surface subsidence is well-suited to infer ground parameters, as the amplitude and timing of the surface displacement depend on properties such as the active layer thickness, soil properties and the water/ice content. We investigate the suitability of this data assimilation scheme to infer subsurface parameters by applying it to a set of well-studied and monitored permafrost sites on Brøgger peninsula (Svalbard, Norway).

Modeling the impact of permafrost degradation on vegetation evolution in the 21st century over the Tibetan Plateau

Rui Chen (Alfred Wegener Inst. Helmholtz C. for Polar and Marine Res., Potsdam; Geography Dept., Humboldt Univ. of Berlin), Thomas Schneider von Deimling (Alfred Wegener Inst. Helmholtz C. for Polar and Marine Res., Potsdam; Geography Dept., Humboldt Univ. of Berlin), Jan Nitzbon (Alfred Wegener Inst. Helmholtz C. for Polar and Marine Res), Simone Maria Stuenzi (Alfred Wegener Inst. Helmholtz C. for Polar and Marine Res), Julia Boike (Alfred Wegener Inst. Helmholtz C. for Polar and Marine Res.; Geography Dept., Humboldt Univ. of Berlin) and Moritz Langer (Alfred Wegener Inst. Helmholtz C. for Polar and Marine Res.; Dept. of Earth Sciences, Vrije Univ.).

Abstract

Permafrost degradation in the Tibetan Plateau is an established fact that is projected to continue until the end of this century. However, the extent to which permafrost degradation affects vegetation evolution is not fully understood, particularly under future climate warming and wetting. In this study, we used reanalysis climate data (1979-2018), the latest CMIP climate data (2019-2100), and CryoGridLite, an efficient computationally permafrost model, to simulate permafrost degradation on the Tibetan Plateau. Our simulations indicate that under the SSP5-8.5 scenario, the current permafrost area (1.04×106 km^2) will experience losses of 49 %, 75 %, and 90 % in the near-term (2025-2049), mid-term (2050-2074), and long-term (2075-2099) compared with the current period (2000-2018). The mean annual ground temperature at 10m depth and active layer thickness for the remained permafrost area will increase by 1.04 ºC, 1.24 ºC, and 1.68 ºC, and by 1.93 m, 1.97 m, and 2.73 m, respectively. To investigate the impact of permafrost degradation on vegetation evolution over the Tibetan Plateau in the 21st century, we combined our simulation results with remote sensing data on normalized vegetation index and net primary productivity provided by Google Earth Engine in the historical period. We used statistical and machine learning methods to analyze changes in vegetation resulting from permafrost degradation trajectories under different future climate scenarios. Our results emphasize the importance of understanding the contribution of permafrost degradation to vegetation and carbon balance, particularly in the context of future climate change.

Synergetic approach to pan-Arctic interactions between hydrology and carbon

Victor Brovkin (Max Planck Institute for Meteorology), Annett Bartsch (BGEOS), Mathias Goeckede (Max Planck Institute for Biogeochemistry) and Martin Heimann (Max Planck Institute for Biogeochemistry).

Abstract

The Arctic is warming almost four times faster than the rest of the planet. A thaw of an ample amount of organic carbon accumulated in the Arctic permafrost during the geological past is considered as a potential tipping element in the Earth System. Will the Arctic turn from a small sink to a strong source of CO_2 and CH_4? Answering this question is challenged by complex interactions between physical, hydrological, biogeochemical, and ecological processes. In the Q-ARCTIC project funded by European Research Council (ERC), we follow a synergetic approach by combining remote sensing and local-scale observations with modelling on scales from a few meters to hundred kilometers. The primary objective of Q-ARCTIC is to close the gap between process scale and ESM grid resolution, with a particular focus on the net effect of disturbance processes and associated changes in hydrology on pan-Arctic scale. To close this gap, we are going to use sub-grid stochastic parameterizations with parameters estimated from high-resolution remote sensing data combined with site-level observations. We start with a case-study of a well-studied region around the Chersky settlement in North-Eastern Siberia. We synchronize the land surface classification between remote sensing and land surface modelling approaches, and compare the quality of high-resolution against low-resolution simulations with observations. By using ESM in Q-ARCTIC, we quantify not only permafrost carbon feedbacks to climate, but also biogeophysical effects of permafrost thaw. As example, we applied two idealized setups of the land surface that induce comparatively “wet” or “dry” conditions in permafrost-affected regions. We found that a modification of the permafrost hydrology within its uncertainty range leads to two very different hydroclimate responses even far away from the Arctic. Surprisingly, wet and dry trajectories resulted in similar terrestrial methane emissions. This and other novel results from Q-ARCTIC will be presented at the meeting.

Climate Downscaling in the Southern Carpathians for Climate Analysis and Permafrost Conditions Change, 1960-2022

Simon Filhol (University of Oslo), Mirela Vasile (Research Institute of the University of Bucharest), Flavius Sîrbu (West University of Timișoara), Alexandru Onaca (West University of Timișoara), Bernd Etzelmuller (University of Oslo) and Sebastian Westermann (University of Oslo).

Abstract

Global climate datasets such as the ERA5 reanalysis data provide multi-decadal timeseries extending from 1960 to present day for a number of meteorological variables. Mountain regions exhibiting large topographical changes within a small area are, nevertheless, poorly captured in the default ERA5 data. The Southern Carpathians located at 45°N have a cryosphere highly sensitive to climate change which raises questions on future permafrost preservation and landscape transformation. We present here 1) a fast and pragmatic method to generate downscaled climate timeseries at the hillslope scale named TopoPyScale, 2) a climatic analysis over the sharpest and highest mountains of Romania based on resulting climate timeseries, and 3) an assessment of possible change in conditions suitable to maintain permafrost. TopoPyScale uses a digital elevation model to compute terrain morphometrics (slope, aspect, sky view factor, sun horizon angle) relevant to correct energy balance terms (temperature, air pressure, incoming radiations, precipitations). For large domains, it incorporates functionalities to reduce redundancy in DEMs using clustering and therefore speedup the process of downscaling. Using this tool, we obtained 62 years long timeseries distributed over the whole Southern Carpathians mountain range. After validation against local weather stations, we could derive a number of climatic indices (e.g. mean annual air temperature, annual freezing degree days, snow cover duration, changes in liquid/solid precipitation ratio etc) in high spatial resolution (100 m), focusing on distinct periglacial landforms (e.g. rock glaciers). Finally, we discuss the significance of resulting patterns as witness of climatic changes in conditions favorable for the presence of snow and permafrost.

Probabilistic subgrid-representation of ice-rich permafrost dynamics in the coupled Earth system model AWI-ESM

Jan Nitzbon (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Moritz Langer (Vrije Unversiteit Amsterdam), Brian Groenke (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Paul Gierz (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research) and Martin Werner (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research).

Abstract

High latitude land areas underlain by permafrost play a crucial role for Earth's climate in the past and at present where they act as a heat sink and carbon source. They are characterized by pronounced spatial heterogeneity of surface and subsurface conditions which is often linked to the presence of excess ice. This is leading to a wide range of climatic conditions where permafrost and non-permafrost conditions can co-exist. Current-generation Earth system models (ESMs) fail to represent this subgrid-heterogeneity and are thus limited in their capacity to project permafrost landscape dynamics and thaw trajectories realistically. We have developed a modular framework for coupling the permafrost model CryoGridLite to the fully-copuled AWI-ESM. In this configuration, CryoGridLite receives daily meteorological forcing data from the atmospheric component of the ESM. Conversely, in the northern high latitude land areas, the subsurface conditions of the ESM are informed by the CryoGridLite simulations. The computational efficiency of CryoGridLite allows for large parameter ensembles by which the subgrid-heterogeneity can be taken into account. In addition, CryoGridLite employs parameterizations of thermokarst-inducing processes such as the build-up and melting of excess ice. Here, we present initial simulation results using the permafrost-enabled version of AWI-ESM for different boundary conditions including the last inter-glacial, the last glacial maximum, pre-industrial, and selected future scenarios. We evaluate the simulations using available measurements of present and proxies of past permafrost conditions. Moreover, we investigate the impacts of the improved representation of permafrost on the resulting climate states simulated by the AWI-ESM.

Influence of rapid sea ice loss events on permafrost

Cécile Osy (UCLouvain), François Massonnet (UCLouvain) and Sophie Opfergelt (UCLouvain).

Abstract

The Arctic has been warming two to four times more rapidly than the global mean in the last decades – a phenomenon known as Arctic Amplification. This warming induces changes for the whole cryosphere, including the permafrost and the Arctic sea ice.

Using reanalysis data (ERA5-Land) has shown that the freezing of the upper soil of the active layer of the permafrost is happening later now than in the past, lengthening the period of carbon emissions. The timing of the drop below 0 °C of the 2 m air temperature has been identified has the principal driver of that delay. While Arctic Amplification is a likely driver of those long-term changes, it is unclear what controls the permafrost variability on shorter time scales.

The hypothesis is formulated that sea ice concentration plays a role through the atmospheric circulation on the air temperature in Arctic, and thus on the permafrost degradation. This study aims to evaluate if rapid sea ice loss events – events where the sea ice concentration is way lower than expected according to the climatology during several years – impacts the onset and the duration of the late shoulder season (season between plant senescence and active layer freezing) of the permafrost. These events are expected to happen more in the future, with summer regularly ice-free from 2050 on. The potential link between sea ice concentration and permafrost may thus have a great impact on the Arctic environment, now and in the future. To evaluate that link, temperature, precipitation and geopotential anomalies (deviations from the average of the height of a surface pressure (here 500 hPa), that allow an evaluation of the atmospheric circulation) in Pan-Arctic permafrost regions are studied in relation to sea ice concentration. Our preliminary results indicate that the September sea ice extent might have an effect on the 2m air temperature on the surrounding land, especially in the Eurasian Arctic, and thus influence the permafrost of those regions. Studying the influence of Arctic sea ice on air temperature conditions for the freeze-back of the active layer is a new angle in the understanding of permafrost dynamics.

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Can organic contaminant concentrations in permafrost soils be upscaled from soil carbon content and landform types? Case studies from Canada and Svalbard.

Rachele Lodi (Ca' Foscari University of Venice and CNR Institute of Polar Sciences), Julia Wagner (Stockholm University Department of Physical Geography), Gustaf Hugelius (Stockholm University Department of Physical Geography), Elena Argiriadis (CNR Institute of Polar Sciences), Jacopo Gabrieli (CNR Institute of Polar Sciences) and Carlo Barbante (CNR Institute of Polar Sciences and Ca' Foscari University of Venice).

Abstract

Arctic permafrost soils are important reservoirs of contaminants on time scales ranging from days to millennia. The physical and chemical processes occurring in permafrost systems, susceptible to perturbations under climate change, impact on the cycling of organic contaminants. The extensive work in the Arctic Monitoring and Assessment Program (AMAP) on Arctic contaminants highlights an acute lack of data on contaminants in Arctic soils, particularly below the permafrost table. A key aspect for mapping contaminants and quantifying potential secondary contaminant release is the identification of parameters and landscape properties that we can use to model and upscale from limited in situ observations. Since empirical data on contaminant distribution is still scarce, we must rely on correlations with other parameters for upscaling. Furthermore, for several organic analytes, it has been shown that environmental parameters such as soil depth and organic carbon content can substantially alter environmental contamination patterns, and this must be taken into account when interpreting organic contaminants environmental concentration patterns in terms of temperature and physicochemical properties as parameters that might affect distribution and potential release. Consequently, the main objective of the present study is to explore the potential influence of Organic carbon concentration (%) and content (kg C / m^3) and landscape features in permafrost soil scenarios on the fate of organic contaminants on a regional scale, improving the ability to produce an initial projection of permafrost thaw impacts. Case studies from Canada and Svalbard are presented to illustrate the study applied to different permafrost environments. We will illustrate the statistical analysis performed and the statistical models derived from the correlations between the different analytes and the most studied chemical-physical factors.

The Influence of Glacial Isostatic Adjustment on Past and Future Subsea Permafrost

Roger Creel (Department of Earth and Environmental Sciences, Lamont-Doherty Earth Observatory, Columbia University, New York, USA), Paul Overduin (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Stiig Wilkenskjeld (Max Planck Institute for Meteorology, Hamburg, Germany), Jacqueline Austermann (Department of Earth and Environmental Sciences, Columbia University, Lamont-Doherty Earth Observatory) and Frederieke Miesner (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research).

Abstract

Subsea permafrost is the consequence of deglacial sea-level rise, which floods frozen coastal lowlands during interglacial periods. Observations of subsea permafrost are scarce and unevenly distributed around the Arctic shelf, with most data available from the narrow North American shelf, and few data from the broad Siberian shelf. An estimated 2.5 million square km of the Arctic continental shelf remain cryotic, but ice contents and temperatures are largely unknown. Although sea-level variations are the most important control on subsea permafrost distribution, subsea permafrost models have ignored processes affecting relative sea level distribution such as glacial isostatic adjustment (GIA), which describes the gravitational, deformational, and rotational effects of liquid and solid water loading on the solid Earth. We modelled heat flow below the circumarctic shelf, including GIA, dynamic sedimentation, and subsea permafrost temperature and ice content over the past 400,000 years and included 17 emission scenarios outlined in the International Panel on Climate Change's 6th assessment report for future permafrost until the year 3000 CE. Earth System Model air temperatures and globally consistent ice sheet models were used to force surface temperatures. Our results suggest that not including glacial isostatic adjustment leads to a substantial overestimate of present-day subsea permafrost thickness, primarily due to the gravitational effects of northern hemisphere ice sheets during glacials. Projections of permafrost development show that subsea permafrost is preserved under low emissions scenarios but mostly disappears under high emissions scenarios.

Susceptibility modelling of retrogressive thaw slumps across the Northern Hemisphere

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Abstract

The average yearly temperatures and precipitation in the Arctic and subarctic areas have increased in the last decades, resulting in increased permafrost disturbances. Retrogressive thaw slumps (RTSs) are characterized by the exposure of ice-bearing permafrost deposits to the ground surface due to erosion, wildfires, dredging and other activities. As RTSs advance by thawing and slumping, they can shed large amounts of sediment into water bodies and release soil organic carbon for decomposition. Here, we compiled a dataset of 16,558 RTS observations across the Northern Hemisphere permafrost region using published datasets and manual mapping with remote sensing data. Then we used statistical modelling techniques to examine the environmental factors that affect RTS occurrence and created the first susceptibility map for RTS occurrence across the permafrost region at ~1 km spatial resolution. We predict high RTS susceptibility in the continuous permafrost regions above the 60th latitude, especially in northern Alaska, northwestern Canada, Yamal Peninsula, eastern Russia, and the Tibetan Plateau. The models indicate that air temperatures and soil properties are the most important environmental factors for the occurrence of RTSs at a landscape scale. This study provides new insights into the circumarctic susceptibility of ice-rich permafrost soils to rapid disturbances like RTSs, where their formation impacts landscape evolution, affects hydrology, and releases soil organic matter and carbon fluxes that contribute to global warming.

Scaling Challenges in Modeling Supra-Permafrost Talik Dynamics

Michelle Walvoord (United States Geological Survey) and David Rey (United States Geological Survey).

Abstract

The temporal development and spatial distribution of supra-permafrost taliks have important implications for biogeochemical and hydrologic processes in permafrost landscapes. These subsurface features represent potential hot spots for year-round microbial activity and generation of carbon fluxes, and they could play a key role in the debated transition of Arctic and boreal regions from carbon sinks to carbon sources. In cases where supra-permafrost taliks are laterally connected through permeable substrate, these zones represent potential pathways for groundwater flow and transport of dissolved constituents, including organic carbon, released from permafrost. Advances have been made toward modeling talik dynamics at multiple scales, but challenges remain in (1) addressing observed fine-scale heterogeneity in talik distribution at large scales, and (2) incorporating lateral hydrologic transport in connected supra-permafrost taliks. This presentation highlights recent site-scale cryohydrogeologic modeling efforts aimed at constraining supra-permafrost talik response to climatic drivers and wildfire disturbance across different permafrost landscapes and soil types. We also present modeling efforts to simulate lateral flow through supra-permafrost taliks at the local scale. Results demonstrate high sensitivity in talik formation timing and expansion to factors affecting the land-surface energy budget, antecedent subsurface conditions, and intrinsic soil hydraulic and thermal properties. Sensitivity analyses provide a basis for observed fine-scale spatial heterogeneity and for future work to improve model representation of supra-permafrost talik connectivity that is necessary for addressing lateral groundwater flow. Next steps toward bridging local to global scale talik modeling in the context of spatial heterogeneity and lateral hydrologic processes that influence permafrost carbon fluxes are discussed.

Assessment of permafrost degradation in the Alps by applying the thermal model CryoGrid Community Model (version 1.0) validated by Petrophysical Joint Inversion of geophysical data

Sarah Morard (University of Fribourg), Christin Hilbich (University of Fribourg), Coline Mollaret (University of Fribourg), Cécile Pellet (University of Fribourg), Florian Wagner (RWTH Aachen University), Sebastian Westermann (University of Oslo) and Christian Hauck (University of Fribourg).

Abstract

The CryoGrid Community Model is a thermal model based on meteorological input and some in-situ knowledge (e.g. porosity). Its modular structure offers the possibility to simulate freezing and thawing processes and quantify ice and water content distribution in the subsurface as a function of time. The extreme heat wave in central Europe in the summer of 2022 offers a good possibility to investigate permafrost degradation with this model and validate its results. For this study, we selected three high-altitude mountain permafrost sites in the European Alps, including Stockhorn (3,410 m a.s.l.), Cervinia (3,227 m a.s.l.), and Schilthorn (2,970 m a.s.l.) with long-term meteorological and borehole data. These data are used for the initialization and valida-tion of the CryoGrid model. In addition, several electrical and seismic tomographic measurements have been performed in a monitoring context at these three sites. The resulting electrical resistivity and P-wave velocity time series can be jointly inverted within a petrophysical joint inversion scheme (PJI) to provide subsurface information on the volumetric rock, water, and ice content. The CryoGrid results regarding the temporal changes in water and ice content distribution could be vali-dated and compared with on-site geophysical measurements. A thorough comparison of these highly complementary data sets would allow a better understanding of the processes involved dur-ing long-term permafrost degradation in high mountains. In future, we aim to reconstruct the past and model the future evolution of permafrost using the 1D thermal model CryoGrid validated by geophysical data. This innovative approach will improve our analysis of permafrost degradation in the Alps. It also will enable us to compare present degra-dation rates at the three sites.

The CryoGrid community model - a multi-physics toolbox for climate-driven simulations in the terrestrial cryosphere

Sebastian Westermann (University of Oslo), Thomas Ingeman-Nielsen (Technical University of Denmark), Kristoffer Aalstad (University of Oslo), Juditha Aga (University of Oslo), Robin Zweigel (University of Oslo), Clarissa Willmes (University of Oslo), Louise Schmidt (University of Oslo), Bernd Etzelmüller (University of Oslo), Andreas Kääb (University of Oslo), Thomas Vikhamar Schuler (University of Oslo), Cas Renette (University of Gothenburg), Léo Martin (Aix Marseille University), Sarah Morard (University of Fribourg), Matan Ben-Asher (CNRS - Université Savoie Mont Blanc), Joana Baptista (University of Lisbon), Annett Bartsch (BGEOS), Tazio Strozzi (Gamma Remote Sensing), Julia Boike (Alfred-Wegener-Institute Potsdam), Frederieke Miesner (Alfred-Wegener-Institute Potsdam), Jan Nitzbon (Alfred-Wegener-Institute Potsdam), Paul Overduin (Alfred-Wegener-Institute Potsdam), Simone Stuenzi (Alfred-Wegener-Institute Potsdam) and Moritz Langer (Vrije Universiteit Amsterdam).

Abstract

The CryoGrid community model is a modular toolbox designed for simulations in permafrost and glacier environments. Within the toolbox, the user can flexibly select between compatible modules, e.g. for the model forcing, the model physics and the model output format. This way, the CryoGrid community model can be configured for a wide variety of application scenarios, from classic point simulations of the ground thermal regime to modeling of permafrost hydrology and transient mapping of the global permafrost extent. Furthermore, CryoGrid includes a module for glacier mass balance, so that simulations in glaciered catchments can be performed within a single consistent model framework. We present example applications, such as the water balance in different permafrost settings, the impact of ponds, ice patches and infrastructure on the ground thermal regime, as well as landscape evolution in ice-rich permafrost. In addition, we showcase the possibilities for spatially distributed mapping of permafrost parameters. The CryoGrid community model is also used for educational purposes, allowing students to operate the model framework via a simplified user interface. Finally, we highlight the challenges of developing and maintaining a community model for permafrost applications and discuss directions for future development.

Numerical modeling to estimate the impact of built infrastructure on permafrost degradation – Case study from Ilulissat, Greenland

Luisa Näke (DTU Construct,DTU,Denmark/Permafrost Research,AWI,Germany/Department of Civil and Environmental Engineering,NTNU), Frederieke Miesner (Permafrost Research Section, Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Thomas Ingeman-Nielsen (DTU Sustain, Technical University of Denmark), Julia Boike (Permafrost Research Section, AWI, Potsdam, Germany / Department of Geography, Humboldt Universität zu Berlin) and Seyed Ali Ghoreishian Amiri (Department of Civil and Environmental Engineering, Norwegian University of Science and Technology).

Abstract

Infrastructure in permafrost landscapes affects the ground thermal regime and may enhance permafrost degradation. Stability and usability of the infrastructure depend likewise on the thermal conditions of the subsurface. Permafrost in the study area in Ilulissat (West Greenland) is typically warm and often ice-rich, so infrastructure is likely to accelerate thawing of the ground. Numerical models can be used to estimate the influence of infrastructure on permafrost development, subsidence, and ponding near roads. In this study, we investigated the influence of roads in Ilulissat using the one-dimensional, laterally coupled heat-transfer model CryoGrid. We used ERA5 reanalysis data (1980-2020) and projections according to the SSP5-8.5 scenario (2020-2100) as climate forcing and validated them with site data from the local weather station (1991-2021). Borehole data from Ilulissat and the north-eastern surroundings provide information on soil stratigraphy properties to first built the model for the natural, undisturbed tundra. In the second model set up, we added the elevated gravel embankment as linear infrastructure to the model with several tiles for the roadway and the shoulder. In a third model run, we quantified the effect of snow by changing the snow distribution near the road to imitate plowing. We utilized measured data from the weather station and iButtons for validation of the model runs. Our simulation show that the construction of a road had a direct influence on the thermal regime by warming the soil. A general deepening of the active layer is projected within the current century, which is supported by borehole observations. Likewise, the associated measures of maintenance such as accumulation of cleared snow affect the response of the soil, as an insulator of the embankment, preventing stored heat from escaping. As the current state permafrost is vulnerable to climate change, it is important to rely on models to provide realistic projections.

Simulating forest cover and terrain effects on ground hydrothermal regime in Mongolia and Siberia

Robin Benjamin Zweigel (University of Oslo), Avirmed Dashtseren (Mongolian Academy of Sciences), Khurelbaatar Temuujin (Mongolian Academy of Sciences), Hanna Lee (Norwegian university of Science and Technology), Matvey Debolskiy (NORCE Norwegian Research Centre), Sebastian Westermann (Uniuversity of Oslo) and Kristoffer Aalstad (University of Oslo).

Abstract

Forest strongly influences the thermal and hydrological regime of the ground through processes such as shading, transpiration, modification of turbulent fluxes and interception. As boreal forest covers large parts of the northern hemisphere's permafrost region, inclusion of forest cover effects is also essential to simulate the hydrothermal state and fate of these areas. This is especially the case towards the southern margin of continental permafrost in Eurasia, where discontinuous permafrost and local forest form a topography-controlled mosaic across the Central Asian Mountains.
We model hydrothermal state using the CryoGrid modelling suite, where we include a single-layer vegetation scheme and terrain corrections. The scheme is based on parameterizations from the Community Land Model 5, capturing the major impacts of vegetation on the surface energy and water balance. New routines for adjusting of forcing data based on TopoSCALE also allow to incorporate the influence of terrain on local climate in mountain regions.
We evaluate our vegetation scheme and terrain corrections against ground measurements and surface energy balance data at sites in Yakutsk, Russia and Ulaanbaatar, Mongolia. For the site in Mongolia, we demonstrate how the addition of our novel schemes is key for accurately simulating the ground thermal regime close to the local and continental permafrost margins.
The inclusion of vegetation and terrain in the CryoGrid model opens up for further studies, such as the fate of water balance of these dry regions during warming, or the effect of disturbances such as fires, logging and intensified land use.

This abstract participates in the Outstanding PYRN Oral Communication / Poster Award

Working Towards a Better Understanding of Hotpot Methane Emissions from Big Trail Lake, Goldstream Valley, Alaska

Kevin Rozmiarek (University of Colorado), Tyler Jones (University of Colorado), Irina Overeem (University of Colorado), Youmi Oh (NOAA), Bruce Vaughn (University of Colorado), Valerie Morris (University of Colorado), Elijah Miller (University of Colorado), Greg Rieker (University of Colorado) and Chloe Brashear (University of Colorado).

Abstract

In the next century, continued permafrost thaw is expected in response to rapid high-latitude warming. Thermokarst lakes are particular hotspots of permafrost carbon release, exhibiting some of the highest methane emissions in the Arctic. In an ongoing research project, we are measuring methane flux at Big Trail Lake (BTL) (Goldstream Valley, Fairbanks, Alaska), a hotspot emission site. We aim to reconcile bottom-up and top-down flux estimates with nested, multi-scale, and concurrent observations ranging from 0.3 - 1000s of square kilometers, using point-source chambers, lake bubble traps, eddy-covariance towers, open-path dual-comb spectroscopy, and fixed-wing drones. We are also measuring carbon-isotopes of methane to better constrain boreal isotopic contributions in global mass-balance modeling. We will report on two seasons of measurements from Fall 2022 and March 2023, as well as future sampling plans. With observations, we are developing a model framework to better understand landscape change, methane emissions, and isotopic signals. We use the Control Volume Permafrost Model (CVPM) tuned to Goldstream Valley. The CVPM is a soil thermal model used to understand active-layer thickness. We will link the CVPM with the IsoTEM model, a process-based carbon isotope biogeochemistry model to calculate the carbon-isotopic signature of methane from global wetland emissions. The combined model framework is in development. We will show results for one of our central hypotheses, that maximum methane emissions from a thermokarst environment (based on BTL) occurs at the vertical soil boundary corresponding to the highest rate-of-change of thawed organic carbon in the total soil column. Beyond the lake, prior observations suggest a power-law relationship for methane emissions, decreasing with distance from the lake, eventually reverting to some background signal. We hypothesize that the kink (or bend) in the power-law represents 0 % thawed carbon beneath the active zone.

Simulating ice segregation and thaw consolidation with the CryoGrid community model

Juditha Aga (Department of Geosciences, University of Oslo), Julia Boike (Alfred Wegener Institute (AWI), Helmholtz Centre for Polar and Marine Research), Moritz Langer (Alfred Wegener Institute (AWI), Helmholtz Centre for Polar and Marine Research), Thomas Ingeman-Nielsen (Department of Environmental and Resource Engineering, Technical University of Denmark) and Sebastian Westermann (Department of Geosciences, University of Oslo.

Abstract

The permafrost thermal regime and the thaw trajectories in a warming climate are highly influenced by the ground ice content, especially for very ice-rich soils. However, lacking field observations challenge the modelling of ice-rich permafrost soils and associated thermokarst as the ground ice content typically has to be prescribed in the model setup. We present a new model scheme, implemented in the CryoGrid community model, which provides a model spin-up with segregated ice formation and associated ground heave. Under warming climatic conditions, thaw consolidation and ground subsidence takes place. The model physics are based on soil mechanical processes, soil hydrology by Richards equation and soil freezing characteristics.
We present the model physics, which are based on soil mechanical processes, soil hydrology by Richards equation and soil freezing characteristics. Furthermore, we performed a sensitivity analysis of factors controlling the formation and thaw of segregated ice. (i) We find that ice segregation is enhanced for high ground temperature gradients and high soil water contents. (ii) Fine-grained soils and organic-rich sediments intensify the process. (iii) External loads decrease the formation of segregated ice. (iv) Sedimentation results in a rise of ground surface and consequently in a thickening of the ice-enriched layer.
The new model scheme allows the analysis of ground ice evolution in both space and time and is a first step forward to an improved description of ground ice distribution in permafrost models.

Destabilization vs. stabilization: Assessing structural uncertainty in modeling C decomposition and mineral protection in permafrost-affected soils

Cosima Schröer (Universität Hamburg), Christian Knoblauch (Universität Hamburg) and Christian Beer (Universität Hamburg).

Abstract

Permafrost thaw may trigger a positive feedback to climate change by turning arctic ecosystems from a carbon (C) sink into a C source, when large soil organic carbon stocks become available for microbial degradation and CO_2 is released into the atmosphere. However, the projected strength of this feedback is highly uncertain because common land surface models omit important interactions between microbes, soil organic C and minerals. How much C will be respired is to a high degree dependent on the microbial access to soil organic C. This access is hindered by C adsorption to minerals or C occlusion in aggregates. In this study, we test three model structures that differ in their formulation of C mineralization and persistence in permafrost-affected soils. One of them is microbial-explicit and reflects C stabilization by mineral adsorption, the second is microbial-explicit and omits the stabilization process, and the third is microbial-implicit and relies on conceptual C pools with different turnover times. We use a combination of fractionation data and a ten-year (2009-2019) dataset of aerobic incubations of soils from the Lena River Delta, Siberia, for model calibration and testing. We show that although all model formulations can explain the CO_2 production curves, they indicate a large spread already in short-term future projections. We highlight that structural uncertainty in modeling C mineralization is high and there is a need to further develop models that agree with current understanding and observations.

SESSION 8
Monitoring of electrical and electromagnetic properties in frozen ground
(including the IPA Action Group IDGSP)

Conveners:

- **Mohammad Farzamian.** *University of Lisbon*; mohammad.farzamian@iniav.pt
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- **Theresa Maierhofer,** *University of Vienna;* theresa.maierhofer@geo.tuwien.ac.at
- **Riccardo Scandroglio.** *Technical University of Munich*; r.scandroglio@tum.de
- **Sebastian Uhlemann.** L*awrence Berkeley National Laboratory*; SUhlemann@lbl.gov

Summary:

Electrical methods are some of the most useful geophysical techniques for detecting, mapping, and characterizing permafrost due to their wide range of potential applications and simple and robust survey design. Today, electrical methods such as Electrical Resistivity Tomography (ERT) are increasingly considered as a standard technique to establish a baseline understanding of the subsurface structure at permafrost sites. Given their high sensitivity to changes in the ice and water content of the subsurface, repeated surveys, as well as continuous monitoring of electrical properties, have become popular for monitoring permafrost degradation in both polar and mountain permafrost environments. This session aims for an overview of current challenges and recent advances in monitoring the electrical and electromagnetic properties of frozen ground, including advances in survey design and monitoring set-up, processing and inversion of collected time-series, laboratory experiments, or quantification of temporal changes in ground ice content. We welcome applied and theoretical contributions based on all relevant electrical and electromagnetic techniques from polar and mountain permafrost environments as well as laboratory investigations. The session will include, but is not limited to, contributions from the IPA action group 'Towards an international database of geoelectrical surveys on permafrost (IDGSP)' (2021-2023), which aims to promote the repetition of historical geoelectrical surveys. Submissions based on individual case studies, first results from joint analysis of the IDGSP data set, database-related topics, etc. are all welcome

Monitoring steep rock wall permafrost using electrical resistivity and induced polarisation, part 1: installation, instrumentation

Josué Bock (CNRS EDYTEM), Florence Magnin (EDYTEM Laboratory (CNRS, University Savoie Mont Blanc), Emmanuel Malet (EDYTEM Laboratory (CNRS, University Savoie Mont Blanc), Ludovic Ravanel (EDYTEM Laboratory (CNRS, University Savoie Mont Blanc), André Revil (CNRS EDYTEM), Matan Ben-Asher (EDYTEM, Université Savoie Mont Blanc, CNRS), Philip Deline (EDYTEM Laboratory (CNRS, University Savoie Mont Blanc), Pierre-Alain Duvillard (STYX4D) and Raphaël Gallet (CNRS EDYTEM).

Abstract

Amongst various techniques used to survey the permafrost, electrical resistivity tomography (ERT) is an efficient method to investigate the presence of permafrost in the subsurface, and to diagnose its evolution through time. Ultimately, ERT measurements could provide relevant information regarding cleft ice and liquid water content within the (fractured) rock, which in turn would give further constraints to understanding permafrost dynamics. Between 2020 and 2021, we installed a permanent ERT device at the Aiguille du Midi (3842 m, Mont Blanc massif, France). The device is made of three 32- electrode cables, 5 m spacing, deployed from the summit down to ~3700 m, on three faces of the central peak, whose aspects are E, S-SW, and NNW. We used a Terrameter LS2 (ABEM, GuidelineGeo) instrument, which we programmed so that it performs automated acquisitions. Remote control of the instrument allowed for regular monitoring of the measurements, and adjustment of the data acquisition protocol. In harsh environment, ensuring sufficient electrical contact with the rock is challenging, and we tested several methods to improve the contact between the electrodes and the ground. A number of technical issues arose: cable defects and damage due to rockfalls, instrument software and hardware malfunction, internal data storage limitation, lightning strikes, and more. In this poster, we will present the various technical developments carried out along this ERT monitoring project: instrument remote control and measurement automation, protocols used to maximize data acquisition, and the results of various electrode settings regarding contact improvement. We will also present technical issues we encountered, and the solutions we developped to overcome them.

Spectral induced polarization imaging to monitor seasonal and annual dynamics of frozen ground at a mountain permafrost site in the Italian Alps

Theresa Maierhofer (TU-Wien, University of Fribourg), Adrian Flores-Orozco (TU-Wien), Nathalie Roser (TU Wien, Department of Geodesie and Geoinformation, Research Unit Geophysics), Jonas K. Limbrock (University of Bonn), Clemens Moser (TU-Wien), Christin Hilbich (University of Fribourg), Andreas Kemna (University of Bonn), Elisabetta Drigo (Geologist freelance), Umberto Mora Di Cella (Environmental Protection Agency of Aosta Valley) and Christian Hauck (University of Fribourg).

Abstract

Warming of permafrost regions with corresponding ground ice loss has prompted continuous monitoring programmes. In this context, various geophysical monitoring systems were set up throughout different mountain ranges worldwide, as geophysical methods provide information on subsurface characteristics such as lithology, water and ground ice content, complementing temperature observations. While electrical resistivity tomography (ERT) monitoring has become a standard approach to assess the evolution of permafrost, complementary geophysical methods have rarely been applied in a permafrost monitoring context. Recently, spectral induced polarization (SIP) measurement approaches have been tested for permafrost applications, because polarization effects associated with residual water films at the ice/mineral surfaces and charge defects in ice may help to better assess ground ice content. Here, we present an SIP monitoring application in high-mountain permafrost terrain, with a focus on the seasonal and annual variations of the frequency-dependence of the observed SIP response. We installed a permanent SIP profile at a permafrost monitoring site in the Italian Alps in 2019 and collected SIP data in the frequency range between 0.1-75 Hz over 3 years. Complementary seismic data were acquired and a petrophysical joint inversion (PJI) was performed, which, together with borehole data, serves as a validation of the SIP imaging results. We particularly investigated the phase frequency effect ϕFE), i.e., the change of resistivity phase with frequency in an interval supposedly affected by the SIP response of ice, providing information not accessible through ERT or single-frequency IP measurements. Temporal changes in ϕFE are validated with laboratory SIP measurements on samples from the site in controlled freeze-thaw experiments. Finally, we investigate the consistency between the ϕFE observed in field data and PJI-derived ground water and ice contents. We demonstrate that SIP is capable of resolving temporal changes in the thermal state and the ice/water ratio associated with seasonal freeze-thaw processes.

Using Ground Penetrating Radar for Permafrost Monitoring from 2018–2021 at CALM Sites in the Pechora River Delta

Maria Sudakova (ECI Tyumen Scientific Centre SB RAS), Marat Sadurtdinov (ECI Tyumen Scientific Centre SB RAS), Galina Malkova (ECI Tyumen Scientific Centre SB RAS), Andrey Tsarev (ECI Tyumen Scientific Centre SB RAS), Andrey Skvortsov (ECI Tyumen Scientific Centre SB RAS) and Sofia Davidenko (ECI Tyumen Scientific Centre SB RAS).

Abstract

The report describes the results of ground penetrating radar (GPR) research combined with geocryological data collected from the Circumpolar Active Layer Monitoring (CALM) testing sites in Kashin and Kumzha in summers 2018 - 2021. The study area was located on the Pechora River delta. Both sites were composed of sandy ground and the permafrost depth at the different sites ranged from 20 cm to 8–9 m. The combination of optimum offset and multifold GPR methods showed promising results in these investigations of sandy permafrost geological profiles. Depending on the thickness of the active layer, GPR was used as the main or additional method for studying and monitoring the near-surface conditions. In this work, the top of the permafrost ranges from depths of 30 cm to 8–9 m, and the reflections were visible according to the GPR data collected with a 300 MHz antenna. The results obtained show not only changes in the base of the active layer, but also in its moisture content. In connection with this, it is necessary to obtain radar data not only using common-offset technique, but also more sophisticated multy-offset techniques.

Changing discontinuous permafrost evaluated using repeat electrical resistivity tomography, northwest Canada

Antoni Lewkowicz (University of Ottawa), Teddi Herring (University of Ottawa), Maxime Duguay (BGC Engineering), Alexandre Bevington (Government of British Columbia) and Sharon Smith (Natural Resources Canada).

Abstract

Changes in permafrost conditions from 2010-2021 were examined using ground temperatures and repeat ERT at eleven permafrost sites in the boreal forest distributed along 1200 km of the Alaska Highway corridor from northern British Columbia (57.4°N) to the Yukon-Alaska border (62.5°N). Sites either were surveyed twice, at intervals of 5 years (two sites) or 9 years (five sites), or near-annually over 11 years (four sites). Wenner arrays were used with 41 or 61 electrodes and a minimum electrode spacing of 1 or 2 m. The annually surveyed sites had permanent electrode arrays while repeat surveys at the other sites were oriented using a marked mid-point and end-point coordinates recorded with a hand-held GPS. PyGIMLi was used to invert the measured resistivities. Mean annual ground temperatures (MAGT) at sites to the southeast of Whitehorse (Yukon) were all above -0.25 °C and apparent warming was less than 0.05 °C. Monitored sites between Whitehorse and the US border had MAGTs from -0.4 °C to -1.6 °C and except for one, warmed by 0.1-0.2 °C. Major along-profile features, such as a resistivity anomaly where a profile crossed a revegetating cut-line, were maintained between surveys, providing confidence in the resurvey technique. Percent changes in resistivity were calculated for areas of interest which generally omitted portions of the sites interpreted in initial surveys as unfrozen. These showed an average reduction in modelled resistivity of 40 % (2011-2021). However, there was a distinct difference between the colder sites which exhibited an average reduction of 16 % and the warmer sites which showed an average change of 64 %. These results clearly demonstrate the value of ERT as a permafrost monitoring technique, especially at temperatures close to 0 °C when internal thaw occurs within the soil and ground temperatures become insensitive to this ongoing change.

New insights into mountain permafrost occurrence and characteristics within a high altitude glacier forefield inferred by a multi-method approach combining historical and new geophysical and remotely sensed data

Christof Kneisel (Institute of Geography and Geology, University of Wuerzburg), Sebastian Buchelt (Institute of Geography and Geology, University of Wuerzburg), Julius Kunz (Institute of Geography and Geology, University of Wuerzburg) and Tim Wiegand (Institute of Geography and Geology, University of Wuerzburg).

Abstract

Periglacial landscapes comprise landforms that are inherently 3D structures, often exhibiting small-scale spatial heterogeneity of surface and subsurface conditions. We illustrate the potential of an integrative approach combining historical and new geophysical and remotely sensed data. Geomorphological observations, 2D and 3D electrical resistivity tomography (ERT) and remotely sensed measurements of surface movement on the Muragl glacier forefield were used to obtain an integrative analysis of a highly complex glacial and periglacial landform consisting of a thrust moraine, creeping permafrost and permafrost-free glacial till. The investigation of permafrost and its development in the glacier forefield Muragl has a tradition of more than 20 years. In the case of the described field site, characterizing the subsurface heterogeneity is close to impossible using drilling or single 2D geophysical surveys alone because of the complex 3D nature of the frozen ground characteristics comprising permafrost and permafrost-free areas in close proximity. Our approach therefore includes the evaluation of historical reconnaissance surveys using 2D ERT including the repetition of existing historical 2D geoelectrical surveys supplemented by detailed mapping using 3D ERT. We have found that joint analysis of the findings from geoelectrical surveying with surface displacement measurements offers a promising approach to the study of periglacial landforms related to ice-rich permafrost, allowing for more comprehensive characterization of permafrost characteristics and better geomorphological interpretation of periglacial morphodynamics. The patchy permafrost distribution pattern in the glacier forefield is determined by several factors, including the sediment characteristics, the snow cover distribution and duration, the aspect and the former glacier distribution and thermal regime. In this contribution we focus on the results from the repeated geoelectrical surveys, including the new insights from the joint analysis with the results of the surface displacement measurements, the latter indicating distinct seasonal movement patterns.

Repeated electrical resistivity tomography surveys for analysis of ground ice loss from various permafrost areas of the world

Christian Hauck (University of Fribourg), Johannes Buckel (TU Braunschweig), Baptiste Dafflon (Lawrence Berkeley National Laboratory), Reynald Delaloye (University of Fribourg), Bernd Etzelmüller (University of Oslo), Mohammad Farzamian (University of LIsbon), Adriàn Flores Orozco (TU Wien), Teddi Herring (University of Ottawa), Christin Hilbich (University of Fribourg), Ketil Isaksen (Norwegian Meteorological Institute), Markus Keuschnig (Georesearch Forschungsgesellschaft), Christof Kneisel (University of Würzburg), Julius Kunz (University of Würzburg), Christophe Lambiel (University of Lausanne), Antoni G Lewkowicz (University of Ottawa), Florence Magnin (Université Savoie Mont Blanc), Theresa Maierhofer (TU Wien), Coline Mollaret (University of Fribourg), Sarah Morard (University of Fribourg), Riccardo Scandroglio (TU München), Sonia Tomaskovicova (Technical University of Denmark), Sebastian Uhlemann (Lawrence Berkeley National Laboratory), Gonçalo Vieira (University of Lisbon), Florian Wagner (RWTH Aachen University) and Julie Wee (University of Fribourg).

Abstract

Permafrost is monitored on a global scale by analysing subsurface temperature time series within global networks such as GTN-P (permafrost boreholes) and CALM (active layer probing). Although successful in capturing the evolution of permafrost, boreholes are costly and restricted to the point-scale. Active layer monitoring by probing is only possible where (i) the ground is soft enough for manual probing and (ii) the active layer is shallow.

Geophysical surveys are non-invasive techniques that can be applied on all permafrost substrates and have a penetration depth that is large enough to monitor active layer changes as well as permafrost thawing in the deeper subsurface. Electric and electromagnetic methods are hereby specifically suitable as electrical resistivity (or its inverse, electrical conductivity) is very sensitive to changes in liquid water and ice content.

To monitor the present and future thawing of laterally heterogeneous permafrost bodies worldwide we propose a simple and very cost-effective method, i.e. the repetition of 2-dimensional electrical resistivity tomography (ERT) surveys on permafrost terrain over long time-spans. ERT surveys became popular in the late 1990's, when multi-electrode measurement systems and 2-dimensional inversion algorithms for data processing became available. Since then, a multitude of ERT surveys on permafrost terrain have been conducted, mostly to prove/disprove its occurrence and to delineate its spatial extent. Within the recently established IPA Action Group IDGSP (Towards an International Database of Geoelectrical Surveys on Permafrost) we started to collect these historical data sets (see Mollaret et al., this conference) with the aim to use them as baseline for future repetition measurements in the context of degrading permafrost.

In this contribution we present first results from the data set comprising all available repetition measurements from different permafrost regions within the past 20 years and analyse them in the context of corresponding permafrost temperature and ice content changes.

Geophysical monitoring of thermohydrological dynamics across an Arctic watershed

Sebastian Uhlemann (Lawrence Berkeley National Laboratory), Ian Shirley (Lawrence Berkeley National Laboratory), Stijn Wielandt (Lawrence Berkeley National Laboratory), Sylvain Fiolleau (Lawrence Berkeley National Laboratory), Craig Ulrich (Lawrence Berkeley National Laboratory) and Baptiste Dafflon (Lawrence Berkeley National Laboratory).

Abstract

Increasing temperatures are rapidly changing the Arctic ecosystem. Yet, we are missing a predictive understanding of the interactions within the bedrock to atmosphere column that are driving ecosystem evolution and carbon-climate feedback. A critical knowledge gap within these systems is the dynamics of surface water - groundwater interactions, and infiltration and groundwater flow processes, which drive permafrost thaw and biogeochemical processes. Geophysical techniques have been shown to be valuable tools to assess the intermediate depths (1 - 10's of m) that are particularly important to understanding the impact of climate change on permafrost thaw dynamics and related hydrological dynamics. In this study we compare the results of two geoelectrical monitoring transects that are installed in the lower and upper part of a watershed located in a discontinuous permafrost region, and that are exposed to different temperature and snow regimes. Given the remote environment, we first introduce the field setup that allowed us to acquire continuous data throughout the last 3 years. We present the variations in ground conditions and associated changes in data quality, which highlight the expected poor data during the winter season, once the ground is frozen. Comparing the results of the lower and upper monitoring line shows distinct hydrological patterns. The lower transect, which is characterized by warmer temperatures, shows snow infiltration weeks before the upper transect, and a response to rainfall events which is driven by the distribution of shallow permafrost. The upper transect indicates that snowmelt and summer rainfall events are mostly causing variations of the groundwater level below the permafrost, with limited surface-water groundwater interaction along the monitored transect. These observations provide additional data that will help in better understanding the complex hydrological processes taking place in discontinuous permafrost environments.

Long-term geoelectrical monitoring of permafrost in alpine bedrock: challenges and results for quantifying climate change effects

Riccardo Scandroglio (Chair of Landslide Research, Technical University of Munich), Maike Offer (Chair of Landslide Research, Technical University of Munich), Lukas Lucks (Chair of Photogrammetry and Remote Sensing, Technical University of Munich) and Michael Krautblatter (Chair of Landslide Research, Technical University of Munich).

Abstract

In high alpine environments, climate change driven permafrost degradation reduces slope stability with critical consequences for people and infrastructures. To properly assess the risk, the rate of these changes must be monitored. In the last years, electrical resistivity tomography (ERT) has been used in more than hundred studies to detect permafrost, but there are very few long-term observations over a decade with uninterrupted monthly repetitions. Here we present recent advantages, constant challenges and long-term results of the extensive geoelectrical monitoring at the north face of Mt. Zugspitze (2962 m a.s.l., DE/AT), in the Kammstollen tunnel. Standard procedures and permanently installed electrodes allow the collection of a unique dataset of consistent measurements since 2007, with monthly repetition since 2014. The investigation of long-term permafrost dynamics is based on detailed analysis of geoelectrical signals including resistivity changes of raw and inverted data, electrode contacts, error estimations and full wave signals. Supporting information like resistivity-temperature calibration, rock surface and borehole temperatures, adjacent geophysical investigations, thermal infrared spectrometry and lysimeters in bedrock enable an advanced interpretation of bedrock hydro-thermal dynamics. In good agreement with air temperature increase, permafrost area shows a slow but constant decrease in the summer months (~15 % in 15 years) and a strong variation in winter, in correlation with snow height. This exceptional dataset and the supplementary information gained in over 100 measuring campaigns, helps to better define the contribution of geoelectrical monitoring for understanding the thermal responses on alpine permafrost environments to climate change induced stresses.

The International Database of Geoelectrical Surveys on Permafrost (IDGSP) project: Overview, first analysis and challenges

Coline Mollaret (University of Fribourg), Teddi Herring (University of Ottawa), Christin Hilbich (University of Fribourg), Christian Hauck (University of Fribourg) and Cécile Pellet (University of Fribourg).

Abstract

In permafrost research, geoelectrical surveys are increasingly being used to detect the presence and extent of permafrost and to characterize 2D stratigraphy and material composition of permanently frozen terrains. However, data exchange among researchers is limited and data is rarely published, making it difficult or impossible to access information on historical surveys. Repeated geoelectrical surveying can enable quantitative evaluations of spatio-temporal permafrost evolution (see also Hauck et al., this conference), but repetition of surveys is rare. Given the potential for using geoelectrical measurements to detect permafrost and evaluate spatio-temporal changes, there is a strong need for coordinated global efforts regarding data, metadata, guidelines, and expertise exchange.

Given this data management and coordination gap, an International Permafrost Association (IPA) action group was initiated in 2021. Its main objective is to bring together the international community interested in geoelectrical measurements on permafrost and lay the foundations for an operational International Database of Geoelectrical Surveys on Permafrost (IDGSP). Since the start of the action group, a database has been designed and setup, numerous metadata and data have been compiled, and public access via a searchable webmap is currently being developed. Thanks to the large international contribution of metadata, the database currently holds metadata for ~ 360 different profiles covering 15 countries. The inclusion of the electrical data itself within the database is currently in progress.

In this contribution, we will give an overview of the database and its contents. We will also describe the advances in data processing approaches in the context of the database (standardized data processing, comparison of historical and recent data, and comparison of data from diverse permafrost environments). Finally, we will present a statistical analysis of the geoelectrical data contained in the database, by focusing on the dependence of obtained resistivity values on geographical location, landform and substrate.

Monitoring steep rock wall permafrost using electrical resistivity, part 2: preliminary inversion results of a year-round series of measurements

Josué Bock (CNRS EDYTEM), Florence Magnin (CNRS EDYTEM), André Revil (CNRS EDYTEM), Matan Ben-Asher (CNRS EDYTEM), Philip Deline (CNRS EDYTEM), Emmanuel Malet (CNRS EDYTEM) and Ludovic Ravanel (CNRS EDYTEM).

Abstract

Permafrost degradation due to global warming can affect the mechanical stability of steep rock faces. A better understanding of the processes involved in permafrost degradation, and the rockfall triggering, is thus of high importance. The increased rockfall hazard also calls for the development of measurement techniques to monitor the permafrost distribution and the liquid water and ice content, and ultimately to develop a predictive tool.

Between 2020 and 2021, we installed a permanent electrical resistivity tomography (ERT) device at the summit of the Aiguille du Midi (~3842m, Chamonix, France), to monitor the permafrost in a steep-slope mountain peak. Measurements were carried out regularly between June 2020 and November 2021, followed by automated acquisition between November 2021 and September 2022. Measurements were carried out on three different faces of the peak, facing East, South, and North-West.

Due to harsh environmental conditions, the sufficient contact resistance was not always reached to allow measurements. A number of technical issues also arose during the monitoring period, and the first filtering and pre-processing of the raw datasets were made accordingly. Cable failure prevented getting continuous measurements over the entire period. Nevertheless, the available data provide significant information to document the temporal evolution of the resistivity, and in turn, the change of ground ice characteristics throughout the year.

In this communication, we will present the the year-round evolution of interstitial ice content deduced from the processing of ERT measurements, and discuss ways to better assess the air, water, and ice ratio changes throughout the year. Finally, we will present laboratory measurements of the electrical resistivity as a function of temperature for several rock samples. The residual liquid fraction deduced from these measurements will be used to constrain a petrophysical model, and get further insight into the air, water, and ice ratios from field measurements.

Development of a low-cost and robust autonomous electrical resistivity tomography monitoring system for remote permafrost environments

Mohammad Farzamian (Department of Geosciences, University of Fribourg, Fribourg, Switzerland), Coline Mollaret (Department of Geosciences, University of Fribourg, Fribourg, Switzerland), Christin Hilbich (Department of Geosciences, University of Fribourg, Fribourg, Switzerland), Christian Hauck (Department of Geosciences, University of Fribourg, Fribourg, Switzerland), Teddi Herring (Department of Geography, Environment, and Geomatics, University of Ottawa, Ottawa, Canada), Gonçalo Vieira (Centre for Geographical Studies, IGOT, Universidade de Lisboa, Lisbon, Portugal), Filip Hrbacek (Department of Geography, Faculty of Science, Masaryk University, Brno, Czech Republic), Miguel Esteves (Centre for Geographical Studies, IGOT, Universidade de Lisboa, Lisbon, Portugal) and Antoni Lewkowicz (Department of Geography, Environment, and Geomatics, University of Ottawa, Ottawa, Canada).

Abstract

Permafrost is a widespread phenomenon in the cold regions of the globe, but is under-represented in global climate monitoring networks. Current permafrost monitoring networks mainly focus on recording borehole temperatures and active layer depths. However, drilling of boreholes is invasive, borehole temperatures do not give information about ground ice content, and data are only valid for the location of the drill-hole. In contrast, geophysical measurement techniques are non-invasive and yield results over transects or landforms. Electrical resistivity tomography (ERT) surveys can be used to infer permafrost and ground ice conditions, but few ERT monitoring systems are operational in permafrost regions, as the system must be inexpensive, robust, and require minimal power to operate and withstand harsh conditions in polar and mountain areas. The PERM2ERT project is a technogrant funded by the Swiss Polar Institute that aims to develop a robust, low-cost, and autonomous ERT (A-ERT) system for permanent installation in remote permafrost regions. We plan to test it in four different environments across the globe: James Ross Island (Antarctic Peninsula), Tien Shan (Central Asia), Yukon (Arctic), and Stockhorn (European Alps). The overall objective of PERM2ERT is to initiate an international A-ERT monitoring network on permafrost, enabling a quantitative analysis of ground ice evolution in permafrost regions under climate change. To attain this goal, we are working on technology development (e.g., remote data transfer, system control using satellite communications, and optimization of energy consumption) and data processing tools (e.g., semi-automated processing tools for filtering, inversion, and visualization of temporally dense A-ERT datasets and integrating climate observations). In this communication we will describe the goals of PERM2ERT, present our progress on technology development and data processing tools, and discuss preliminary experiences and results obtained from the A-ERT systems installed at Stockhorn (November 2022) and James Ross Island (February 2023).

Repeated ERT surveys on rock glaciers – challenges, results, and unexpected observations

Christin Hilbich (University of Fribourg), Johannes Buckel (TU Braunschweig), Reynald Delaloye (University of Fribourg), Regula Frauenfelder (Norwegian Geotechnical Institute, Oslo), Christian Hauck (University of Fribourg), Christof Kneisel (University of Würzburg), Tifenn LeBris (Université Grenoble Alpes), Coline Mollaret (University of Fribourg) and Sina Schneider (EcoLot, Bern).

Abstract

The IPA action group 'Towards an International Database of Geoelectrical Surveys on Permafrost (IDGSP)' promotes the repetition of existing historical geoelectrical measurements on permafrost landforms with the aim to yield a more complete picture of the resistivity evolution over time and space and to detect temperature and ground-ice/water changes in response to climate change. The IDGSP action group aims at developing guidelines for survey repetition and data processing. Typical challenges faced when repeating historical measurements are the comparability of different measurement dates, measurement geometries and configurations. A special case for the repetition of geoelectrical surveys are creeping permafrost landforms, such as rock glaciers, which may lead to additional challenges related to their movement, including the surface coordinates and topography changing over time, which may in the case of permanently installed electrodes also affect their original spacing. Interpretation of resistivity changes on rock glaciers is, therefore, a delicate task. In order to come up with a strategy on how to repeat and compare ERT measurements on rock glaciers, we here present the results from a number of repeated profiles on rock glaciers and discuss the implications of our findings and the related uncertainties (e.g. due to difficult re-location of profiles due to imprecise GPS coordinates, or changing profile position and topography with time). In general, electrical resistivities in Alpine permafrost decreased in the past two decades, which is also seen in many rock glacier data. However, an interesting feature observed for several individual rock glacier profiles is a conspicuous resistivity increase of (parts of) the resistive/ice-rich zone. In the context of largely decreasing resistivities on permafrost landforms worldwide, this observation is unusual, as it would point to ice aggradation or drying processes, conditioned that no other (e.g. numerical) effects or processes are present. In our presentation, several, both technical and geomorphological hypotheses will be discussed to understand this unexpected phenomenon

Coupling warming permafrost and rockwall erosion: the contribution of geophysical monitoring

Riccardo Scandroglio (Chair of Landslide Research, Technical University of Munich), Maike Offer (Chair of Landslide Research, Technical University of Munich), Benjamin Jacobs (Chair of Landslide Research, Technical University of Munich), Daniel Dräbing (Utrecht University, Department of Physical Geography), Robert Kenner (WSL Institute for Snow and Avalanche Research - SLF, Davos) and Michael Krautblatter (Chair of Landslide Research, Technical University of Munich).

Abstract

Rockfall events in warming permafrost rockwalls are hazardous for humans and infrastructures worldwide, requiring continuous and precise monitoring. Geoelectrical and seismic measurements are established techniques for assessing permafrost spatial distribution, while terrestrial laser scanning enables the quantification of rockfall location and volume. For the first time, we combine these techniques in a long-term monitoring and compare decadal data to quantify climate change driven erosion on rock slopes. We conducted our measurements from 2006 to 2022 on the permafrost-affected Steintaelli rock ridge, located at 3150 m in the Swiss Alps. Electrical Resistivity Tomography and Seismic Reflection Tomography along five parallel transects across the ridge have been repeatedly collected. Laboratory-calibrations and 3D inversions provided frozen volumes and permafrost degradation rates. Applying change detection algorithms to the terrestrial LiDAR scans of the ridge and of the adjacent rock walls enabled us to quantify permafrost-induced rock deformations and rockfall rates in the same time frame. Geophysical measurements in the last 16 years show a drastic permafrost volume reduction of up to 65 %. Although the year 2021 presents exceptionally inverse trends due to the long lasting snow cover, measures in 2022 confirm the general long-term degradation, well in agreement with the recorded air temperature increase. Preliminary analysis of the terrestrial laser scans suggest a significant rockfall activity and at least two active rockwall instabilities in the vicinity of the geophysical measurements. We provide one of the first quantitative study on permafrost induced rock deformation, in order to better understand high alpine instabilities driven by global warming.

SESSION 9
Remote sensing of Disturbances in Permafrost

Conveners:

- **Alexandra Runge.** *Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research*; alexandra.runge@awi.de
- **Mark J. Lara.** *Department of Plant Biology, University of Illinois, USA / Department of Geography, University of Illinois;* markjlara@illinois.edu
- **Anna Liljedahl.** *Woodwell Climate Research Center, USA / Water and Environmental Research Center, University of Alaska Fairbanks*; aliljedahl@woodwellclimate.org

Summary:

Permafrost is warming at a global scale. Patterns of landscape reorganization in response to disturbances such as permafrost thaw and degradation have become widespread across northern ecosystems; which may profoundly impact indigenous Arctic communities and infrastructure. These dynamic permafrost disturbance processes vary dramatically on the landscape spanning gradients of space (i.e., local-to-regional) and time (i.e., abrupt-to-gradual). Hence, to understand present and future pathways of permafrost mediated landscape reorganization, remote sensing observations and targeted assessmentsspanning varying temporal and spatialscales are necessary and can bridge the gap between field observations and modelling efforts. The variety of available remote sensing sensors, datasets covering spatio-temporal scales and emerging processing possibilities make it a relevant research field. A growing array of active and passive sensors and techniques can characterize surficial landscape changes and associated subsurface properties and dynamics. This session aims to solicit novel remote sensing applications covering dynamic disturbance processes in permafrost landscapes. We welcome studies that use air to spaceborne observations that span scales of time (short to long-term) and space (local to circumpolar), and include aspects of computational scalability, big data processing, time-series analysis, machine and deep learning, Unmanned Aerial Systems, or field-based modelling applications. We are particularly interested in studies focusing on permafrost landscape disturbancessuch as wildfire, thermokarst, thaw slumps, active-layer detachmentslides, thermal erosion, coastal processes, surface water dynamics, or any other dynamic periglacial process.

The impact of wildfires on the winter SAR C-Band Backscatter in Permafrost regions

Xaver Muri (b.geos), Annett Bartsch (b.geos), Aleksandra Efimova (b.geos), Helena Bergstedt (b.geos), Barbara Widhalm (b.geos) and Gerald Frost (ABR Inc.).

Abstract

In artic regions wildfires have a stronger impact to the environment than just burning the vegetation and soil organic matter. These disturbances caused by wildfires also effect the underlaying permafrost. Impacts can be even observed in winter time, under frozen conditions. The disturbed area may show altered snow and soil properties, even years after the fire event. C-band SAR observations have been proven of high value for identifying snow structure change across the Arctic. Acquisitions under frozen conditions reflect surface roughness and volume scattering, from which snow, soil roughness as well as vegetation properties can be derived. Several sites across the Arctic have been selected to quantify the impact of wildfires. They cover continuous permafrost and are mainly located in tundra regions. Burned areas are considered starting from the 1940s. Focus is on Sentinel-1 following a space for time substitution method. In addition, reference areas in non-disturbed areas are analysed for comparison. Results demonstrate that there is a long-term influence of wildfires to C-band backscatter, what might result from altered snowpack properties. Even after the recovery of the vegetation, areas of wildfire events show a stronger C-band backscatter in VV-polarization than in the reference areas.

Remote sensing of lake desiccation in the recent past in permafrost landscapes: focus on the Hudson Bay Lowlands

Lucile Cosyn Wexsteen (Université de Sherbrooke, GRIL, CEN et CARTEL), Frédéric Bouchard (Université de Sherbrooke, GRIL, CEN et CARTEL) and Dermot Antoniades (Université de Laval, CEN, GRIL).

Abstract

In the circumpolar North, recent climate warming has been at least two times greater than the global mean. The Hudson Bay Lowlands (HBL), in the subarctic zone of Canada, represents the second-largest permafrost peatland area in the world and contains thousands of shallow lakes, mostly formed by the thawing of ice-rich permafrost (thermokarst). Three major ecozones are identified in the region: the taiga (boreal spruce forest), an interior peat plateau (palsa bog) and the coastal tundra/fen. The HBL provides vital wildlife habitat for more than 500 different species, including polar bears and migratory birds. However, since the early 21st Century, lake-level drawdown or complete desiccation has been observed. This kind of hydrological disturbance could, in the long-term, dramatically impact HBL biodiversity. The main goal of this project is to determine how warming since the late 20th Century has triggered widespread permafrost thawing and has impacted the regional hydrological balance, including lake connectivity. Preliminary results, based on satellite imagery (LANDSAT, SENTINEL and their products), show that more than a quarter of the surface water is represented by non-permanent water bodies (seasonal, ephemeral). In addition, significant changes in surface water dynamics over the last 30 years, such as the appearance of new seasonal lakes and the loss of many coastal lakes, were observed. Changes were also detected in land cover, with an important loss of forest in the southern HBL between 2010 and today. Furthermore, between 1948 and 2016, the mean annual air temperature increased by around 1.9°C. In order to reconstruct the hydrological balance and the potential impacts of climate change on aquatic/terrestrial ecosystems, sediment core analyses will be carried out. Interactions between peatlands (which represent more than 35 % of the area) and thermokarst lakes, including organic matter accumulation and transfer over time, will also be investigated.

This abstract participates in the Outstanding PYRN Poster Award.

Variability in spectral properties of retrogressive thaw slumps at Vaskiny Dachi research station, central Yamal Peninsula

Nina Nesterova (Alfred-Wegener-Institute for Polar and Marine Research, Potsdam, Germany; University of Potsdam, Potsdam, Germany), Ingmar Nitze (Alfred-Wegener Institute for Polar and Marine Research, Potsdam, Germany), Guido Grosse (Alfred-Wegener-Institute for Polar and Marine Research, Potsdam, Germany; University of Potsdam, Potsdam, Germany) and Marina Leibman (University of Tyumen, Tyumen, Russia; Earth Cryosphere Institute, Tyumen, Russia).

Abstract

Retrogressive Thaw Slumps (RTS) are cryogenic landforms that occur as a result of ice-rich permafrost thawing and ground ice melting. This phenomenon leads to changes in the local environment and carbon emissions. RTS passes different stages of activity: active, stabilized, and ancient. Stages can be determined based on their proportion within a particular RTS. In this study, we analyzed the spectral properties of RTS landforms using satellite imagery in the vicinity of Vaskiny Dachi research station, Yamal Peninsula, West Siberia. High-resolution ortho-mosaics were collected from UAV surveys in 2021 and were used to map different landform classes associated with RTS, including wet mud, dry mud, stabilized, ancient, and undisturbed tundra. Surface reflectance values were extracted for each class within RTS using multispectral Sentinel-2, Landsat 8, and PlanetScope imagery (10m, 30m, and 3m spatial resolution, respectively). The results of the study showed that Sentinel-2 and PlanetScope images in true color were sufficient for visual interpretation of the variability within RTS and false color composites (NIR-R-G) allowed the best visual detail. All classes were found to be distinguishable at different wavelengths based on the Sentinel-2 image, with spectral separation especially present in the NIR and SWIR bands. Spectral differences between ancient and stabilized classes were not noticeable in the lower spatial resolution Landsat images or in the 4-band PlanetScope images. The highest within-class variance was found in the wet mud and dry mud classes. High-resolution satellite imagery can be used to visually interpret the variability within RTS and distinguish between the different stages based on their spectral properties, allowing a better assessment of temporal RTS dynamics. Further data collection is needed to improve the accuracy of RTS landform class delineation. This work was partially funded by the Russian Science Foundation grant #22-27-00644.

Snow accumulation, reduced snow albedo and snowmelt along the Inuvik-Tuktoyaktuk highway, Canada

Jennika Hammar (Alfred Wegener Institute, Potsdam, Germany), Inge Grünberg (Alfred Wegener Institute, Potsdam, Germany), Steve V. Kokelj (Northwest Territories Geological Survey, Government of Northwest Territories, Yellowknife, NT, Canada), Jurjen van der Sluijs (Northwest Territories Centre for Geomatics, Yellowknife, NT, Canada), Timothy Ensom (Northwest Territories Geological Survey, Government of Northwest Territories, Yellowknife, NT, Canada) and Julia Boike (Alfred Wegener Institute, Potsdam, Germany and Humboldt-Universität zu Berlin, Germany).

Abstract

Roads on permafrost have an impact on natural processes in the surrounding potentially leading to permafrost degradation. Snow accumulation next to the road affects the soil thermal and hydrological regime, and road dust reduces snow albedo, which affects the snowmelt timing. There is still little knowledge about the spatial extent of snow accumulation and snowmelt effects along Arctic highways. Here, we used remote sensing techniques to quantify the spatial effect of the Inuvik to Tuktoyaktuk Highway in Northwest Territories, Canada on snow accumulation, snow albedo and snowmelt timing. We utilized satellite imagery (Sentinel-2, Landsat-7 and -8) to calculate the normalized difference snow index before, during and after highway construction and snow albedo between February and May in 2020. We quantified the snow accumulation at road segments in the Trail Valley Creek area using digital elevation model differencing. The embankment height influenced the magnitude of the snow accumulation. Mean snow depth in unaffected terrain was 0.5 m, but ranged from 0.8 to 1 m and 1.3 to 1.4 m near low and high embankments, respectively. Enhanced snow accumulation reached distances of 36 m from the road and the predominating wind direction influenced the snow accumulation with more snow on the northern side of the road. Road dust played an important part and reduced the snow albedo up to 300 m from the road, inducing a 10 days earlier snowmelt within 100 m distance. The road affected the snowmelt up to 600 m distance, an area which seems undisturbed at first glance. Our results contribute to a better understanding of the spatial scale of snow cover changes along road corridors that is difficult to obtain by ground-based observations. These observations help to develop hypotheses for designing field and model experiments to test the relative importance of snow and dust effects on permafrost.

Short and Long-term impacts of thermokarst on vegetation change in northern Alaska

Mark J. Lara (University of Illinois at Urbana-Champaign), Emma M. Hall (University of Illinois at Urbana-Champaign), Caroline Ludden (University of Illinois at Urbana-Champaign), Aiden I.G. Schore (University of Illinois at Urbana-Champaign), Wenqu Chen (University of Illinois at Urbana-Champaign), Christian G. Andresen (University of Wisconsin-Madison) and Melissa L. Chipman (Syracuse University).

Abstract

Thawing and degrading permafrost is restructuring high-latitude ecosystems. Thermoerosional gullies are draining lakes, thawing ice-wedges are creating extensive trough and pit networks, while the melting of buried glacial ice is advancing the headwalls of thaw slumps across vast regions of the Arctic. Here, we summarize ongoing research efforts to characterize inter-annual to centennial time-scale patterns of vegetation change following permafrost degradation in northern Alaska. We use a combination of chronosequence field surveys, unoccupied aerial systems (UAS), and time-series image analysis of air- and spaceborne sensors to evaluate the short and long-term impacts of thermokarst on vegetation change. We summarize new observations describing (1) plant community change following catastrophic and gradual lake drainage, (2) thermokarst pit and pond terrestrialization and desiccation, and (3) shifts in dominant woody and herbaceous plant species following thaw slump initialization. Results suggest the rate, pattern, and composition of vegetation change is dependent on a range of local microtopographic factors that influence moisture, snow depth/persistence, and potential solar radiation and interacting biophysical factors that influence vegetation dispersal and species-specific resource acquisition. We use UAS-derived multispectral (6cm spatial resolution), hyperspectral (0.5cm spatial resolution), and LiDAR data to map vegetation communities and track patterns of vegetation dispersal across a range of drained lake basins to find relatively predictable patterns of decadal vegetation change, dependent on the mode of lake drainage. We find similarities in short-term patterns of vegetation change observed in catastrophically drained lakes and retrogressive thaw slumps, however local topography and solar insolation appear to control long-term patterns of vegetation change within both new and ancient thaw slump scars. Observations suggest that the patterns of vegetation change following permafrost disturbances may be heterogeneous and dependent on not only topographic and biophysical factors, but landscape disturbance history.

Land Cover Patterns for selected Retrogressive Thaw Slumps and Drained Lake Basins in Yamal-Gydan region, West Siberia

Rustam Khairullin (b.geos GmbH, Austria), Clemens von Baeckmann (b.geos GmbH, Austria), Artem Khomutov (Earth Cryosphere Institute Tyumen Scientific Centre SB RAS), Annett Bartsch (b.geos GmbH, Austria) and Marina Leibman (Earth Cryosphere Institute, Tyumen Scientific Centre SB RAS).

Abstract

The Yamal-Gydan geographical region of the north of West Siberia is one of the most industrialized parts of the Russian Arctic. Rich gas and oil reservoirs induce rapid growth of infrastructure pressure on natural landscapes. Along with climate warming in the Arctic, infrastructure causes excessive increase in drained lake basins (DLBs) and retrogressive thaw slumps (RTSs). Activation of these processes in their turn can damage existing infrastructure. Both phenomena can undergo cycles. Lake drainage can be followed by refilling and repeated drainage if connected to floodplains and RTSs can activate and reactivate periodically. These cycles of plant recovery within active surfaces and their impact can be analyzed with very high-resolution satellite imagery time series. Two key sites have been investigated, central parts of Yamal and Gydan peninsulas covering areas of 200 and 60 sq. km, respectively, to track changes and formation of RTS for a period from 2009 to 2019. All RTSs were split into different categories, based on their status in 2010, 2013 and 2018 for the Yamal peninsula and 2009, 2013 and 2019 for the Gydan peninsula. In the next step, Sentinel-2 satellite imagery was used to identify lake drainage events near these areas between 2016 and 2022. Statistical analysis of all the RTS's categories and selected DLB's was done using the land surface classification developed for ESA DUE Globpermafrost and Permafrost_cci projects based on combination of unsupervised and supervised classifications of Sentinel-1 and Sentinel-2 satellite imagery. The results of the analysis allow us to identify similarities and differences in succession of vegetation for DLBs and RTSs in this macro-region.

Areal change in peatland permafrost landforms over 73 years in coastal Labrador, northeastern Canada

Yifeng Wang (Queen's University), Robert Way (Queen's University) and Jordan Beer (Queen's University).

Abstract

Peatland permafrost landforms, such as palsas and peat plateaus, often represent the most marginal and southern lowland permafrost occurrences in the Northern Hemisphere. While peatland permafrost is traditionally associated with continental conditions, large swaths of peatland permafrost complexes were recently identified along the previously understudied coastline of the Labrador Sea in northeastern Canada. Thaw of palsas and peat plateaus in coastal Labrador is expected to have hydrological and ecological impacts on important caribou habitat, culturally relevant berry abundance, and global permafrost carbon storage. Using a combination of historical aerial photography (1948, 1985, 1992, 1994) and high-resolution satellite imagery (2017-2021), we assess multi-decadal areal changes to peatland permafrost complexes at six locations along the Labrador Sea coastline spanning from within the community of Red Bay (51.7 N) to north of the community of Hopedale (55.7 N). Preliminary analyses reveal areal declines of up to 93 % at individual complexes with a recent (1992-1994 to 2017-2021) mean rate of change of -19 %/decade. Patterns of permafrost distribution and rates of thermokarst development are also compared between palsa bogs and peat plateau complexes, with preliminary analyses showing greater variation in thaw rates amongst palsa bogs compared to peat plateau complexes. Understanding recent change to peatland permafrost complexes in coastal Labrador is an important step towards predicting future habitat change in northeastern Canada and will inform local thaw-related adaptation strategies for these ecologically and culturally important environments.

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Identifying and interpreting permafrost vulnerability with machine learning

Adrian Höhl (Data Science in Earth Observation, Technical University of Munich (TUM)), Konrad Heidler (Data Science in Earth Observation, Technical University of Munich (TUM)), Alexandra Runge (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Guido Grosse (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research) and Xiao Xiang Zhu (Data Science in Earth Observation, Technical University of Munich (TUM)).

Abstract

Permafrost is a key indicator of global climate change and is considered an Essential Climate Variable (ECV). Current studies show a warming trend of permafrost globally, which induces widespread permafrost thaw, leading to near-surface permafrost loss at local to regional scales and impacting ecosystems, hydrological systems, greenhouse gas emissions, and infrastructure stability. Permafrost describes the thermal state of the ground, however, it is strongly connected to surface conditions and influenced by changes in the atmosphere, biosphere, geosphere, and cryosphere. Relevant surface variables are land surface temperature, albedo, snow cover, soil moisture, land cover, and fire. The EO-based datasets from the ESA Climate Change Initiative (CCI) depict the trends and changes of these variables in homogenized long-term datasets. Furthermore, they provide a modeled permafrost product, which reveals changes and trends in ground temperature for the last two decades. So far, a combined assessment of all these ECV products with relevance to permafrost characteristics to better understand, quantify, and project permafrost thaw and its potential local to regional trajectories on a panarctic scale is still missing. Therefore, we evaluate different machine learning models, like extreme gradient boosting and support vector machines, to predict permafrost vulnerability based on the combined surface variable trends. Additionally, our explainable framework strives to comprehend and obtain scientific insights by making the AI model's decisions accessible to a human. The applied methods include SHAP and LIME. By doing so, the influence of each surface variable on permafrost vulnerability can be assessed in a data-driven way, in order to better understand the varying regional trends that can be seen throughout the panarctic regions.

Integrating InSAR Ground Movement into the Permafrost and Meteorological Response System in Longyearbyen, Svalbard

Line Rouyet (NORCE Norwegian Research Centre AS), Hanne H. Christiansen (University Centre in Svalbard (UNIS), Lotte Wendt (NORCE Norwegian Research Centre AS), Daniel Stødle (NORCE Norwegian Research Centre AS), Tom Rune Lauknes (NORCE Norwegian Research Centre AS) and Yngvar Larsen (NORCE Norwegian Research Centre AS).

Abstract

Active layer freezing and thawing induces subsidence and heave of the ground surface. Permafrost thawing, active layer thickening and ice melting induce long-term subsidence trends. On slopes, the additional effect of gravity leads to gradual creep or abrupt slides/falls of rock/soil masses. Documenting ground movement is therefore important to assess infrastructure stability and slope hazards in/around Arctic settlements. The movement patterns also indirectly document the ground thermal dynamics, valuable for the environmental monitoring of polar regions.

Since 2015, the Sentinel-1 satellites have provided unprecedented capability for large-scale monitoring of ground movement using Synthetic Aperture Radar Interferometry (InSAR). In mainland Norway, the InSAR Norway Ground Motion Service (GMS) (https://insar.ngu.no) provides openly available displacement time series over the whole country. In Svalbard, recent research has shown the value of InSAR to map the distribution, magnitude and timing of subsidence/heave patterns and document the kinematics of permafrost landforms on mountain slopes. However, an InSAR-based GMS for the archipelago has not yet been implemented.

The PermaMeteoCommunity project develops a response system for permafrost hazards in Longyearbyen. Real-time observations of meteorology and permafrost variables combined with modelling will provide a preparedness tool for the Longyearbyen community. To complement in-situ measurements, InSAR data is processed to map past ground movement in/around Longyearbyen. Based on 2015-2022 Sentinel-1 images, Small Baseline Subset (SBAS) time series are generated for each snow-free season. The results are visualized in an interactive WebGIS based on the NORCE Geo Viz technology used for InSAR Norway. It allows for identifying moving areas, plotting time series and comparing the displacements with other datasets. With a further integration into the operational response system, the results will contribute to better understand the relations between environmental variables and hazardous processes. They will also serve as pilot products for the future implementation of an InSAR Svalbard GMS.

Ground surface displacement along the coast of the Laptev Sea in Northeastern Siberia detected by InSAR

Takahiro Abe (Mie University) and Yoshihiro Iijima (Mie University).

Abstract

Recent climate change has resulted in permafrost degradation. Ground temperature in the continuous permafrost regions in the Arctic has increased over the past decades, resulting in changes to hydrology, landscapes, as well as to the lives of local people due to permafrost thawing. Particularly in the high-latitude Arctic, permafrost temperature has increased up to about 1 ºC per decade and increased active-layer thicknesses have been observed since the 1990s in some regions. However, there is a lack of observational studies covering the vast and remote area of northeastern Siberia. Observational results are essential to support effective modeling studies on a broad regional scale. In this study, we conducted an interferometric synthetic aperture radar (InSAR) analysis to detect surface displacement related to ground freeze/thaw cycle near communities located along the coast of the Laptev Sea. ALOS-2 L-band SAR data were obtained from 2015 to 2022 and Sentinel-1 C-band SAR data from 2017 to 2021. Preliminary results of ALOS-2 InSAR time-series analysis showed that inter-annual line-of-sight (LOS) lengthening (i.e., subsidence), which is presumably related to permafrost thaw, was detected in several areas along the coastline as well as the vicinity of settlement in Naiba (N70.85, E130.74). Significant subsidence greater than 10 cm was also observed at a site of 2017 tundra fire. Seasonal LOS lengthening (subsidence) in summer and shortening (uplift) in early winter up to a few centimeters were detected in Sentinel-1 stacked interferograms. The magnitude of the seasonal displacements varied each year, which may be related to air temperature and summer precipitation. Both low- and high-centered ice-wedge polygons are common in this area, and we will discuss the relationship between their development, ground surface displacement, and local topography.

Detecting surface deformation within the South Shetland Islands (Antarctica) using SAR interferometry

Thomas Schmid (Centro de Investigaciones Energéticas Medio Ambientales y Tecnológicas -CIEMAT), Stéphane Guillaso (GFZ German Research Center for Geosciences Potsdam), Franck Garestier (University of Caen-Normandy), Claudia Giménez Poblador (Universidad Complutense de Madrid) and Jerónimo López-Martínez (Universidad Autónoma de Madrid).

Abstract

Periglacial processes and landforms together with the presence of permafrost are among the most relevant geomorphological features in the ice-free areas of the South Shetland Islands. The most important changes occur during the austral summer months when land surface covers are most affected by the freeze thaw cycles, causing terrain displacements due to subsidence and uplift of the ground as well erosion and accumulation of sedimentary material. The objective of this work was to determine surface ground displacements within Byers Peninsula on Livingston Island using Interferometric Synthetic Aperture Radar (InSAR). Data was used from the ESA Sentinel-1 satellite constellation repeat interval as interferometric wide swath C band in HH mode, and as level 1 SLC product. A stack of images were acquired with a repeat time of 12-days for the time periods of 21/12/2020 to 15/03/2021 and 16/12/2021 to 10/03/2022. A 10 m resolution digital elevation model was created from the existing topographic map to achieve terrain corrections. The open-source software program from ESA (Sentinels Application Platform - SNAP version 8.0) was used to calculate interferograms and determine the displacements during the given time periods. Average displacement values are minimal of 1 to 2 cm during the time periods indicated and are most probably influenced by seasonal variations when snow cover is present as well as fluctuating soil moisture content. However, when minimal snow cover is present, displacements of up to 7 cm are observed around the glacier forefront and in certain areas of the upper platforms and slopes, where permafrost and periglacial features such as patterned ground and stone fields are more present. The results provide an initial approximation of subsidence and uplift occurring in the ice-free area and serves for monitoring these areas when newly acquired data will be available in the coming years.

Using historical and recent satellite imagery to quantify and study permafrost degradation in gully-dominated landscapes in the Russian High Arctic

Cornelia Inauen (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Guido Grosse (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Ingmar Nitze (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Moritz Langer (Vrije Universiteit Amsterdam, Department of Earth Sciences, Faculty of Sciences) and Irena Hajnsek (ETH Zürich, Dep. of Civil, Env. and Geomatic Eng., Institute of Environmental Engineering).

Abstract

Thermo-erosional gullies play an important role in permafrost degradation both at catchment scale by changing the hydrological network and the drainage patterns and at landform scale by accelerating ground ice loss though thermal erosion.
The aim of our study is to analyse spatio-temporal degradation pathways in gully-dominated landscapes by quantifying the extent of permafrost degradation on historical and recent high-resolution optical satellite imagery dating back to the 1980s (Hegaxon, SPOT). Our study sites are located on ice-rich Yedoma permafrost in the Russian High Arctic and depict gully development at different stages. On the New Siberian Islands, a dense and well-developed gully network is present and satellite imagery shows that degradation since the 1980s has mainly occurred along ridges and slopes. This is expressed by extensive baydzherakh formation and an increase of melt ponds on poorly drained ridges. On Khardang Island in the Lena Delta, the gully network development shows gully pathway extension while melt ponds and baydzherakh areas did not increase significantly.
Different degradation stages (e.g. baydzherakh patterned areas, melt ponding, and undisturbed Yedoma upland or slopes) are represented by specific textural characteristics in the historical grey-scale imagery. We therefore tested different machine-learning algorithms to segment the landscape into degradation stages. In particular, we compared clustering of statistical textural measures such as Grey-level co-occurrence matrix (GLCM) texture features to deep learning Convolutional Neural Networks (CNN) directly applied on the grey-scale imagery.
The resulting segmentation builds the base for statistical analyses to study correlations to (geo) morphological conditions (e.g. topography, exposition, catchment/drainage properties) and environmental drivers (e.g. snow cover, climatic or geologic conditions) allowing to draw conclusions about relevant processes, feedback mechanisms, and (de)stabilisation effects driving permafrost degradation in these thermo-erosional gully settings. The remotely sensed information will guide future conceptualisation and parametrisation of modelling gully-dominated permafrost landscapes and their thermo-hydrological dynamics.

Identification and Recent Dynamics of Geoecological Mosaics in the Tundra of Kangiqsualujjuaq (Subarctic Canada)

Diana Martins (CEG/ IGOT - Universidade de Lisboa), Gonçalo Vieira (CEG/ IGOT - Universidade de Lisboa), Pascale Roy-Léveillée (Centre d'Études Nordiques (CEN), Université Laval), Pedro Freitas (CEG/ IGOT - Universidade de Lisboa) and João Canário (Centro de Química Estrutural, Instituto Superior Técnico - Universidade de Lisboa).

Abstract

The global increase in temperatures has environmental impacts in the Arctic and Subarctic. Permafrost degradation, increased growth of shrubs and trees, and the formation of thermokarst ponds are widespread in ice-rich settings within the discontinuous and sporadic permafrost zones, for instance in the Canadian Subarctic. As a result, previously frozen organic carbon is mobilized and made available for microbial decomposition and emission to the atmosphere in the form of greenhouse gases, constituting a positive feedback to global warming. Here we present the results of a very high resolution spatial analysis of the geoecological units of a tundra-forest transition site and discuss their influence on ponds characteristics. The study area is located on the southeastern shore of Ungava Bay, 8 km northwest of Kangiqsualujjuaq, in a raised glacial valley. The area presents a complex set of geoecological units which result from a history of deglaciation, marine submergence, emergence, permafrost aggradation, and thaw. The analysis was based on ultra-high resolution UAS optical and multispectral imagery (Micasense 10 band rededge MX dual) collected in September 2022, along with historical aerial photographs and very high-resolution multispectral satellite imagery. The joint analysis of the digital surface model, geomorphological map and vegetation communities map allowed to identify the main geoecological units at unprecedented resolution. Temporal dynamics in each geoecological unit since 1960 was accessed using historical aerial photographs. Statistical analysis using GIS was used to associate environmental conditions to each geoecological unit, including type of deposit, morphometry, snow cover, wind exposure, etc. This research is part of the PERMAMERC project - Mercury Biogeochemistry, Fate and Impact in Permafrost Thaw Ecosystem, funded by the Foundation for Science and Technology, Portugal. Diana Martins is funded by the FCT-PERMAMERC project (PTDC/CTA-AMB/4744/2020).

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Studying changes and disturbances in tundra terrain using UAVs

Matthias Siewert (Umeå University), Sofie Sjogersten (University of Nottingham) and Johan Olofsson (Umeå University).

Abstract

In this contribution, I will present on-going and completed research to track dynamic disturbances and changes in tundra ecosystems and of permafrost features using high-resolution imagery from unoccupied aerial vehicles (UAVs). We have flown UAVs over several study areas in the Abisko region, northern Sweden, since 2016. UAVs have proven to return reliable spatial information with regular RGB imagery while at the same time providing highly resolved 3D point-cloud and digital terrain model data. Furthermore, multispectral sensors allow characterizing vegetation productivity and abundance using multiple light bands, commonly the green, red, red-edge and infrared band, while thermal imagery helps to understand the radiation balance.
We observe rapid changes in palsa mires where we compare a 7 year time-series with high-resolution historical aerial photographs to detect changes in spatial extent of permafrost peat plateaus. In another study, we have referenced UAV data to satellite imagery and investigated scaling relationships for biomass and gross primary productivity to highlight the relevance of a higher spatial resolution to understand these important ecosystem variables. Finally, disturbances by herbivores are important components of the tundra ecosystem. We have mapped vole and lemming cycles and applied change detection to show the impact by a rodent peak on tundra vegetation. These examples provide an overview of our current use of UAVs and their potential in tundra and permafrost environments.

The use of GNSS and UAVs in complex geocryological studies

Anastasiya Pozharskaya (Faculty of Geography, Lomonosov Moscow State University) and Fedor Iurov (Faculty of Geography, Lomonosov Moscow State University).

Abstract

Permafrost is an unstable environment, especially sensitive to anthropogenic activities. Its development requires comprehensive geocryological studies necessary to make a forecast of the state of permafrost, including the development of deposits and the construction of pipelines, and the creation of infrastructure in the north. The use of UAVs is a new monitoring method that allows obtaining high-precision data and optimizing the observation of objects due to a larger spatial coverage of the territory and the least time spent. In geocryological studies, this method is becoming increasingly in demand: its advantage is the relative availability, speed of obtaining information, and high quality of aerial photographs. GNSS, in turn, can further improve the accuracy of the data received. This year, when collecting data during geocryological studies, namely, when studying dangerous cryogenic processes at monitoring sites and key areas in the Lower Ob (Labytnangi, Kharp), remote sensing data (UAVs) and geodetic technologies (GNSS receivers) were experimentally used to further create a local GIS site to facilitate analysis and data collection. The paper focuses on obtaining orthorectified images and digital terrain models (DTM) with a very high spatial resolution, as well as creating a cartographic database of areas with developing cryogenic processes.It is assumed that the use of the latest technologies will allow creating a single (and expanded) representative database of collected data. This will make it possible not only to predict the development of cryogenic processes, but also to more easily trace both the dynamics of changes in a single characteristic and the mutual influence of various parameters on long-term time scales. The use of Earth remote sensing technologies in the permafrost zone makes it possible to bring permafrost monitoring to a new level, which is especially important in the context of climate change and the development of Arctic territories. The use of UAVs and GNSS makes it possible to obtain clear and systematic results of long-term studies and facilitate the prediction and study of permafrost.

Permafrost monitoring from space – what have we learned so far?

Annett Bartsch (b.geos), Tazio Strozzi (Gamma RS) and Ingmar Nitze (Alfred Wegener Institute for Polar and Marine Research).

Abstract

Direct monitoring permafrost from space is limited but land surface features and dynamics can be linked to belowground conditions. We will provide a summary of remote sensing techniques which have been successfully applied and proved to be most promising in linking earth observation data with permafrost conditions. We will show examples from the CCI+ Permafrost and GlobPermafrost projects (both ESA funded) and address research gaps in the discussion.

Space observable parameters related to ground temperature, specifically land surface temperature and surface status, have been shown to be applicable. Trend patterns can be observed, which are in line with in situ observations. Northern hemisphere ground temperature changes from year to year for example, correlate with sea ice concentrations.

Abrupt thaw has been identified as a climate tipping point with regional impact. Ground temperature time series need to be therefore complemented by monitoring above surface features, which reflect abrupt thaw such as lakes and drained lake basins, thaw slumps, coastal erosion and ground subsidence. The utility of satellite data has been proven at local to regional scale in all cases, but circumpolar implementation is still lacking. General drying (water surface loss) can be already observed across the Arctic using indices from medium resolution observations. Regional studies indicate increasing thaw slump activities throughout the last 20 years. Recent advances have been made with e.g. the Copernicus Sentinel missions, InSAR techniques and machine learning. However, observations in much higher spatial resolution are required for detailed analysis of landscape processes in heterogeneous permafrost affected environments.

The state of the art for inventorying the kinematic attribute of rock glaciers at regional scales and monitoring the rate of motion of rock glaciers at local scale is use of satellite radar interferometry. However, higher spatial and temporal resolution should be considered for future missions.

Comparison of Sentinel 2 and Landsat 8 for retrieval of land surface albedo on Disko Island, Greenland

Jannika Gottuk (Alfred Wegener Institute, Potsdam, Germany; Institute of Geography, Universität Hamburg, Germany), Simone Stuenzi (Alfred Wegener Institute, Potsdam, Germany) and Julia Boike (Alfred Wegener Institute, Potsdam, Germany; Geography Department, Humboldt Universität zu Berlin, Germany).

Abstract

Albedo – the reflectivity of a surface - is an important component in the energy budget, impacting the local to global climate. In the remote Arctic, observations are limited but satellite remote sensing data offer nearly continuous observations. Here, we evaluated how albedo retrieved from two medium-resolution satellites can reproduce the small-scale variability of Arctic land surfaces. We compared the spatial and temporal variability of albedo derived from Sentinel 2 (20 m per pixel) and Landsat 8 (30 m per pixel) in the summer and autumn from 2015 to 2022. The study area was located at the southern tip of Disko Island (69.27 °N, -53.47 °S) in West Greenland. The study sites covered moraines, wetlands, a lake, and a wide range of vegetation. We collected ground-based albedo over two transects (80 and 240 m) within the footprints of the satellite sensors to assess spatial heterogeneity. In total, we obtained 170 albedo data points between August 29th and September 8th, 2022. The field data showed noticeable differences between surface characteristics and vegetation compositions with albedo ranging from 0.05 to 0.28. Black, bare soil, dark stones, and patches with surface water had albedos < 0.1. Areas dominated by pale vegetation, such as mosses, lichens, Equisetum spec., and Salix glauca showed the highest albedo values (> 0.2). We aim at computing Landsat and Sentinel albedo combined with MODIS anisotropy information and narrow to broadband conversion. Our study contributes to the understanding and quantification of past and future land cover changes, such as shifts in vegetation composition and coverage, and their impact on the energy budget.

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Continental-scale drivers of lake drainage in permafrost regions

Ingmar Nitze (Alfred Wegener Institute), Mark Lara (University of Illinois at Urbana-Champaign) and Guido Grosse (Alfred Wegener Institute).

Abstract

Lakes are ubiquitous with high-latitude ecosystems, covering up to 60 % of the land surface in some regions. Due to their influence on an array of key biogeophysical processes, the recent decline in lake area (via gradual and abrupt) observed across permafrost ecosystems may hold significant implications for shifting carbon and energy dynamics. Since lakes are often highly dynamic, understanding the main drivers of lake area change may ultimately enable the prediction of lake persistence in a warmer climate; key to anticipating future carbon-climate feedbacks from Arctic ecosystems. Here we conducted a data-driven analysis of >600k lakes across four continental-scale transects (Alaska, E Canada, W Siberia, E Siberia), combining remote sensing-derived lake shape parameters and spatial dynamics with other ecosystem datasets, such as ground temperatures, climate, elevation/geomorphology, and permafrost landscape parameters. We grouped our lake-change dataset into non-drained, partially and completely drained lakes (25-75 %, >75 % loss) and used the RandomForest Feature Importance to calculate the relative importance of each parameter. Furthermore we predicted the probability of lake drainage under current environmental conditions and changing permafrost temperatures. Initial results suggest a strong importance of ground temperatures, lake shape, and local geomorphology on lake drainage. Spatially coarser datasets of permafrost and thermokarst properties did not reveal correlations with the result. Our drainage prediction results show distinct spatial patterns, which are matching regional lake drainage patterns. Our model estimated ground temperature as one of the main impact factors, with an increased drainage likelihood in permafrost regions from -5 to 0 °C. Going forward, we will further test for short term influences, such as extreme weather events and wildfire on widespread lake drainage. As this analysis is purely data-driven, a comparison or combination with physics-based models and predictions will help to better validate our analysis.

Quantifying the evolution of retrogressive thaw slumps over 50 years in central Tibet

Zhuoxuan Xia (Earth System Science Programme, Faculty of Science, The Chinese University of Hong Kong, Hong Kong SAR, China), Zhuoyi Zhao (Earth System Science Programme, Faculty of Science, The Chinese University of Hong Kong, Hong Kong SAR, China) and Lin Liu (Earth System Science Programme, Faculty of Science, The Chinese University of Hong Kong, Hong Kong SAR, China).

Abstract

Thermokarst landforms, as the consequence of excess ground ice melting and subsequent thaw settlement, are widely distributed on permafrost areas under climate change. One typical abrupt thaw is the retrogressive thaw slump (RTS), which typically retreats at high rates and continuously affects the local environment for decades until stabilization. However, on the Qinghai-Tibet Plateau, characterized by warm permafrost, the investigation of long-term RTS evolutions was impeded by the remote, harsh, and in-approachable areas. With the help of the Keyhole (KH) satellite imagery with high spatial resolutions (varying from 1.8 to 9.1 meters), we can trace the RTSs on the plateau back to the 1960s. Combined with our previous investigations using 2016-2019 PlanetScope Scene images with spatial resolutions of 3-5 meters, we can quantify the evolution of retrogressive thaw slumps spanning over 50 years.
We conducted a case study in the Beiluhe region in central Tibet, where RTSs were clustered. Based on manual identification and delineation from the KH-4 and KH-9 images acquired 8/1963-9/1969 and 3/1973-10/1980, we found 95 RTSs on 16/11/1968, and 28 more were initiated till 24/12/1975. Compared with the inventory in 2019, only 13 locations affected by RTSs in 1968 were still under disturbance 51 years later. The majority (86%) of RTSs in 1968 had stabilized and experienced revegetation over the decades. Most of the recent active thaw slumps were initiated in 2016-2017.
Based on these new observations, we will further investigate the spatial-temporal characteristics of the RTS activities towards a quantitative understanding of the decadal evolution of these slope thermokarst landforms on the fast-warming Qinghai-Tibet Plateau.

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Scaling Strategies for AI in Permafrost Remote Sensing

Konrad Heidler (Data Science in Earth Observation, Technical University of Munich (TUM), 80333 Munich, Germany), Ingmar Nitze (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Telegrafenberg A45, 14473 Potsdam, Germany), Guido Grosse (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Telegrafenberg A45, 14473 Potsdam, Germany) and Xiao Xiang Zhu (Data Science in Earth Observation, Technical University of Munich (TUM), 80333 Munich, Germany).

Abstract

A large challenge in remote sensing of permafrost disturbances is the variability of permafrost regions across the Arctic. Oftentimes, machine learning models show degraded performance when applied to locations not seen during training. An exemplary task for this is the detection of retrogressive thaw slumps (RTS), a highly localised landform often occuring in spatial clusters that is caused by rapid thaw of ice-rich permafrost. As these features are usually rather small (tens to hundreds of metres in diameter), high-resolution remote sensing products like PlanetScope or Sentinel-2 are used. This in turn reduces the areas that can be reliably labelled by a human annotator.

Recent advances in machine learning research open up new ways of dealing with such settings. For the application of RTS detection, we explore three approaches for improving pan-Arctic generalisation of the models.

1. Strong data augmentation: Random adjustments to image colours, mirrorings, rotations, blurring and warping transformations help the model generalise better, improving the RTS detection performance from an Intersection-over-Union (IoU) of 26.0 % to 31.4 %. 2. Multi-temporal training: By not only training on the original acquisition, but instead matching all acquisitions within a ±2 week window to the annotations, the model is forced to deal with changing imaging conditions like illumination or cloud cover. In our experiments, this strategy further improved model performance to 36.4 %. 3. Semi-supervised learning (SSL): In SSL, additional unlabelled imagery is used to complement the labelled training images. We adapt a recent SSL framework called FixMatchSeg to the use-case of RTS detection, and use unlabelled Sentinel-2 tiles as additional training inputs. This boosts detection performance to an IoU of 41.6 %.

We believe that these strategies are a valuable building block for scalable monitoring of RTS, opening up possibilities for pan-Arctic studies and near-real time monitoring of various dynamic Permafrost disturbances.

Disappearing subarctic thermokarst lakes

Fabian Seemann (Stockholm University; Technische Universität Dresden) and A. Britta K. Sannel (Stockholm University; Bolin Centre for Climate Research, Stockholm, Sweden).

Abstract

Rapid climatic changes cause permafrost to thaw, initiating thermokarst landforms such as lakes. Thermokarst lakes cover large extents of the northern circumpolar permafrost region and are significant sources of greenhouse gases. For the assessment of current and potential future lake developments continuous monitoring is required. In the Tavvavuoma palsa mire, located in the sporadic permafrost zone of northern Sweden, lake dynamics have been observed between 1963 and 2003, but subsequent developments remain unknown. Therefore, this project combined GIS, field and statistical methods to explain spatio-temporal lake dynamics by investigating lake morphology and regional climate characteristics. Between 2003 and 2021 the thermokarst lake area and number decreased by 10 % and 48 %, respectively. 42 % of the shorelines were affected by erosion. The intensity of erosion correlated significantly with the height and slopes of bluffs facing the lakes. Along some sections active erosion was causing shoreline retreat but the dominant trend in this landscape was lake drainage and terrestrialisation. The limnicity (proportion of lakes) in the palsa mire decreased from 12.6 % in 2003 to 11.4 % in 2021, which is a continuation of the observed trend between 1963 and 2003. Permafrost degradation causing an enhanced hydrological connectivity is the driving factor for the limnicity, although evaporation effects likely play an important role as well. Due to the current warming trend of ca. 0.4 °C per decade in northern Sweden, the drainage trend is likely to continue.

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Assessing palsa changes with high resolution UAS-Borne LiDAR in northern Sweden

Cas Renette (Gothenburg University) and Heather Reese (Gothenburg University).

Abstract

LiDAR data were acquired in 2022 from an Unmanned Aerial System (UAS) to investigate palsa mire dynamics in a study area of northern Sweden. The high point density, up to 1000 points/m2, enabled us to create a detailed digital terrain model (DTM) that could clearly identify individual cracks and blocks of peat along the degrading edge of the palsas. We also compared these data to the airborne LiDAR data acquired in 2015 to assess the lateral and volume changes over the years. The LiDAR data obtained in 2015 had a low point density of ca 1.4 points/m2, resulting in a DTM with a 2 m grid cell. Our findings show that the two largest palsas lost both area and volume between 2015 and 2022. The UAS-based LiDAR data will be further used as a baseline to provide a detailed understanding of the seasonal changes of this palsa mire. This is particularly important as high rates of thaw are predicted to lead to the disappearance of palsa mires in Sweden by 2100. This research highlights the potential of using UAS-based LiDAR scanning to study permafrost-mediated landscape evolution. The study also emphasizes the importance of continued monitoring of palsa mires, and the potential for remote sensing techniques to provide the necessary data for such monitoring.

This abstract participates in the Outstanding PYRN Oral Communication / Poster Award

Permafrost-wildfire interactions in the Yukon-Kuskokwim River Delta characterized with InSAR, PolSAR, and imaging spectrometry

Roger Michaelides (Washington University in St. Louis) and Mark Lara (University of Illinois).

Abstract

Permafrost regions are warming at rates nearly 4x the global rate. This amplified warming may not only threaten the stability of permafrost, but may increase the frequency and severity of tundra fires across the Arctic, further exacerbating permafrost degradation. We present results investigating vegetation-permafrost-wildfire interactions on the Yukon-Kuskokwim River Delta (YKD). We analyzed C-band Interferometric Synthetic Aperture Radar (InSAR) observations from ESA's Sentinel-1 constellation in conjunction with L-band InSAR and P-band PolSAR observations from NASA's Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) airborne instrument flown as part of the Arctic Boreal Vulnerability Experiment (ABoVE) to quantify permafrost thaw patterns across a cluster of tundra fire scars that span the period 1971-2019. We also used NASA's Airborne Visible/Infrared Imaging Spectrometer Next-Generation (AVIRIS-NG) to describe the spatial patterns of plant species/functional diversity among fire scars of variable ages and within scars across gradients of SAR-derived subsidence.

The 12-day repeat of the Sentinel-1 Constellation provides novel insight into the seasonal dynamics of permafrost thaw in burned and unburned tundra. In recently burned tundra, increased subsidence during the thaw season is balanced by higher rates of refreeze during autumn refreeze. Elevated seasonal subsidence is observed in older (~10 year) fire scars, although repeated burning within a decade of each fire does not seem to result in increased thaw relative to singly burned tundra. Complementary high resolution UAVSAR observations shed novel insight into how post-fire subsidence is affected by fine-scale tundra surface heterogeneity and moisture regimes. Plant diversity metrics suggest both time-since burn and the intensity of local subsidence, notably influences vegetation cover and abundance. Together, InSAR, PolSAR, and imaging spectrometry can provide unique insights into the temporal behavior of burned permafrost.

Depth-resolved temperature and deformation measurements to evaluate soil movements and their controls in an Arctic permafrost environment

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Abstract

The landscape evolution in response to permafrost thaw is of concern from a climate, hydro-biogeochemical, infrastructure, and natural hazard perspective. Part of this evolution involves a redistribution of sediment and organic material, which impacts the storage and release of soil carbon. These movements are driven by a variety of complex mechanisms involving weather forcing, soil freeze-thaw cycle, subsurface hydrology, and permafrost characteristics. A better understanding of the soil deformation triggers and kinematics is needed to improve the estimates of current and future soil carbon storage and release. In this study, we investigate the soil deformation triggers and kinematics during the thaw season along a set of adjacent hillslopes in a discontinuous Arctic permafrost environment. Time series of deformation and temperature data are obtained from a dense, low-cost sensor network providing depth-resolved measurements to depths up to 1.8m at 59 locations across a 2 km^2 watershed, located on the southern Seward Peninsula. During the monitoring period, displacements of a few millimeters to tens of centimeters were recorded. These displacements showed different spatio-temporal patterns that vary as a function of the topographic position, the subsurface structure, and the thermal and hydrological states. While some locations showed a clear relationship between seasonal thaw depth and soil deformation, other locations remained either stable or deformed mostly in response to rainfall events. A detailed analysis of the data allowed us to highlight the different factors controlling the deformation (e.g. slope aspect, permafrost depth, bedrock depth, soil moisture, etc.). We were thus able to characterize the impact of each factor on the evolution of the hillslopes' morphology. This study provides a better understanding of the mechanisms controlling hillslope deformation, the associated hazards, and the possible impact on soil carbon distribution.

Quantifying plot-level canopy heights from traditional aerial photography on Alaska's North Slope

Shira Ellenson (Dewberry), Anna Klene (University of Montana), Nikolay Shiklomanov (George Washinton University) and Donald Walker (University of Alaska Fairbanks).

Abstract

As the Arctic has warmed, vegetation productivity has also been increasing. While satellite remote sensing is useful for summarizing Arctic-wide trends, changes in tundra species heights, densities, composition, and distribution can be missed at coarse resolution. Smaller, plot-scale studies are necessary to better understand vegetation dynamics at fine scales occurring on the ground. In 1995 high-resolution traditional aerial photographs and in-situ measurements of vegetation characteristics were taken at a series of plots established on the Alaskan North Slope as part of the US National Science Foundation's Arctic System Science Flux Study. In a first step to utilize older high-resolution imagery in conjunction with modern drone imagery to measure long-term changes in canopy heights, a modern photogrammetry workflow and LiDAR-based classification was applied to these air photos to generate canopy height models (CHMs) at varying resolutions. These CHMs were then compared to field measurements taken in 1995. Finer resolution CHMs performed better with shorter canopy heights (10 cm pixel resolution CHMs yielded differences of 0 to 2.8 cm at sites with mean canopy heights of 2.3 to 5.8 cm), and coarser resolution CHMs worked better with taller shrub tundra canopy heights (25 cm resolution CHMs yielded differences of 0.7 to 1.6 cm at canopy heights of 13.8 to 18.5 cm). These results suggest that using high-resolution remote sensing paired with in situ measurements can estimate canopy heights for tundra vegetation, hopefully allowing small changes to be detected through time.

Deep Learning over PlanetScope imagery reveal dense and diverse permafrost thaw pond hotspots in Eastern Hudson Bay, Subarctic Canada

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Abstract

Thaw ponds result from the collapse, erosion and subsidence of ice-rich permafrost, being a significant and widespread abrupt thaw mechanism in the Arctic and Subarctic. They form in organic or inorganic deposits showing diverse optical properties and different interactions with the climate system. Since the end of the Little Ice Age, Eastern Hudson Bay has been revealing an increase of permafrost thaw ponds. However, due to their small size (< 1 hectare) and remoteness, their biogeochemical role and significance are not clearly understood and cannot be tracked using traditional surveying and sampling methods. New remote sensing platforms like PlanetScope, formed by 200 nanosatellites orbiting the Earth and acquiring 3 m spatial resolution daily imagery, along with non-linear image classification algorithms based on Deep Learning, allow for the automatic and consistent regional delineation of these ponds for the first time. Here, we apply an instance segmentation algorithm (Mask-RCNN) using a large and very diverse training dataset of thermokarst and glacial ponds and lakes, as well as coastal and river/stream sectors. We assess the accuracy and confidence of the algorithm and prove its effectiveness to detect ponds using a two-scale validation approach: 1) Very high resolution scale, based on PlanetScope imagery aided by very high resolution satellite base maps; 2) Ultra high resolution scale based on drone imagery. The regional implementation of the algorithm using a PlanetScope mosaic with almost 400 images in the boreal forest-tundra zone of Eastern Hudson Bay, Northern Quebec, from the sporadic to the discontinuous permafrost zones, revealed 300,000 thaw ponds and several very high pond density hotspots, with over 200 ponds per square kilometer. We present these results and associate them with in-situ observations on water properties (CDOM, Chl-a and SPM) for a better understanding of the biogeochemical significance of thaw pond hotspots.

Machine Learning based probable Permafrost mapping of Higher Himalayas in Kinnaur district, Himachal Pradesh.

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Abstract

In the Himalayan region, permafrost is present at high-altitude areas (> 3800 m above m.s.l) that are vulnerable to degradation due to global warming. Estimating and assessing the permafrost distribution in the Himalayan mountains is required for vulnerability assessment. While current global mountain permafrost distribution models provide a good understanding of permafrost distribution at the national/regional level, they struggle to show its local-scale variability. This work shows finer scale modelling of the permafrost distribution for the Kinnaur district, Himachal Pradesh, India using machine learning algorithm. We utilised six parameters namely slope, aspect, curvature, normalised difference vegetation index (NDVI), normalised difference moisture index (NDMI) and mean annual air temperature (MAAT) along with rock glaciers to prepare the probable permafrost distribution map using support vector machine (SVM). We derived NDVI, NDMI and MAAT using Landsat-8 imagery and obtained slope, aspect, and curvature from ALOS PALSAR DEM. The performance of the model was assessed using five cross-validation techniques, including hold-out validation, k-fold cross-validation, stratified k-fold cross-validation, leave-one-out cross-validation, and repeated random train test split. The model achieved an AUC value of around 91% for all the cases, and the resulting map was validated using field images from crowd-sourced images. This study provides a high-resolution representation of permafrost distribution in the Kinnaur Himalayas. The probable permafrost area was found to be 27.3 % of the total study region. This result could be used for better understanding of the impact of climate change on mountain permafrost and the development of effective adaptation strategies.

Combining geophysical data, microtopography, and very-high resolution UAV imagery to map lowland permafrost degradation in the Stordalen mire, Abisko, Sweden.

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Abstract

In situ field studies in thawing permafrost regions have shown that organic carbon (OC) geochemical stability and therefore its emissions resulting from decomposition depends a.o. on the variability in soil water content, which can be directly related to microtopography. An assessment of the evolution of OC stability as a function of thermokarst development requires high-resolution quantification of thermokarst-affected areas, as lowland thermokarst development induces fine-scale spatial variability (~ 50 – 100 cm). Here, we investigate a gradient of lowland thermokarst development at Stordalen mire, Abisko, from well-drained undisturbed palsas to inundated fens, which have undergone ground subsidence. We produced orthomosaics and digital elevation models from very-high resolution (10 cm) UAV photogrammetry as well as a spatially continuous map of soil electrical conductivity (EC) based on Electromagnetic Induction (EMI) measurements performed in September 2021. In conjunction, we monitored in situ the soil water content and ionic strength corresponding to maximum thaw depth from the different stages of thermokarst development at the same period. The measured values for soil EC show contrasting results along the gradient consistent with the results of the landscape classification derived from the orthomosaics and digital elevation models. Palsas are flat areas with low soil EC (drier), whereas fen areas are subsided areas with higher EC (water-saturated). Transitional zones are well identified based on their much higher slope, and broad range of EC (high range of water saturation and ionic strength). Importantly, the transition zones are only detected using a very fine spatial scale (i.e., 10 cm) coupled to information on the microtopography. Future work will quantify the temporal evolution of this gradient in recent years. Identifying an acceleration of the physical permafrost degradation in the Stordalen mire has implications for the associated permafrost carbon emissions and their estimation at the site scale.

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An experiment to compare digitized labels of retrogressive thaw slumps by domain experts

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Abstract

Machine-Learning techniques have become increasingly beneficial for feature detection and segmentation in computer vision and image processing. This includes the remote detection of permafrost degradation features, such as retrogressive thaw slumps (RTS). To retrieve and validate high-quality deep learning models, we require a high quantity and consistent quality of labels. Currently there are no standard procedures for creating such labeled data. In addition, there is a lack of consensus on which features to include in mapping efforts (e.g. debris tongues), which increases uncertainty and comparability among labels. We conducted an experiment to evaluate label uncertainty among domain experts. Experts digitized RTS with little accompanying instruction, in two different 2.5 x 2.5 km (sub-)arctic sites (Peel Plateau, Canada + Bykovsky Peninsula, Russia) using (1) 3m PlanetScope multispectral imagery, (2) 30m Landsat multispectral imagery, (3) 10m Sentinel-2 multispectral imagery, and (4) the 2m ArcticDEM. Twelve domain scientists with backgrounds in geomorphology and geoinformatics or both, from various countries and geographic focus areas, participated in this experiment. We compared the digitized areas using the Intersection-over-Union segmentation performance (IoU) metric. At the Peel site, which is well known among all participants and contains RTS with a typical scalloped shape, we see a good agreement between participants, particularly in the active parts of the RTS. We experienced differences in the interpretation of the debris tongue as well as stable vegetated sections of the RTS. In the Bykovsky site, which is characterized by elongated RTS along a steep coastal bluff, we observed a much larger mismatch between experts. Here we experienced the same differences in the inclusion of the stabilized parts, but several participants mistakenly identified non-RTS features. This stresses the need for site specific knowledge and preferably field experience for reliable label creation. Overall, this experiment emphasizes the need for standardized procedures on how to create consistent RTS training labels. This study is the starting point for preparing comparable training/validation data for machine-learning-based monitoring of permafrost degradation features across the pan-Arctic.

Remote sensing-based quantification of periglacial and glacial surface changes (Bayelva basin, Svalbard)

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Abstract

Global warming has led to a widespread degradation of the Earth's glaciers and permafrost areas. The consequences of glacial melt and permafrost thaw are severe for humans and ecosystems on site and across the planet. Warming trends are particularly high in Svalbard corresponding to twice the Arctic and seven times the global average. While there has been previous research on glacial mass loss in Svalbard, knowledge on permafrost subsurface changes is mostly limited to a few in situ observations. In this study, we quantified periglacial and glacial changes in the Bayelva basin (near Ny-Ålesund, Svalbard). We calculated surface elevation changes at the Brøggerbreen glaciers and in the permafrost areas of the glacier foreland from high resolution digital elevation models from 1936, 2008, 2010, 2019 and 2020. In periglacial areas of remarkable surface subsidence, we furthermore used optical remote sensing data to analyse changes of other surface characteristics that may indicate permafrost thaw. We clearly detected surface changes in the glacial and periglacial realm with a heterogeneous pattern throughout the Bayelva basin. The Brøggerbreen glaciers retreated up to 200 m in distance between 2010 and 2019. Within the periglacial area, we observed the strongest changes at ice-cored moraines, with a maximal surface subsidence of 34 m between 2008 and 2020. At the same time, most permafrost areas showed only submeter elevation changes that were more difficult to detect. The active layer at the Bayelva research site thickened from 100 cm in 1998 to 150 cm in 2022. Permafrost areas also showed changes in surface moisture with increasing air and soil temperatures. Our results demonstrate rapid glacial melt, but also smaller subsidence in permafrost areas in the Bayelva basin. We conclude the great importance of high resolution digital elevation models for assessing surface changes in remote Arctic regions.

Sentinel-1 time series for retrieving soil freeze/thaw states in peatland permafrost

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Abstract

Permafrost is an important component of Arctic environments and is highly sensitive to climate change. Despite being one of the coldest climate regions on Earth, permafrost regions undergoing higher rate of warming than other regions worldwide. Increased temperature can alter the carbon balance and release more carbon from the Arctic into the atmosphere, inducing permafrost degradation along with accelerating global warming. In addition, the rapid permafrost thawing in the Arctic also has a significant effect on the ecosystem such as shifts in vegetation phenology, the groundwater cycle, and human activities. For better monitoring and quantifying disturbances in permafrost, such as degradation and its magnitude, an essential initial step is accurate detection of the soil freezing / thawing (FT) state. The land surface FT state is a sensitive indicator of changes at the ground surface and can detect the terrestrial climate signal. Therefore, accurate quantification of spatiotemporal FT state dynamics is crucial to improving our understanding of Arctic ecosystem sensitivity and responses to future climate changes. The goal of this study is to evaluate the potential of using Sentinel-1 synthetic aperture radar time-series for monitoring the spatiotemporal dynamics of FT state over the Abisko peatland site in the permafrost areas of northern Sweden at high resolution. In-situ measurements of soil temperature and the ground-based FT index were used for the validation process. From 2017 to 2022, the soil FT state estimated by Sentinel-1 VV showed higher sensitivity to soil temperature and ground-based FT index compared to Sentinel-1 VH. The Sentinel-1 based soil FT retrieves were in a good agreement with the in-situ measurements. Overall, it is concluded that the soil FT state obtained by using Sentinel-1 offers great potential for monitoring the spatiotemporal heterogeneity of FT transitions in high-latitude permafrost regions.

Quantifying and characterising abrupt permafrost thaw at a pan-Arctic scale

Charlotte Pearson (University of Hertfordshire).

Abstract

The changing dynamics of the Arctic region remain under monitored despite it experiencing warming up to four times greater than the global average (Miner et al., 2022). Permafrost thaw is anticipated to become more widespread under continued global warming trends (Biskaborn et al., 2019). However, despite its far-reaching impacts, it is one of the least well documented components of the Arctic system (Schuur and Mack, 2018). The occurrence, development and subsequent thawing potential of permafrost is influenced at global, regional, and local scales by geographical, geological, topographical, and meteorological conditions (Jorgenson et al., 2010). Where permafrost exhibits a high ground ice content and high porewater pressure, this increases surface slope vulnerability to abrupt thaw disturbances, such as active layer detachment slides (ALDS) (Lewkowicz, 2007) and retrogressive thaw slumps (RTS) (Burn and Lewkowicz, 1990). Abrupt thaw disturbances, and in particular, ALDS, across the Arctic and subarctic remain poorly examined at high spatiotemporal resolutions over large scales (Turetsky et al., 2019). The magnitude of carbon emissions as a result of permafrost thaw will in turn dictate permissible levels of anthropogenic greenhouse gas emissions that result in global warming of 1.5-2°C by 2100, hence there is a prescient need to incorporate these into budgets (Natali et al., 2021). However, the positive feedback loop from high latitude reservoirs is largely unaccounted for within models which typically tend to be one-dimensional (Vonk and Gustafsson, 2013). This research seeks to fulfil the requirement for advancing our understanding of the sensitivity of permafrost environments by developing novel remote sensing methods to detect ALDS. Google Earth Engine (GEE) and advanced machine-learning approaches are being utilised to present an automated detection and assessment of ALDS from satellite imagery and pan-Arctic elevation data (ArcticDEM) that captures large-scale regional diversity, as well as interannual dynamics.

This abstract participates in the Outstanding PYRN Oral Communication / Poster Award

Monitoring surface soil temperature in the Arctic permafrost areas in winter using passive microwave satellite remote sensing

Juliette Ortet (Centre d'Études Spatiales de la BIOsphère / Université du Québec à Trois-Rivières), Arnaud Mialon (Centre d'Études Spatiales de la BIOsphère), Alexandre Roy (Université du Québec à Trois-Rivières), Yann Kerr (Centre d'Études Spatiales de la BIOsphère), Alain Royer (CARTEL - Université de Sherbrooke), Simone Bircher-Adrot (MeteoSwiss) and Mike Schwank (Swiss Federal Institute for Forest, Snow, and Landscape Research).

Abstract

The studies of Arctic permafrost areas encounter high challenges because of its large and remote territories and the extreme weather conditions. Consequently, the current situation urges to develop new observation methods to better monitor the surface temperature evolution and the Arctic permafrost state. The passive microwaves satellite mission SMOS (Soil Moisture and Ocean Salinity) measures the brightness temperatures (TB) at L band (1.4 GHz e.g. 21 cm). The measured TB are linked to the surface effective temperature and because of L-Band has a much longer wavelength compare to snow microstructure, dry snow is almost transparent at L band, allowing the possibility to retrieve soil temperature under snow cover. Our objective is to determine the soil surface temperature under snow cover in the Arctic region in winter using L-Band SMOS observations.
We developed an algorithm that enables to retrieve the soil surface temperature from the satellite microwave measurements. The processing takes into account various components of the high latitudes environment, such as open water, soil moisture, organic content of the soil and snow covered soil. The algorithm and the obtained results are validated with in-situ measurements (soil, snow, vegetation) acquired in the Canadian Arctic from several campaigns.
The results will lead to a study of the variability in space and time of the Arctic soil temperature throughout the last decade and its impact on the circumpolar permafrost. Our project will take advantage of 12-year of SMOS observations. It includes the 2010-2020 decade which was the warmest period ever observed and dramatically impacts the permafrost state. The presentation will introduce the SMOS satellite observations in the Canadian Arctic and the proposed method to derive the soil temperature underneath the snow. First preliminary results of the soil temperature retrievals will be discussed.

Thermokarst processes observed by remote sensing and ground surveys at intact and disturbed tundra on the North Slope, Alaska

Go Iwahana (International Arctic Research Center, University of Alaska Fairbanks), Takahiro Abe (Mie University), Robert Busey (International Arctic Research Center, University of Alaska Fairbanks), Simon Zwieback (Geophysical Institute, University of Alaska Fairbanks), Franz Meyer (Geophysical Institute, University of Alaska Fairbanks) and Kazuyuki Saito (Japan Agency for Marine-Earth Science and Technology).

Abstract

Spatio-temporal variation in both inter-annual and seasonal surface displacements caused by ground freezing/thawing and thermokarst, especially after surface disturbances, are critical information to estimate the rate of permafrost loss and related carbon release. Although there is an increasing number of studies for ground surface displacement by SAR Interferometry (InSAR) in permafrost regions, there is still a lack of detailed field-based knowledge of the displacement to validate and interpret the remotely-sensed data. We conducted high-precision RTK/PPK GNSS positioning surveys to measure surface displacements related to frozen ground dynamics in intact tundra and thermokarst development triggered by surface disturbances on the North Slope, Alaska, together with measurements of ground thaw depth and surface moisture from 2017 to 2019. Twelve plots were selected from the northwestern edge of the Anaktuvuk River Fire scar and along the Dalton Highway to cover various aspects of topography and disturbance stages. We also conducted C-band/L-band InSAR analyses over the selected field survey sites for the corresponding period. Comparison of changes in ground conditions and surface deformation at intact, mechanically disturbed, and burned tundra sites revealed detailed behaviors of ground surface displacement depending on disturbance history, topography, and ground ice conditions. While seasonal thaw settlement varied mainly following meteorological conditions at intact tundra plots, the inter-annual variations at various thermokarst-affected plots were affected by changing surface conditions caused by thermokarst. The measured behaviors of surface displacement aligned well with measured displacement by InSAR using UAVSAR and ALOS2 data except for anomalous subsidence along the troughs of ice-wedge polygons at earlier stages of thermokarst. The InSAR analyses also revealed down-slope frost creep displacement in intact tundra and thermokarst subsidence in natural and anthropogenic disturbance areas.

Acceleration of early and late summer thaw subsidence around Batagay, Northeast Siberia, detected by ALOS-2 InSAR time series analysis

Kazuki Yanagiya (Japan Aerospace Exploration Agency), Masato Furuya (Faculty of Science, Hokkaido University), Go Iwahana (International Arctic Research Center, University of Alaska Fairbanks), Petr Danilov (Institute of Northern Applied Ecology, North-Eastern Federal University in Yakutsk), Nikolai Fedorov (Melnikov Permafrost Institute), Alexey Desyatkin (Melnikov Permafrost Institute) and Alexander Fedorov (Melnikov Permafrost Institute).

Abstract

Interferometric Synthetic Aperture Radar (InSAR) can detect relative ground displacement within a satellite image and effectively monitor thaw subsidence and frost heave in the permafrost region. In order to widely reveal the permafrost degradation, some attempts have been made to estimate active layer thickness or amount of ground ice melting by InSAR image. However, detailed spatio-temporal deformation processes are still unclear due to low spatio-temporal resolution and interferometric coherence loss. Here, we show the intra-seasonal thaw subsidence process around Batagay, Northeast Siberia, detected by high spatial (5 m~) and temporal (14 days~) images of L-band SAR Satellite ALOS-2, which generally maintains better coherence than C-band satellite. In addition, we have monitored thaw depth since 2019 within the two fire scars burned in 2018 and 2019. The fire scars are on the same slope as Batagaika mega slump, the world's largest known retrogressive thaw slump. We found that thaw subsidence started prior only inside the fire scars in early summer (May-June), once stopped in mid-summer (June-July), and progressed again in late summer (July-September), including outside of the fire scars. InSAR time series suggests not only the amount increase found by previous studies but the timing of subsidence is accelerated within the fire scars. Also, late-summer subsidence was previously reported in the Alaskan permafrost region due to the melting of top-of permafrost ice with an extremely warm and wet climate in 2019. Therefore, late-summer subsidence around Batagay indicates that similar underground ice melting might have occurred over a broad range (55×125 km) in the 2022 summer.

Integrating Machine Learning and Statistical methods to enhance rock glacier-based Permafrost prediction in Northern Kargil regions.

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Abstract

Rock glaciers are often used as proxies for permafrost distribution in high-mountain environments where direct estimation of permafrost areas is challenging. These landforms are characterized by a mixture of rock and ice, and their movement and deformation provide important clues about the thermal state of the underlying permafrost. The presence of permafrost significantly impacts the stability of the landforms and the associated geomorphological processes, as well as the water balance in the surrounding catchment. Integrating different conditioning factors and rock glaciers makes it possible to infer the distribution and evolution of permafrost in these environments. In this study, we aim to use rock glaciers as a proxy for permafrost and to develop a hybrid permafrost model by combining both statistical and machine learning models. We have used the Frequency Ratio (FR) ensembled Artificial Neural Network (ANN) model to predict permafrost distribution over the Northern Kargil region of the Indian Himalayas. Out of 211 rock glaciers identified using high-resolution imagery from Google Earth, 70 % (148) were used as a training dataset and the remaining 30 % (63) as a testing dataset. The study considered six influencing factors Slope, Aspect, Elevation, Mean Annual Air Temperature (MAAT), Solar radiation and Lithology for permafrost modelling. The results revealed that 30 % of the total geographic area has a high and very high probability of permafrost occurrence. The results have been validated by calculating the Area Under a Curve (AUC), which shows an accuracy of 96 %. The results of this study will contribute to the development of more cost and resource-effective approaches for probable permafrost mapping and improve the understanding of permafrost dynamics in changing climatic scenarios.

Surface Deformation Monitoring of the Lena River Delta with Sentinel-1 SAR Interferometry

Tazio Strozzi (Gamma Remote Sensing), Nina Jones (Gamma Remote Sensing), Sebastian Westermann (Department of Geosciences, University of Oslo), Andreas Kääb (Department of Geosciences, University of Oslo), Julia Boike (Alfred Wegener Institute, Potsdam & Geography Department, Humboldt-Universität zu Berlin, Berlin), Sofia Antonova (Alfred Wegener Institute, Potsdam), Alexandra Veremeeva (Alfred Wegener Institute, Potsdam), Guido Grosse (Alfred Wegener Institute, Potsdam) and Annett Bartsch (b.geos GmbH, Korneuburg).

Abstract

Low-land permafrost areas with an ice- and water-rich seasonal active layer are subject to intense vertical surface deformation processes due to phase changes between ice and liquid water at seasonal to multi-year time scales. The intensity of these effects strongly varies with the soil composition and soil water content, both of which are large-scale parameters that are very heterogeneously distributed. With widespread permafrost degradation projected to occur in a rapidly warming Arctic, information on the amplitude of seasonal frost/thaw cycle-induced ground movements over long time periods and across large regions are of increasing interest. Satellite differential SAR interferometry (DInSAR) from various space missions has been successfully applied in the past to measure seasonal as well as year to year developments in the freeze-thaw cycle.

We analyzed a series of satellite SAR data acquired between 2016 and 2021 from Sentinel-1 over the Lena River Delta at the Laptev Sea coast in Northeast Siberia. The Lena River Delta is located in the zone of continuous permafrost and is characterized by typical tundra vegetation, which includes sedges, grasses, dwarf shrubs and a well-developed moss layer. Typical active layer thicknesses range from 25 to 50 cm and underlying permafrost soils and sediments often are very ice-rich. The climate features long, extremely cold winters and short, cool summers. Snow usually starts to accumulate in September, begins to melt in May and is then typically gone in less than a month. Snow depth can vary significantly depending on topography and wind action but typically does not exceed a few decimetres.

The DInSAR phase is routinely used to estimate surface displacement, but it is also influenced by changes in atmospheric, soil moisture, vegetation and snow cover conditions, introducing special challenges in data processing and interpretation. In our contribution we will describe various aspects of the implemented processing chain, including the selection of interferograms used in the time-series analysis, the adjustment for partial temporal coverage during winter and especially in spring after the beginning of the thawing season using temperature data, filtering of large-scale atmospheric disturbances, conversion from satellite line-of-sight to vertical displacement, and the inversion methodology to derive seasonal deformation [m] and degradation rate [m/year] maps. We will discuss our final products in comparison to available landcover and geomorphological maps, deformation maps derived from other satellite SAR missions, temperature and precipitation data, and in-situ measurements of subsidence.

SESSION 10
Steep rock slope permafrost processes and hazards

Conveners:

- **Kaytan Kelkar**, *Geophysical Institute Permafrost Laboratory (GIPL), University of Alaska*; kakelkar@alaska.edu
- **Florence Magnin**, *Laboratory of Environments, Dynamics and Mountain Territories (EDYTEM), Universite Savoie Mont Blanc, CNRS*; florence.magnin@univ-smb.fr
- **Bernd Etzelmuller**, *Department of Geosciences, University of Oslo;* bernd.etzelmuller@geo.uio.no

Summary:

Permafrost in steep rock slopes has gained increasing attention in the last two decades because of the increased frequency and magnitude of rock slope failure in high mountain terrain. Rockfalls, rock avalanches and subsequent cascading processes (e.g. displacement waves, debris flows, snow avalanches) are an impending hazard to human lives and infrastructure. These emerging hazards present a growing scientific and societal relevance and require immediate attention. Determining spatiotemporal trends of rock slope failure and linking permafrost dynamics to slope instability is a significant challenge facing researchers. The role of permafrost dynamics as a trigger for slope failure and the mechanical properties of rockwalls spanning seasonal to millennial timescales is still not very well understood. Thus, key research questions have come to light 1) How do steep frozen rock slopes respond to climate parameters? 2) What are the predisposed permafrost conditions and mechanisms causing slope instability? 3) What is the spatiotemporal distribution of unstable steep frozen rock slopes? This session invites all studies aiming to enhance our understanding of steep periglacial rock slope processes and hazards. Contributions focusing on field observations, monitoring, remote sensing, geomorphology, modelling, mapping, hazard characterization, and assessment, as well as mitigation and adaptation strategies are welcome.

Thermal photogrammetry as tool for rock wall active layer thickness modelling

Stefano Ponti (University of Insubria), Irene Girola (University of Insubria) and Mauro Guglielmin (University of Insubria).

Abstract

Rock wall instability is one of the most visible effects of permafrost degradation in alpine environments. Models often loose the local scale resolution and field data are not easy to collect due to the harshness of the steep peaks. Here we want to present an advanced technology and method to assess the active layer thickness (ALT) on alpine rock walls. We based our experimental setup both on ground data and remote sensing conducted in 2021-2022. The first step consisted in the installation of thermistors that hourly recorded the rock surface temperature at the Gran Zebrù South Face (Italian Central Alps). Two of them were also equipped with deeper sensors that allowed us to extrapolate the depth of the 0 °C isotherm. The second step relied on the use of multiple UAV photogrammetric surveys associated with thermal imaging and conducted in different days and times. As a result, the thermal 3D models of the rock wall were transformed into the apparent thermal inertia (ATI) and then into the heat transfer coefficient (HTC) through the addition of the potential solar radiation. Subsequently, a robust linear regression was obtained between HTC and the ALT calculated in situ, where the rock temperatures were recorded. The regression was used to model ALT both in 2021 and 2022. The results show a general increase of ALT just after one year except for localized thinnings, probably due to the little winter snow accumulation on very steep areas. The proposed model has also been compared with the Stefan's solution and the alpine permafrost index map (APIM). There is a great interest to share and use this simple proposed method in order to: a) develop climate change risk maps in mountaineering areas, and b) understand the future trend of rock wall dynamics as a trigger of the landscape change.

Combining ERT, SRT and GPR to decipher permafrost and fluid flow in fractures

Maike Offer (Technical University of Munich), Markus Keuschnig (GEORESEARCH Forschungsgesellschaft mbH), Riccardo Scandroglio (Technical University of Munich) and Michael Krautblatter (Technical University of Munich).

Abstract

Alpine permafrost reacts highly sensitive to the ongoing global warming, which significantly impacts its thermal and hydrostatic regime. This change in subsurface properties, especially in steep permafrost-affected rock faces, critically affects the stability and increase the risk of relevant damages on high alpine infrastructures. Since these infrastructures are predominantly founded in low porosity bedrock, it is necessary to get an improved process understanding of ice-poor permafrost dynamics to mitigate severe costly repairs or failures. While water and ice content has been carefully quantified and monitored in recent studies, the warming effect of water in fractures has remained poorly investigated. However, it is believed to have a significant impact on the thermo-mechanical regime of the rock slope.

Here, we present for the first time a multimethod approach that includes three geophysical methods and borehole temperatures to long-term monitor the steep north flank below the Kitzsteinhorn cable station (AT, 3.017 m a.s.l.). First insights of the ground ice and liquid water variation over one year were observed by continuous automated electrical resistivity tomography (ERT) from February 2013 to February 2014. In summer 2022, the ERT measurement were repeated and supplemented by seismic refraction tomography and ground penetration radar to identify changes in resistivity and detect water presence in the slope. Additional lab experiments were conducted to (i) provide quantitative relations between temperature and electrical resistivities as well as p-wave velocities and to (ii) determine the effect of liquid water in fractures in a frozen environment on resistivity measurements.

This innovative approach allows to detect water in fractures and demonstrate that it potentially enhances the warming of the surrounding rock in a bottom-up direction. In the context of climate change, this study improves the risk assessment for high alpine infrastructures with foundations in thawing permafrost.

Permafrost landslides with molards as a geomorphological landmark of permafrost degradation: a worldwide survey

Costanza Morino (Laboratoire EDYTEM, CNRS UMR 5204, Université Savoie Mont Blanc, France), Susan Conway (Laboratoire de Planétologie et Géosciences, CNRS UMR 6112, Nantes Université, France), Florence Magnin (Laboratoire EDYTEM, CNRS UMR 5204, Université Savoie Mont Blanc, France), Philip Deline (Laboratoire EDYTEM, CNRS UMR 5204, Université Savoie Mont Blanc, France), Kristian Svennevig (Geological Survey of Denmark and Greenland, Denmark), Alexander Strom (Geodynamics Research Center, JSC Hydroproject Institute, Russia), Reginald Hermanns (Geohazards and Earth Observation, Geological Survey of Norway, Norway), Carla Tapia Baldis (Geocryology Unit, Ianigla, CCT Conicet, Mendoza, Argentina) and Axel Noblet (Department of Earth Sciences, University of Western Ontario, Canada).

Abstract

Periglacial territories are experiencing a high warming rate, which is exacerbating landslide extreme events in terms of frequency and magnitude, in addition to their increased unpredictability. Rapidly identifying whether a landslide event is related to permafrost degradation is becoming increasingly important to understand the state of periglacial slopes in response to climate change. Our study looks at how to use the landform called "molard" as a marker of permafrost degradation in arctic, sub-arctic and mountain environments. Molards in permafrost terrains are mound of loose debris that derive from the degradation of blocks of ice-rich sediments mobilised by a landslide. Once the ground ice has thawed, its cementing action is lost, inducing collapse of the material into molards. So far, few examples of permafrost molards have been reported in literature, and up to now they have been considered a rare morphological feature with a very local significance. Here we reconstruct the permafrost, geological, geographical settings of thirty three landslides characterised by molards showing that they are a widespread form in terrains characterised by various permafrost distribution, from continuous to isolated. The source materials of these landslides are predominantly composed of loose debris or rheologically weak bedrock, a predisposing characteristic to host ground ice. This evidence can be pivotal in identifying those terrains in permafrost environments that are prone to gravitational failures. Permafrost molards are a much more common landform than previously expected, and they are essential in deciphering the state of permafrost terrains. It should be noted that morphologically similar landforms frequently described as "hummocks" have also been reported from areas where permafrost conditions are absent. The geomorphological and possible genetic difference of "molards" and "hummocks" is part of ongoing studies.

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Elevation-dependent paraglacial and periglacial processes drive rockfall activity in the European Alps

Daniel Draebing (Utrecht University), Till Mayer (University of Bayreuth), Benjamin Jacobs (Technical University of Munich) and Sam McColl (GNS Science).

Abstract

Rockfalls are important agents of erosion and a hazard in mountain regions. A compilation of rockfall erosion rates from the European Alps indicates that erosion rates increase with elevation. Previous studies have hypothesized one or more explanations for this relationship, such as an elevation-dependent increase in paraglacial processes such as debuttressing, or periglacial processes such as permafrost thaw or frost weathering. Herein we consider all of these processes in the first quantitative evaluation of the elevation-dependency on rockfall erosion rates.
Within a glaciated alpine valley in Switzerland we quantified the relationships between rockfall erosion rates to frost weathering, permafrost distribution and deglaciation. We monitored rockwall thermal regime using rock temperature loggers between 2016 and 2019 and used these data to run a thermo-mechanical frost cracking model and a permafrost distribution model. We reconstructed glacier retreat using historical images and glacial landforms. The volumes, and equivalent erosion rates, of rockfalls between 2016 and 2019 were assessed using repeat terrestrial laserscanning. Principal component analysis demonstrated that frost weathering, permafrost distribution and deglaciation all strongly influence the rockfall erosion rates measured. We found that erosion rates increase with increasing elevation, decreasing modelled mean annual rock surface temperature (MARST), and decreasing deglaciation age. Integrating the spatial distribution of MARST and deglaciation revealed that both periglacial and paraglacial rockfall-drivers increase with elevation.
The observed spatial erosion patterns at our case-study site correspond well to our compilation of regional rockwall erosion data for the European Alps. Therefore, our data suggest that a combination of paraglacial and periglacial processes drives rockfall activity and that both exert a primary control on erosion in high mountain areas. Our research contributes new understanding of alpine rockfall processes and informs efforts to mitigate rockfall hazards in a changing climate.

17 years of high-altitude rock wall monitoring by terrestrial laser scanning (Mont-Blanc massif)

Léa Courtial-Manent (ISTerre - EDYTEM), Alexandre Lhosmot (Chrono-Envrionnement - EDYTEM), Ludovic Ravanel (EDYTEM), Jean-Louis Mugnier (ISTerre), Pierre-Allain Duvillard (Styx4D), Antoine Rabatel (IGE), Philip Deline (EDYTEM) and Florence Magnin (EDYTEM).

Abstract

Since the end of the 20th century, each decade has been warmer than the previous one. For instance, Europe has faced three major series of heat waves during the summers of 2003, 2015 and 2022. For the latter, the monthly temperature anomaly reached 3°C compared to the last 40 yr average and even the top of Europe, Mont Blanc (4808 m a.s.l.; French-Italian Alps) was momentarily affected by positive temperatures (up to 10°C). A consequence was the numerous rockfalls affecting the massif due to permafrost degradation. To quantify the morphological evolutions of steep rock slopes located in permafrost-affected areas in the current context of climate warming and induced permafrost degradation, we used terrestrial laser scanning over 17 years (2005-2022) on a series of rock walls of the Mont-Blanc massif. The data acquired results in one of the most extensive databases of high-Alpine rockfalls fed by 12 surveyed rock walls whose elevation is in the range 2950-4600 m a.s.l. Overall, more than 110 high-resolution scans were acquired and ~400 rockfalls were registered, ranging from 0.2 ± 0.1 to 15,578 ± 188 m^3. 40 events were > 100 m^3 while 58 % of the rockfall volumes were < 10 m^3. These results show that the rockfall magnitude-frequency distribution follows a power law. The exponent b, which represents a frequently used variable to characterize spatio-temporal rockfall variations, ranges from -0.35 to -0.95 with a mean of -0.53 ± 0.19 (90 % confidence level). The depth of failure distribution follows a non-linear relation where 97 % of the scars < 5 m deep. Rockfalls mainly occur when the slope ranges from 60 to 75° (49 %) and for altitude in the range 3400-3700 m a.s.l (56 %). No clear pattern for the orientation of the rockwalls has been observed, although differences in sun exposure can play an important role within the same rock wall. Rock fractures also play a role as they determine a part of the frequency/volume relationship and enable water infiltration and heat convection (i.e., warming in depth). Among the 12 surveyed rock walls, the eastern face of Tour Ronde (3440-3792 m a.s.l.), characterized by a mean annual rock surface temperature between -2 to 2°C, had in 2018 a yearly total rockfall volume more than twice the one of 2011, highlighting the recent and dramatic effects of permafrost degradation.

Mapping release and propagation areas of permafrost-related rock slope failures in the French Alps to identify hot spots for hazard assessment

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Abstract

Permafrost-affected rockwalls are increasingly impacted by the effects of climate change and rising air temperature leading to rock slope failures. These events pose a threat for human lives and infrastructure, which underlines the need of better knowledge about their triggering mechanism and propagation. The aim of this study was to propose a mapping approach of susceptible release areas of rock slope failures and resulting runout distances at a regional scale. This information helps identifying hotspots for subsequent hazard assessment. To do so, we used an inventory of 1389 rock slope failures (volume > 102 m^3) recorded in the Mont-Blanc massif from 2007 to 2019 and determined the topographical and permafrost conditions that are most prone to their triggering using a digital terrain model and a permafrost map. These conditions are used in a multi-criteria GIS approach to identify potential unstable slopes at the French Alps scale. Then, the potential release area map is used as input to map the run out of potential events, using a propagation model based on a normalised area dependant energy line principle. The resulting maps of release and propagation areas will be used to point out human assets (mountaineering routes, high mountain infrastructure, tourism areas) and lakes (that can provoke cascading hazards) which could be impacted by rock slope failure hazards. This work is a first step to identify hot spots for a regional hazard assessment where more detailed analyses will be required to evaluate potential risks at a local scale.

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Monitoring permafrost-affected rockwalls, an approach combining permafrost modelling, geophysical surveying and runout simulations. The cases of the Vallon d'Etache and Crête des Grangettes in the French Alps

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Abstract

In high mountains environments, permafrost degradation causes rockwall instabilities, sometimes leading to rock slope failures. These processes could be a threat for human lives and activities, it is therefore essential to improve our knowledge about their triggering and propagation mechanisms. This study focuses on two rock slope failures which occured in the Vallon d'Etache (Maurienne Valley, France) and the Crête des Grangettes (Ecrins massif, France) in 2020. These events have respectively volumes around 270 000 m^3 and 35 000 m^3. In both cases, ice in the rockfall scars suggests the presence of permafrost, but its local distribution and its role in the triggering of the events remain to be confirmed. The aims of this study are (i) to assess thermal conditions in which both events were triggered and (ii) to model their propagation. To do so, we first propose a method that combines rockwalls temperature monitoring, statistical modelling of permafrost distribution, geophysical surveys (Electrical Resistivity Tomography) and laboratory measurements (petrophysical model) to explain the thermal conditions under which the rockfalls occurred. Then, 3D models acquired by photogrammetry are used to obtain high-resolution DEMs in order to measure their volumes, and to provide consistent inputs for runout modelling. This multi-method approach allows to understand the context and the processes leading to rockfall triggering of two events in the French Alps. We also propose depth-averaged flow simulations to model the runout characteristics of the Vallon d'Etache rock slope failure.

Building resilience in Longyearbyen by developing improved observations and predictions of permafrost dynamics controlling slope stability

Hanne Hvidtfeldt Christiansen (The University Centre in Svalbard, UNIS), Marius O. Jonassen (The University Centre in Svalbard, UNIS), Aleksey Shestov (The University Centre in Svalbard, UNIS), Knut Ivar Lindland Tveit (The University Centre in Svalbard, UNIS), Line Rouyet (NORCE research institute) and Arne Instanes (Instanes A/S).

Abstract

2500 inhabitants of the Longyearbyen village live at 78°N in Svalbard, located in a narrow valley with steep mountain slopes. Active layer detachment sliding naturally dominates the lower mountain slopes, which are also where infrastructure is located. Air temperatures in Svalbard have increased by 1°C/decade since 1971, while precipitation has increased by 4 % annually, with most intensification occurring in the autumn. For the Longyearbyen society to adapt to this size climate change in the best possible way with respect to thawing permafrost, we have developed a local-based research collaboration between academia, local authorities, and local businesses, including also national partners. This, the PermaMeteoCommunity research project, develops a permafrost and meteorological response system. It consists of instrumented boreholes in the lower slopes, just above the infrastructure, but also directly below infrastructure, for direct observations of ground temperature and pore water pressure in the active layer and top permafrost. Also, a network of meteorological stations recording air temperature and precipitation with high spatial and temporal resolution is being installed covering the valley. Using IoT technology all observations are being connected to an open online platform, displaying all observations in near real-time. High resolution local short-term modelling is also being included into the response system. Local authorities and decision makers will through the response system have direct access to key information during extreme weather events such as autumn rainstorms, which can induce active layer detachment sliding, as was widespread during the latest warmest period in autumn 2016. Also, basic geocryological mapping of the ground ice amount in the top permafrost across the variability of landforms in the village is carried out to produce ground ice maps, and as input to the response system. The system will also contain historical InSAR analyses of remotely sensed ground surface movement in the valley.

Mechanical and hydrological controls of rock slope failures in polythermal cryospheric rock slope regimes

Felix Pfluger (Chair of Landslide Reserch, Technical University of Munich), Michael Krautblatter (Chair of Landslide Reserch, Technical University of Munich) and Christian Zangerl (Institute of Applied Geology, University of Natural Resources and Life Sciences - Vienna (BOKU).

Abstract

Permafrost degradation is a driving force for rock mass failure in high alpine landscapes worldwide. The timing of failure is yet difficult to predict. As classic rock mechanical models are not adequately describing the nature of rock mass failures in cryospheric environments we applied a rock-ice-mechanical model taking into account rock mass and joint properties depending on a changing thermal regimes. Using the rock-ice-mechanical model we show how permafrost features affect the stability in near-surface depths whereas for higher depths rock mechanics are prevailing. At shallow depths failure is controlled by shearing along given discontinuities. At higher depths brittle to ductile failure of previously intact rock becomes more important. The rock-ice-mechanical model is applied to a directly observed rockslide failure event (~1 Mio. m^3) at the north face of Bliggspitze (Paragneiss host rock, Kaunertal valley, AT) in 2007. Taking into account the history of glaciation and presence of permafrost together with field observations, we try to decipher the combined processes that eventually lead to failure. As a majority of recent failures in permafrost rock faces occurred in structured rock walls with coincident presence of ice patches and water outflow, we evaluate the effect of (i) potentially transient water pressure in sealed fracture systems as well as the (ii) transition or loss of fracture ice as possible triggers for rock mass failure. Furthermore, we assume that thawing of metamorphic rocks critically influences slope stability especially if foliation runs parallel to rock slope. The generic rock-ice-mechanical model framework is found to be suitable to explain deep-seated rockslides and rock avalanches as a result of changing cryosphere.

Rockwall permafrost in cordillera Blanca (Peru): first evidences and measurements

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Abstract

The evolution of rock-wall permafrost has important geomorphological and societal implications, because changes in its temperature and ice-content can lead to an increase in the frequency or even magnitude of landslides in high mountain areas. Although there are studies of permafrost in the tropical Andes, there are no specific studies on the presence, distribution or historical evolution of rock-wall permafrost. Between 11th and 17th October 2020, four temperature sensors were installed at the near surface (c. 10 cm depth) of steep rock faces of the cordillera Blanca from 4469 to 5175 m a.s.l. These sensors are distributed at four sites on the right ridge of the Pirámide glacier (Llullán-Parón catchment, cordillera Blanca) located between 77°38’ W and 8°58’ S. With the collected of rock surface temperature (RST) data, a statistical model explaining the RST according to air temperature or elevation and sun-exposure or incoming solar radiation (depending on which parameters are the most significant) will be calibrated in order to map permafrost distribution in the cordillera Blanca rock-walls. In this communication we will present the RST measurements and the modelling approach together with a preliminary map and assessment of permafrost distribution. These first measurements and assessment of the permafrost distribution in rockwalls could help us to better understand its possible distribution in the tropical Andes, but it is necessary to adjust the model with more RST measurements and for a longer time.

Erosion rates of high-Alpine mountain rock walls of the Mont-Blanc massif (European Alps) on decadal and centennial time scales

Léa Courtial-Manent (ISTerre - EDYTEM), Jean-Louis Mugnier (ISTerre), Ludovic Ravanel (EDYTEM), Alexandre Lhosmot (Chrono-Environnement - EDYTEM), Arthur Schwing (ISTerre), Anta-Clarisse Sarr (ISTerre) and Julien Carcaillet (ISTerre).

Abstract

Rockfall frequency is increasing in high Alpine areas such as in Mont-Blanc massif (MBM) due to permafrost degradation, mainly related to climate warming and the multiplication of heat waves. In this context, questions about the evolution of permafrost-related processes and associated risks are rising. In this study, two approaches are combined to quantify the erosion rates at different time scales. Two approaches are here combined in the MBM: i) concentration of cosmogenic nuclides (10Be) in supraglacial sediments originating from the rock walls and amalgamated during glacial transport is used to quantify long-term erosion rates and ii) diachronic comparison of topographic measurements carried out by a terrestrial laser scanner is used to quantify the dynamics of rock walls over short-time scales. The database used is composed of 45 supraglacial samples (gravel and sand) from 10 glaciers of the MBM, and 62 high-resolution 3D models for 12 walls scanned over 17 years (2005-2022) in the same massif. The preliminary results indicate a very high dispersion of the estimated erosion rates according to the methods and the considered rockwalls. Long-term erosion rates (102 to 103 years) obtained using 10Be concentration measurements range from 0.07 ± 0.01 and 4.33 ± 1.2 mm.yr-1 while those obtained by diachronic analysis of LiDAR scans range from 0.3 and 29.8 mm.yr-1. First analyses also indicate that the two methods give fairly similar results for: - for the highest rock walls (> 4000 m a.s.l.) with mean erosion rates of ~2.3 mm.yr-1 (scans) and ~1.1 mm.yr-1 (10Be); - for the rock walls of the Mer de Glace basin (3300-4000 m a.s.l.) with mean erosion rates of ~12.4 mm.yr-1 (scans) and ~14.7 mm.yr^{-1} (10Be). Although the estimation of uncertainties associated with these quantifications is still ongoing, the preliminary results already suggest that both methods provide comparable results and clearly outline the influence of the permafrost state. The erosion rate for areas with cold permafrost (mean annual rock surface temperature lower than -2°C) is nearly 10 times lower than the areas affected by warm permafrost.

Regional characteristics of rockwall permafrost in Central West Greenland – 68N

Marco Marcer (Arctic DU), Pierre-Allain Duvillard (Styx 4D consulting engineers), Sona Tomaškovicová (DTU Sustain), Kristoffer Aalstad (University of Oslo), Baptiste Vandecrux (Geological Survey of Denmark and Greenland), André Revil (University Savoie Mont-Blanc), Steffen Ringsø-Nielsen (Arctic DTU), Ahmad Ghorbani (NAGA Geophysics), Jessy Richard (Styx 4D consulting engineers) and Thomas Ingeman-Nielsen (DTU Sustain).

Abstract

In Greenland, the public interest in landslides has increased since the 2017 Karrat event, which caused four casualties and the displacement of several settlements. A typical question asked by the stakeholders about this landslide concerns the role of permafrost and climate change. Answering is not straight forward, because in Greenland there is no knowledge of rockwall permafrost at the national scale to date. In order to start addressing the issue, Arctic DTU began researching rockwall permafrost in 2020 in the Qeqqata Kommunia, West Greenland, 68N. This area offers climatic characteristics ranging from maritime influence at the coastline, to dry continental climate towards the Greenland Icesheet (GrIs). Here, we monitor Ground Surface Temperature (GST) at elevations ranging from sea level to 1300 m.a.s.l. across the region. The GST data allow calibrating an empirical function linking atmospheric forcing – data from downscaled ERA5 reanalysis - to bedrock surface temperatures. This relation is then used to compute atmospheric boundary conditions for 1D and 2D numerical simulations of heat transfer at the landscape level for longer time scales. Model results are compared to temperature data from two lowland boreholes (100 m depth) and subsurface geophysical data - electrical resistivity tomography - acquired at each site describing freezing/thawing conditions. Overall, we observe sporadic mountain permafrost on the coastline, transitioning to continuous permafrost at elevations around 400 m.a.s.l., while towards the GrIs continuous permafrost is prevalent from sea level. By extrapolating the numerical simulations to 2100 (using emission scenarios RCP8.5 and 2.4), we observed a significant loss in rockwall permafrost. This is more dramatic at the coastline, where continuous permafrost is expected to retreat above 800 m.a.s.l on north facing slopes in the worst-case scenario. Overall, our results indicate fragile permafrost conditions on the mid-latitude coastline of West-Greenland.

Permafrost distribution and rock slope movements around the recently deglaciated Mont Fort summit (3329 m a.s.l., Swiss Alps)

Christophe Lambiel (University of Lausanne), Cynthia de Menech (University of Lausanne), Sebastián Vivero (Department of Geosciences, University of Fribourg), Florence Magnin (EDYTEM Laboratory (CNRS, University Savoie Mont Blanc), Ludovic Ravanel (EDYTEM Laboratory (CNRS, University Savoie Mont Blanc), Lucie Dunand (EDYTEM, Université Savoie Mont-Blanc), Pierre-Alain Duvillard (STYX4D) and André Revil (CNRS EDYTEM).

Abstract

Permafrost distribution has been extensively studied in debris accumulations such as rock glaciers, talus slopes and moraine deposits, as well as in rock walls so far, but intermediate slopes (i.e. roughly between 40° and 50°) have received far less attention. Debris-covered and fractured bedrock surfaces may be present on these slopes and a significant snow cover can develop throughout the winter. Such patterns are widely present in high Alpine environments and may be affected by slope movements linked to glacier retreat and permafrost degradation.

In order to increase our knowledge on this type of environments and to investigate the role of permafrost degradation and glacier retreat on steep slope stability, we have been conducting multidisciplinary research on the Mont Fort (3329 m a.s.l., Western Swiss Alps), a highly fractured summit occupied by a small retreating glacier on its northwest flank and on which a cable car station is located. Thermal monitoring is ensured by two boreholes of 20 and 12 m depth and by about 20 surface temperature sensors installed in rock walls or debris. The ground characteristics were investigated through five electrical resistivity profiles. This data set was used to calibrate a model of permafrost distribution around the summit. Complementary, repeated annual uncrewed aerial vehicle surveys and terrestrial laser scanning surveys were performed to monitor slope movements. Despite the high heterogeneity of slope gradients and surface characteristics, our data show a widespread permafrost distribution. Where surface debris is present, even south-facing slopes are underlain by permafrost, indicating the primary role of surface characteristics on permafrost distribution. In addition, significant slope movements were identified just below the cable car station. The combined effect of recent glacier retreat and permafrost degradation was identified as the primary cause of this slope destabilization.

Understanding permafrost in bedrock slopes of intermediate steepness

Pia Blake (Carleton University) and Stephan Gruber (Carleton University).

Abstract

Permafrost thaw as a connection between climate change and the stability of bedrock slopes has received considerable attention during the past 20 years. Most investigations of their thermal regime focused on near-vertical bedrock and neglected slopes with an intermediate steepness of about 35–75 degrees, even though these make up the majority of bedrock slopes. This neglect has a reason: Intermediate slopes are highly heterogeneous, often with local accumulation of debris, patches of vegetation, and a snow cover that is strongly affected by erosion and deposition from wind and avalanches. As a consequence, observations and simulations are more challenging that in near-vertical or gently inclined slopes.

Drawing on a review of observations and simulation studies, we identify and describe the known phenomena and processes that make these slopes of intermediate steepness complicated. For each process, we describe what is known or can be anticipated about spatial patters (steep or gentle slopes, convex or concave, shaded or sun-exposed) and temporal patters (winter or summer, cold or warm locations). Based on this review, we estimate plausible ranges of surface offsets for slopes of intermediate steepness and propose priority areas for further study.

SESSION 11
Emerging geophysical methods for permafrost investigations

Conveners:

- **Adrián Flores-Orozco**, *TU Wien*, flores@geo.tuwien.ac.at
- **Coline Mollaret**, *University of Fribourg*, coline.mollaret@unifr.ch
- **Jonas Limbrock**, *University of Bonn*, limbrock@geo.uni-bonn.de
- **Christian Hauck**, *University of Fribourg*, christian.hauck@unifr.ch

Summary:

Electrical resistivity tomography, ground penetrating radar and seismic refraction tomography are geophysical methods that have been widely applied to investigate the extension of permafrost rocks as well as to monitor their temporal variations. Within the last years, there has been a significant improvement in the measuring instruments as well as in the modeling and inversion algorithms; thus, permitting the application of new methods for permafrost investigations. This session aims at presenting emergent geophysical methods for permafrost investigations: from the instrumentation and data collection, to the presentation of inversion and modeling algorithms for an improved interpretation of geophysical signatures. We welcome case studies or technical contributions for emerging methods, such as time- or frequency-domain electromagnetic (EM), surface-waves seismic, seismic interferometry, induced polarization, or multi-method approaches as well as innovative algorithms for the processing, inversion and interpretation of geophysical signatures. This includes studies across different scales: from numerical and laboratory studies to land, water and airborne investigations.

Application of separate-coils Frequency Domain Electromagnetic (FDEM) instruments for the characterization of rock glacier substrates

Mirko Pavoni (Department of Geosciences, University of Padua), Jacopo Boaga (Department of Geosciences, University of Padua), Alberto Carrera (Department of Agronomy, Food, Natural Resources, Animals and Environment, University of Padua), Alexander Bast (Climate Change, Extremes and Natural Hazards in Alpine Regions Research Center CERC, Davos Dorf, Switzerland) and Marcia Phillips (WSL Institute for Snow and Avalanche Research SLF, Davos Dorf, Switzerland).

Abstract

Ground Penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT) measurements are usually applied for the characterization of rock glacier substrates. The GPR method can be very useful to estimate rock glaciers' internal structure. Nevertheless, due to the coarse-blocky surface, collecting GPR measurements without a snow cover is complicated and therefore the surveys are mainly carried out during the early spring when the instrument can be easily dragged. However, in this period is not possible to define the seasonal thickness of the active layer. This target can be efficiently achieved with ERT surveys performed during the warm season. Nevertheless, ERT measurements require high logistic and time efforts, and it is challenging to ensure good galvanic contact between the electrodes and the blocky ground surface. In this work, we propose an alternative contactless geophysical method to characterize rock glacier substrates: Frequency Domain Electromagnetic (FDEM) surveys performed with a separate-coils device. The applied instrument allows to characterize the subsurface structure from a few meters to several tens of meters depth. Preliminary results of measurements carried out on a debris-covered glacier (Calderone Glacier, Italy) and two Swiss rock glaciers (Flüelapass and Schafberg, Engadin) will be presented. The inverted electrical conductivity sections were calibrated with the results of FDEM forward modeling procedure. The latter has been performed considering prior information about the layers composing the frozen subsoils. The obtained FDEM models agree with the results of GPR and ERT surveys carried out on the same investigation lines, demonstrating the potential of the applied FDEM instrument to estimate rock glaciers' internal structure. Nevertheless, we are not proposing the separate-coils FDEM method as a substitute for GPR and ERT techniques, which undoubtedly have higher resolution and accuracy, but rather as a convenient method that can be used to efficiently and rapidly extend their results.

Near surface continues TEM mapping of saline permafrost environment

Thomas Højland Lorentzen (Technical University of Denmark), Mason Andrew Kass (Aarhus University), Sonia Tomaškovicová (Technical University of Denmark), Anders Vest Christiansen (Aarhus University), Pradip Kumar Maurya (Aarhus University) and Thomas Ingeman-Nielsen (Technical University of Denmark).

Abstract

Transient electromagnetic (TEM) methods have over the last decade developed into continuous methods supplying high quality data with unmatched spatial data coverage. In April of 2021 we conducted a TEM a survey near Ilulissat, West Greenland, using a towed TEM system known as SnowTEM. Ilulissat is located on saline permafrost, where near surface geological information is of high value to the local municipality in relation to a planned expansion of the town and its infrastructure. Over a span of 7 days we covered an area of approximately 640 hectares with approximately 15000 processed usable sounding.

The data is found to be dominated by induced polarization (IP) effects, which manifest as a negatively valued contribution to data, and result in a range of different decay shapes. Some of these decay shapes are known from literature, but we also observe two decay shapes not previously reported. We observe a clear spatial dependency of the decay shapes, and correlation with the presence of surface water features is also apparent.

A series of inversion and forward modeling exercises were performed to investigate the possible link between permafrost conditions and IP effects on the TEM data. The inversion problem was found to be highly non-unique and ill-posed, manifesting in an extreme starting model dependency and a large range of models that fit the data. These challenges limit the use of standard TEM Workflows, and the possibility for quantitative interpretation of the inversion result. Based on forward modeling we show that the spatial distribution of decay shapes may be explained by a subsurface model with dipping bedrock overlain by the relevant cryostratigraphy of the area. This allows for a qualitative interpretation of data, and the production of mapping products useful in community planning.

Passive seismic exploration of permafrost beneath Arctic rivers, lakes, and seas

Michael Angelopoulos (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Trond Ryberg (GFZ German Research Centre for Geosciences, Section Geophysical Imaging), Christian Rasmussen (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Christian Haberland (GFZ German Research Centre for Geosciences, Section Geophysical Imaging), Bennet Juhls (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Scott Dallimore (Geological Survey of Canada, Natural Resources Canada, Sidney, Canada), Julia Boike (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research) and Pier Paul Overduin (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research).

Abstract

Low sea levels during the last Ice Age terrestrially exposed millions of square kilometers of Arctic landscapes, creating subsea permafrost, which has been subsequently submerged. In onshore settings, permafrost can also exist beneath water bodies such as coastal lagoons, rivers, and thermokarst lakes. Often ice-rich, sub-aquatic permafrost contains frozen organic carbon, making it a potential driver of climate change when it thaws. Despite its significant extent in the Arctic, we have few direct measurements of the morphology and degradation rate of sub-aquatic permafrost. Passive seismic is a promising geophysical surveying method for mapping unfrozen sediment thickness above sub-aquatic permafrost. This technique records ambient seismic noise for several minutes to identify shear wave velocity contrasts in the subsurface by using the H/V method. The H/V ratio, plotted as a function of frequency, displays peak(s). These peak(s) may be caused by geological interfaces, including the ice-bearing permafrost table (IBPT) where a strong velocity contrast (unfrozen vs. frozen sediments) is expected. We present passive seismic data collected with the Mobile Ocean Bottom Seismic Instrument (MOBSI) from the Beaufort Sea near Tuktoyaktuk in Canada, Ivashkina Lagoon on the Bykovsky Peninsula, as well as lakes and rivers in the Lena Delta, Siberia, Russia. We use borehole data and frost probe measurements for specific soundings to identify IBPT-related peaks and calibrate shear wave velocities for frequency to depth conversion. Using an objective IBPT-peak picking algorithm, we employ a "shortest-path" approach to connect peaks and generate 2D IBPT profiles. We suggest that MOBSI detects the IBPT beneath the Beaufort Sea, Ivashkina Lagoon, and some areas of thermokarst lakes. Identifying the IBPT is problematic at sites where there are other strong shear wave velocity contrasts (e.g. sediment/bedrock contacts), a seasonally frozen layer, or simply where the IBPT is too deep.

Geothermal evidence of shallow Weichselian permafrost in lowland of Northern Bohemia, Czechia

Jan Šafanda (Institute of Geophysics, Czech Academy of Sciences), Petr Dědeček (Institute of Geophysics, Czech Academy of Sciences), Tomáš Uxa (Institute of Geophysics, Czech Academy of Sciences) and Vladimír Čermák (Institute of Geophysics, Czech Academy of Sciences).

Abstract

The subsurface temperature - depth profiles measured in boreholes bear a signature of the past climatic changes. A link between past climate changes and the present-day subsurface temperature - depth profiles is the propagation of variations in the ground surface temperature into the subsurface through heat conduction, which is the dominant mode of heat transfer in basement rocks. Ground surface temperature changes are recorded as transient perturbations to the steady-state subsurface temperature regime. Perturbations related to the Last Glacial – Holocene changes are contained in the upper 1.5 – 2 km of the Earth's crust.
We present results based on interpretation of such transient perturbations observed in the temperature log of 2 km deep borehole Litoměřice drilled in 2007 and repeatedly logged down to 1700 m in the period 2007 – 2020. A detailed knowledge of temperature gradient together with thermal conductivity, diffusivity and heat production measurements on the drill-core samples of mica schist that occurs below 900 m depth enabled us to analyse the heat flow vertical variations in the lithologically homogeneous depth section 900 – 1700 m. We came to the conclusion that temperature-depth profile in this section contains a robust climate signal of the last glacial cycle. The reconstructed ground surface temperature history indicates the magnitude of the Last Glacial – Holocene warming about 15 K and the occurrence of a temperature minimum 15 – 20 ka. The long-term mean ground surface temperature around +1 °C suggests that the borehole site was permafrost free for most of the glacial cycle. Existence of about 100 m deep permafrost is possible in the coldest part of the last glacial.

The research is supported by the Czech Science Foundation, project no. 21-23196S

An Inversion scheme for MASW data collected on saline permafrost soils.

Thomas Højland Lorentzen (Technical University of Denmark) and Thomas Ingeman-Nielsen (Technical University of Denmark).

Abstract

Permafrost presents unique challenges for quantitative near surface geophysical mapping. The use of Multichannel Analysis of Surface Waves (MASW) is challenged due to their multimodal nature, where higher modes commonly dominate when the subsurface show large velocity contrast or velocity inversion. Such situations are common in areas with saline permafrost, typically ice rich layers near the top of the permafrost are underlain by layers with high porewater salinity and high unfrozen water content. We investigated such a setting in Ilulissat, West Greenland, by use of hammer seismics in April 2021. To gain the best possible dataset we used both a p- and s- wave hammer sources and 3-component geophones to collect a dataset containing both Reighley and Love waves. No available MASW inversion scheme was found to be able to handle the complexity of the data nor the expected subsurface models. We therefore developed a novel probabilistic, informed prior, joint inversion of dispersion curves of surface waves.

The inversion is parametrized with discrete thin layers that allow for arbitrarily complex and realistic models and similarly complex prior information, that limits the non-uniqueness of the inversion problem. To make this computationally feasible we make use of a reformulated thin layer approximation of the stiffness matrix and propose a less computational heavy likelihood function based on the condition number of the stiffness matrix. The likelihood function is independent of mode and allows for handling of higher modes without assigning a mode number to the data. The combination of complex structural prior information and a multimodal sampling approach allow us to produce reliable subsurface models in the case of highly multimodal data, without the risk of mode misidentification, or the need to estimate the wavelet of the source.

Estimating permafrost distribution using colocated temperature and resistivity measurements

Sebastian Uhlemann (Lawrence Berkeley National Laboratory), Ian Shirley (Lawrence Berkeley National Laboratory), Jack Lamb (Stanford University), Sylvain Fiolleau (Lawrence Berkeley National Laboratory), Evan Thaler (Los Alamos National Laboratory), Chen Wang (Lawrence Berkeley National Laboratory), Craig Ulrich (Lawrence Berkeley National Laboratory), Stijn Wielandt (Lawrence Berkeley National Laboratory), John Peterson (Lawrence Berkeley National Laboratory), Susan Hubbard (Oakridge National Laboratory) and Baptiste Dafflon (Lawrence Berkeley National Laboratory).

Abstract

Knowing the distribution and thickness of permafrost bodies is crucial for predicting the trajectory of Arctic ecosystems, how much greenhouse gasses they may release, and what hazards their thaw may incur. Yet, borehole observations are very limited, and too sparse to understand the highly heterogeneous subsurface structure in discontinuous permafrost environments. Geophysical imaging has been shown to be able to overcome these limitations by providing spatially resolved images of permafrost distribution, which can be linked to their the thermohydrological properties. However, the nature of these measurements and associated data interpretation, but also common geological settings, limit their use for mapping the base of permafrost.

We first present a synthetic study that aims at estimating how well the distribution and depth of permafrost can be mapped using unsupervised and supervised learning techniques, but also common approaches that make use of observed resistivity thresholds. The results show that supervised classification has a superior performance, indicating the need for colocated temperature and resistivity measurements. Using such data, we predict the spatial distribution of permafrost bodies within several watersheds on the Seward Peninsula (Alaska) that are characterized by different annual temperatures, and use supervised classification to map their thickness. While, as expected, the permafrost area increases with decreasing temperature, we also observe that differences in vegetation distribution and slope angle have a significant effect on the permafrost extent. While colocated temperature and resistivity measurements were essential to perform this study, we also show that such colocated measurements are important to understanding permafrost distribution in general.

Recent and ongoing transformations of the Nevado Coropuna tropical cryosphere (Central Andes): the Ground-Penetrating Radar perspective

Adriano Ribolini (Università di Pisa), Luis Mariano Del Río (Universidad de Extremadura), Ramón Pellitero (UNED. Universidad Nacional de Educación a Distancia), Álvaro Navarro (Universidad Complutense de Madrid), Beto Ccallata (Observatorio Vulcanológico del INGEMMET en Arequipa), Pablo Masías (Observatorio Vulcanológico del INGEMMET en Arequipa), Donato Flores (Comunidad Campesina de Unro), Edwin Calachua (Comunidad Campesina de Unro), Álvaro Arredondo (Guías de Espeleología y Montaña (GEM), Pablo Guijarro (Guías de Espeleología y Montaña (GEM) and Jose Úbeda (Universidad Complutense de Madrid).

Abstract

The evaluation of presence and origin of ground-ice in the non-glaciated peripheral areas of Nevado Corpuna can contribute to a more refined estimation of its real extent, as well as of the ongoing and recent transformation processes (i.e. permafrost aggradation/degradation). We carried out GPR surveys in sectors immediately outside the glacial tongues which diverge from the glaciated area, both on rock glaciers and debris-covered glaciers. The data acquisition was made with an unshielded antenna operating at a central frequency of 25 MHz, and according longitudinal and cross profiles. We defined a processing sequence particularly effective in removing in air-reflections generated by isolated blocks on the surface, and the numerous point-source diffractions. The signal-to-noise ratio consents a data imaging interpretable up to 25-30 m of depth, according to the estimated velocity of GPR waves propagation. In some sectors we calibrated the GPR data (depth and reflection amplitude) with those obtained from Vertical Electric Sounding. The rock glaciers examined show a reflective pattern consistent with a permafrost that extends from 2-4 m to more than 20 m depth. The GPR reflections also depict a permafrost stratigraphic architecture, and potential deformation structures in the frozen layers (i.e. shear planes). The GPR profiles made on debris-covered glaciers show a high-amplitude reflection consistent with the presence of near-surface (2-3 m depth) (sedimentary) ice, which in depth exhibits a radar facies less characterized by reflection events than those of rock glaciers. Also in this case an ice stratigraphy and potential deformation features in layers highly rich in ice are visible. The GPR data allowed a view of ice-ground presence in the ice-free areas in Nevado Coropuna and can be integrated with the glaciological evolution of the last decades to build a forecasting model that considers the transformation from clean-ice to debris-covered glacier or permafrost landforms.

Investigating signal penetration depth in multi-frequency Synthetic Aperture Radar imagery over lowland permafrost

Paloma Saporta (German Aerospace Center (DLR), Alberto Alonso-González (Universitat Politècnica de Catalunya) and Irena Hajnsek (German Aerospace Center (DLR).

Abstract

Synthetic Aperture Radar (SAR) is an established technique to study geophysical phenomena occurring at the Earth surface. In the case of lowland permafrost monitoring, SAR is particularly interesting as it combines wave penetration capabilities within scatterers in the scene and large-scale imaging. In order to examine which ground layer the radar signal reaches, it is crucial to estimate the signal's penetration depth within the soil, and through the vegetation covering it. We propose a study based on the PermaSAR airborne campaign which was conducted by the German Aerospace Center (DLR) in the Canadian Arctic. This study focuses on a well-studied lowland permafrost site in the Canadian Artic, namely the Trail Valley Creek catchment close to Inuvik (New Territories, Canada). The catchment is characterized by tundra vegetation over continuous permafrost. Acquisitions over the test-site were performed successively in summer 2018 and winter 2019, corresponding to thawed respectively frozen state of the vegetation and active layer. The sensor was operated with signals at three different wavelengths, namely X (3cm), C (6 cm) and L- band (23 cm). Those three signals are sensitive to different natural objects and are expected to penetrate differently into frozen soil. Fully polarimetric images were acquired, allowing to separate different types of scattering mechanisms. Finally, the flight geometry features several parallel tracks, allowing for interferometric processing resulting in the location of the height of the scatterer within one resolution cell. We present here a preliminary investigation towards the characterization of the penetration of SAR waves into the frozen ground by observing and analyzing the penetration effect as retrieved from the phase center height bias.

Influence of temperature and ground ice content on broadband SIP signatures: Utilizing insights from controlled freeze-thaw experiments for improved characterization of Alpine permafrost sites

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Abstract

Geoelectrical methods are increasingly used for the non-invasive characterization and monitoring of permafrost environments given their sensitivity to phase changes between liquid and frozen water in the subsurface. Since it is challenging to distinguish between air and ice in the pore space of soils and rocks based on electrical resistivity alone, due to their similarly high values, more recently also the spectral induced polarization (SIP) response is measured in permafrost studies given the distinct SIP signature of ice. Results are promising, indicating the potential of SIP measurements for ice content quantification and thus an improved thermal characterization of permafrost sites. In order to improve the understanding of the SIP signature of partially frozen soils and rocks as a function of temperature, ice content, texture and mineralogy, we conducted laboratory measurements on solid rock and loose sediment samples from different Alpine permafrost sites in a frequency range from 10 mHz to 45 kHz during controlled freeze-thaw cycles (+20 °C to -40 °C). Additionally, broadband SIP field measurements were collected at two of the sites (Zugspitze, Schilthorn), covering variations in ice content, temperature and lithology. All laboratory and field measurements reveal the same systematic behaviour of the SIP response: While the magnitude of the complex resistivity increases with decreasing temperature and increasing ice content, the resistivity phase spectra exhibit the well-known relaxation behaviour of ice at higher frequencies (1 kHz - 45 kHz), with relaxation time and polarization magnitude depending mainly on ice content, and temperature and rock type. The observed similarities in the described dependencies in the laboratory and field measurements indicate the possibility of a site-specific calibration of the field responses in terms of temperature and ground ice content, which provides the basis for an improved thermal state characterization of the considered sites using the SIP method.

Improved characterization of alpine permafrost by including structural constraints from transient electromagnetic data into spectral induced polarization imaging

Lukas Aigner (TU Wien, Department of Geodesie and Geoinformation, Research Unit Geophysics), Nathalie Roser (TU Wien, Department of Geodesie and Geoinformation, Research Unit Geophysics), Clemens Moser (TU Wien, Department of Geodesie and Geoinformation, Research Unit Geophysics), Umberto Morra Di Cella (Regional Agency for Environmental Protection, Aosta valley, Italy), Christian Hauck (Department of Geosciences, University of Fribourg, Switzerland) and Adrián Flores Orozco (TU Wien, Department of Geodesie and Geoinformation, Research Unit Geophysics).

Abstract

Recent developments show that the spectral induced polarization (SIP) method can help to reduce the ambiguity between air, ice, and rocks in the interpretation of anomalies in electrical resistivity images. However, SIP surveys need relatively long survey layouts to reach a large depth of investigation (DOI). Additionally, large blocks render the electrode installation in SIP measurements difficult which affects the quality of the data and further reduces the DOI. Transient electromagnetic (TEM) measurements can overcome such limitations as TEM soundings require no galvanic contact with the ground and can reach a larger DOI with smaller survey geometries. We demonstrate the applicability of TEM soundings for alpine permafrost investigations to delineate the active layer and bedrock depths as well as ice rich areas. Through numerical and field experiments we show that sign reversals observed in TEM decay-curves are related to induced polarization (IP) effects associated to surface conduction mechanisms of ice. We propose a code that permits the forward modeling and inversion of single-loop TEM soundings taking the dispersion of the electrical resistivity into account. Moreover, we investigate the combination of SIP and TEM data to characterize alpine permafrost sites with enhanced resolution. We collected TEM and SIP data at the Gran Sometta (Aosta Valley, Italian Alps) and the Murtél (Upper Engadin, Swiss Alps) rock glaciers to test the imaging capabilities of SIP profiling, TEM soundings and the combination of both methods. Our results show that ice-rich areas are characterized by an increase of the IP response at high frequencies (> 10 Hz) in SIP surveys, and TEM decay-curves that are affected by an increased number of sign reversals. Moreover, the results from structural constraint inversion of SIP data demonstrate an improved delineation of ice-rich areas as well as an improved resolution of the contact to the bedrock.

Petrophysical Aspects of Ice Content Estimation from High-Frequency Induced Polarisation (HFIP) spectra

Andreas Hördt (TU Braunschweig), Franca Ulrich (TU Braunschweig), Madhuri Sugand (TU Braunschweig) and Dennis Kreith (TU Braunschweig).

Abstract

Ice content is an essential parameter in permafrost research. It controls heat transport and storage and therefore is a key parameter in any numerical simulation that predicts the fate of permafrost in the context of global warming. Despite its importance, ice content measurements are only conducted sporadically, as it is challenging to collect datasets with high spatial resolution. One promising geophysical method to estimate ice content is High-Frequency Induced Polarisation (HFIP), which determines the electrical permittivity over a broad frequency range between 1 Hz and 200 kHz. Since the permittivity of water ice exhibits a characteristic behavior in that range, the method is in principle suitable to estimate ice content. There is a number of complexities to bear in mind when estimating ice content at field scale, which includes electromagnetic coupling effects, measurement error quantification, and 2-D inversion. Here, we investigate two aspects of a petrophysical model that is used to recover ice content from the frequency-dependent permittivity with an inversion scheme. First, we investigate the impact of low-frequency polarization, i.e. the polarization of sediments occuring at considerably lower frequencies than that of ice. Using a model previously suggested in literature, we show that such low-frequency polarization can reliably be separated from the ice polarization and does not have a significant impact on the determination of ice-related parameters. Second, we investigate the influence of potentially unknown temperature variations. We show that temperature does not affect ice content estimation and furthermore it is possible to determine temperature as a free parameter during inversion. We conclude that ice content estimation from HFIP data is relatively robust and not easily distorted by potentially unknown lithology or temperature.

Quantitative interpretation of spectral induced polarization signatures in different mountain permafrost landforms with varying geologies and ice contents

Theresa Maierhofer (TU-Wien, University of Fribourg), Adrian Flores-Orozco (TU-Wien), Nathalie Roser (TU-Wien), Christin Hilbich (University of Fribourg) and Christian Hauck (University of Fribourg).

Abstract

Ground water and ice content are key parameters to understand the current state of mountain permafrost. To capture their spatial variability throughout different permafrost landforms, geophysical methods are cost-effective means of subsurface investigation. Recent developments focus on combined electrical and seismic measurements to estimate volumetric ice, water and air contents by linking the electrical and seismic properties through a petrophysical four-phase model. Due to the capacitive properties of ice and the ice-water interface, surface conductivity has to be considered in addition to electrolytic conduction, but its importance for different permafrost occurrences is unclear due to a lack of data. Spectral induced polarization (SIP) approaches have been tested for permafrost applications, because polarization effects due to unfrozen, interfacial water and protonic defects in ice help for an improved delineation of the ground ice content. In this contribution, we focus on an extensive SIP imaging data set collected in a frequency range between 0.1 Hz and 75 Hz at 10 representative and morphologically different Alpine permafrost sites (i.e., Switzerland, Austria, Italy and Germany). The selected study areas (located around 2600 – 3500 m a.s.l.) include rock glaciers and talus slopes with high ice contents and bedrock permafrost with lower ice contents and provide comprehensive validation data. Within our analysis we focus on the phase frequency effect (ϕFE, i.e. the difference in phase between high and low frequencies), exploiting the spectral information gained through SIP field measurements and providing insight into subsurface heterogeneity that cannot be resolved entirely through ERT and single frequency IP data. We further compare our results with ice content estimates and propose a methodology to improve the quantification of ice content and to account for the contribution and spatial variability of surface conductivity.

Monitoring active layer dynamic using a low-cost Ground-Penetrating Radar system. A laboratory analog test case.

Emmanuel Léger (GEOPS Laboratory - Paris Saclay University), Albane Saintenoy (GEOPS Laboratory - Paris Saclay University), Mohammed Serhir (Université Paris-Saclay, CentraleSupelec, CNRS, Laboratoire de Génie Electrique et Electronique de Paris) and François Costard (GEOPS Laboratory - Paris Saclay University).

Abstract

Monitoring active layer dynamic is critical for improving the near surface thermal and hydrological process understanding in the cryosphere, as the thermal and hydrological active layer processes influence drastically the perenity of the underlying permafrost as well as the bio-geo-chemical phenomena. Point-scale measurements are classically used but require in situ measurements, implying trenches and/or digging. As an alternative geophysical measurements, especially high frequency Ground-Penetrating Radar (GPR) is particularly suited for monitoring the active layer freezing and thawing processes due to its non invasive nature and its sensitivity to water dielectric permittivity in frozen and liquid states. This study presents the laboratory test of a low-cost GPR system within a laboratory experiment of active layer freezing and thawing monitoring prior to field deployment. The system is an in-house built low power monostatic GPR antenna coupled with a reflectometer piloted by a single board computer. The GPR system data are compared with classical thermal and volumetric water content measurements to test the ability of the system to closely monitor the frozen front/bottom of the active layer reflection. Correspondence between the frozen front electromagnetic reflection and temperature allowed to retrieve the frozen soil bulk permittivity and a simple thermo-hydrodynamical modeling coupled with an electromagnetic numerical simulation gives a first trial on interpreting the reflection origins.

Petrophysical joint inversion to estimate spatio-temporal changes in ground ice content: investigation of different petrophysical relations using synthetic data

Coline Mollaret (University of Fribourg), Christin Hilbich (University of Fribourg) and Christian Hauck (University of Fribourg).

Abstract

In permafrost research, quantification of ground ice and unfrozen water is both crucial and difficult to estimate. For a quantification based on geophysical field data, a petrophysical joint inversion (PJI) framework was recently developed and applied by several research groups. This PJI jointly inverts a set of geophysical data (P-wave travel times and electrical apparent resistivity) to get estimates of the four phases (water, ice, air and rock contents) based on petrophysical equations. The most commonly used petrophysical equation for the electric properties is Archie's law, which is, however, based on partly inappropriate assumptions for permafrost environments.
In this contribution, we use synthetic data representing different type of ground material and different ice contents and compare results of PJI estimations using Archie's law with PJI estimations using other petrophysical equations such as the electrical resistivity geometrical mean model (which assumes a random distribution of the four phases). We show that in certain cases the geometric mean model gives much better results than Archie's law being able to detect both ice-poor and ice-rich zones. The reason for this is that the ambiguity between both solid phases (i.e. ice and rock) – both not explicitly considered in Archie's law – is avoided using the geometric mean model in which the resistivities of ice and rock are considered individually. We will discuss the applicability of the different petrophysical equations and how they succeed in retrieving the synthetic true data. In a second step, we apply the method to field data and discuss the advantages and limitations of the approach for a reliable estimate of ice content as well as its temporal changes in a monitoring context.

An open framework for time-lapse petrophysical joint inversion of geophysical permafrost monitoring data

Florian Wagner (Geophysical Imaging and Monitoring, RWTH Aachen University, Germany), Johanna Klahold (Institute of Earth Sciences, University of Lausanne, Lausanne, Switzerland) and Christian Hauck (Department of Geosciences, University of Fribourg, Fribourg, Switzerland).

Abstract

Permafrost degradation is evident on a global scale and can result in the emission of greenhouse gases from thawing permafrost soils and rock falls or landslides in alpine regions. Geophysical monitoring methods offer the unique potential to monitor permafrost dynamics non-invasively at high spatial and temporal resolutions. The quantitative estimation of the pore-filling constituents, i.e. ice, water, and air contents, from a single geophysical method, however, remains to be a challenging endeavor. This is mainly due to the ambiguous relation between these parameters and their geophysical signatures. This is further complicated by unknown porosity distributions and uncertainties in the petrophysical equations, which have many additional parameters that are often assumed to be spatially and temporally constant. A partial remedy to this ill-posed problem is the use of multiple geophysical methods with partially complementary sensitivities in joint inversion frameworks.

In this contribution, we present a methodology for the inversion of geoelectrical and seismic refraction data using petrophysical and temporal coupling. The petrophysical coupling enables the direct estimation of pore-filling constituents honoring petrophysical relations and physical plausibility (i.e. volumetric constraints). The temporal coupling enables the differentiation between parameters that are assumed to be invariant within a monitoring window (e.g., porosity) and other parameters, which are expected to exhibit a dynamic behavior (e.g., ice and liquid water contents). We demonstrate the advantages and limitations of this time-lapse joint inversion framework based on synthetic experiments and field data from the Schilthorn, Swiss Alps. The latter were validated with respect to the thickness of the active layer derived from independent borehole temperature measurements. Finally, we provide an outlook on promising extensions to this freely available inversion code such as the inclusion of different geophysical measurement methods and more sophisticated petrophysical laws. This study contributes to the improvement of process understanding in permafrost systems and the parameterization of corresponding process models based on multiple geophysical modalities.

Vertical electrical sounding in the tropical permafrost of the Nevado Coropuna volcanic complex, central Peruvian Andes

Velnia Chacca Luna (Instituto Nacional de Investigación en Glaciares y Ecosistemas de Montaña), Ramón Pellitero (UNED. Universidad Nacional de Educación a Distancia), José Úbeda (Universidad Complutense de Madrid) and Adriano Ribolini (Università di Pisa).

Abstract

Accelerated glacial retreat is giving room for permafrost formation in the Western (arid) flank of the Tropical Andes, where the largest portions of World's tropical permafrost are found. Geophysical surveys are an optimal method for the characterization of the interplay between debris-covered glaciers, sediments, and permafrost. We show the results of 4 Vertical Electrical Sounding (VES) profiles carried out on the eastern and western flanks of Nevado Coropuna (15°32'S, 72°39'W) at 5160 and 5330 m above sea level, respectively. The analysis of the numerical results, together with field observations, have allowed distinguishing 4 types of materials for the study areas according to their resistivity ranges and determining the depth of the permafrost layer. For the eastern zone, an active layer greater than 1 m thick with a range of resistivities between 6600 and 150000 Ωm was found, along with a permafrost layer ranging from 3 and 21 m depth exhibiting an resistivity between (10000 - 13000 Ωm) and basal unfrozen sediments/bedrock with a resistivity of (~2200 Ωm). In the western study area, the VES explored a debris-covered glacier finding a resistivity value above 21000 Ωm up to 27 m of depth. The data found in the Nevado Coropuna fit with those frequently found in the glacial-periglacial deposits in the Andes, where intense sediment mineralizations may cause an increase in sediment/rocks conductivity. The VES profiles provided information about the permafrost existence and potential ice content at depth, opening the door for a more robust interpretation of glacial and periglacial deposits present in the vicinity of Nevado Coropuna glacier. Results also highlight the effectiveness of VES for detecting permafrost in high tropical mountains, where surface condition and logistics are usually challenging. In addition, resistivity data will allow calibrating subsurface imaging provided by Ground Penetrating Radar prospections in the same areas.

Two-dimensional estimation of ice-content distribution in permafrost peatlands using high-frequency induced polarisation.

Madhuri Sugand (TU Braunschweig), Andreas Hördt (TU Braunschweig), Andrew Binley (Lancaster University) and Franca Ulrich (TU Braunschweig).

Abstract

Permafrost peatlands, which widely cover northern boreal and subarctic regions, are vulnerable to ground destabilisation due to climate change induced degradation. The thickening active layer or thawing peat can result in the formation of thermokarst lakes which triggers a series of thermal, ecological, and hydrological changes to the landscape. At present, ice-content estimation and modelling rely on observations at the point-scale from disturbed sampling. However, such data collection is difficult due to the remoteness of these regions, challenging terrain or, in some cases, protected status. Geophysical studies may prove advantageous in such areas with relatively rapid 2-D subsurface mapping.

The method of high-frequency induced polarisation (HFIP) has been recently used to study the presence of ice, as its permittivity shows a characteristic frequency dependence in the ranges of 100 Hz to 100 kHz. The measured HFIP spectrum is also a function of temperature and volume fraction of ice and therefore, in addition to detecting ice, it is possible to obtain an understanding of the subsurface conditions. Consequently, our study aims to apply HFIP to detect the presence of ice and estimate its volumetric content using a two-component mixture model.

We present field results from a recent campaign undertaken in Abisko, Sweden. Two-dimensional HFIP profiles were conducted at two peat permafrost sites: Storflaket and Heliport. For data validation, one permafrost core (up to 3 m) was extracted at each site. The measured frequencies were inverted individually with ResIPy, and analysis of the spectral data allows the identification of ice-rich (large, high-frequency phase peaks), ice-poor (small, high-frequency phase peaks) and no-ice (no distinct phase peaks) zones. Ice content is estimated for ice-bearing sections, and the results correspond with prior field knowledge. Thus, HFIP could be an auxiliary or alternative technique for monitoring permafrost regions.

Passive seismic methods on rock glaciers : observations and dynamics modeling

Antoine Guillemot (ISTerre CNRS - Géolithe Innov), Eric Larose (ISTerre CNRS) and Laurent Baillet (ISTerre - UGA).

Abstract

Among mountain permafrost landforms, rock glaciers are composed of a heterogeneous mixture of rock debris, ice and liquid water. They can reach surface velocities of several m/yr for the most active ones, potentially causing emerging hazards linked to permafrost thawing and debris flows. As a complement to usual geophysical methods (georadar, active seismics, geoelectrics) providing interesting tools for investigating the subsurface, and to in-situ and remote sensing methods that track kinematics of these instabilities, passive seismic instrumentation offers a continuous monitoring at depth. Such instrumentation has been deployed for several years at Gugla, Tsarmine (Valais, Switzerland) and Laurichard (Hautes-Alpes, France) rock glaciers. From seismic ambient noise, Coda Wave Interferometry has been applied to compute daily dV/V (or relative change velocity of the surface waves) which are directly linked to the elastic properties of the medium at depth, and therefore its rigidity and density. For the three sites studied, seasonal variations of shear stiffness have been measured, and located by using a 1D coda wave inversion. These changes in mechanical properties of the medium are related to seasonal hydro-thermal forcing. We developed a simple viscoelastic model to explain the seasonal variability of the deformation rate of rock glaciers. By using observed shear stiffness as a parameter varying over time, we reconstructed well the creep rates observed, strengthening the key role of meltwater and rainfall on rock glacier dynamics at a seasonal scale. In the long term, a pluriannual seismic monitoring allows to detect changes in ice content, by tracking long-term changes in rigidity within the rock glacier body. Such permanent instrumentation paves thus the way to quantify the permafrost degradation.

3D Spectral Induced Polarization for the estimation of ice content and hydraulic properties in an active rock glacier

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Abstract

Active rock glaciers play a major role in the hydrological cycle of high-mountain environments, for instance as they store water in form of ice and can act as a buffer for heavy rainfalls. However, methods to quantify subsurface ice and hydrogeological properties of rock glaciers are still an open area of research. Ice and water content can be measured by in situ methods in boreholes, which are spatially limited and expensive, while geophysical methods can provide high resolution yet indirect information about these subsurface properties. Here, we aim to quantify water content and hydraulic conductivity in the active layer and ice content in the permanently frozen layer by using the spectral induced polarization (SIP) method, which provides the frequency dependent conductive (conductivity) and capacitive properties (polarization) of the subsurface at low frequencies. While the water content is linked to the electrical conductivity through Archie's law, the capacitive properties are used to define geophysical length scales, which relate to the pore geometry, to predict the hydraulic conductivity. Ice content estimations are associated with induced polarization effects observed above 10 Hz in SIP field measurements. We collected SIP mapping data along 8 crossing profiles in a frequency range of 0.1-200 Hz on the Gran Sometta rock glacier (Aosta Valley, Italy), consisting of two lobes, in October 2022. Estimations of the hydraulic conductivity are validated by high resolution resistivity monitoring data collected during the injection of a tracer-test, while ice content estimations are validated by laboratory investigations of frozen rock samples. The results demonstrate that both lobes of the Gran Sometta rock glacier contain a high ice content, with a lower ice content between the lobes. The highest hydraulic conductivity values based on SIP data are found in a range of cm/s which is in agreement with results of the tracer test.

Wide spread occurrence of the suprapermafrost subaerial taliks in continuous permafrost of Central Yakutia

Liudmila Lebedeva (Melnikov Permafrost Institute SB RAS), Ivan Khristoforov (Melnikov Permafrost Institute SB RAS) and Kencheeri Danilov (Melnikov Permafrost Institute SB RAS).

Abstract

Central Yakutia in Eastern Siberia is covered by continuous permafrost 200-500 m thick. Taliks exist under the large rivers and lakes. Subaerial taliks are not expected due to low air temperature. The mean air temperature at Yakutsk is -9.5°C. However, subaerial taliks in Central Yakutia are occasionally found in pine forests. The aim of our research was to assess the spatial distribution of subaerial suprapermafrost taliks in Central Yakutia using GPR profiling. We carried out geophysical surveys on 90 profiles with a total length of more than 21 km to detect suprapermafrost taliks. We found taliks on 25 profiles out of 90. The typical talik size is from tens to hundreds meters, thickness is from 3 to 20 meters. The fraction of talik in the total length of the completed profiles was 18.2 %, which is much higher than previously published assessments. The results of the verification drilling showed good agreement with the GPR data. All identified subaerial taliks were found at the well-drained gentle slopes covered with sparse pine forests, where homogeneous sandy deposits are distributed from the surface. According to the Permafrost Landscape Map of the Republic of Sakha (Yakutia), all identified taliks are located in pine or pine-larch forests, which occupy 12.5 % of the territory of Central Yakutia. Assuming that the selected profiles are representative of this type of vegetation, the proportion of the area of Central Yakutia where suprapermafrost subaerial taliks are present is 2.3 %. It is unexpectedly high for the studied region covered by thick continuous permafrost. Assessment of suprapermafrost subaerial talik fraction in pine forests (18.2 %) and Central Yakutia (2.3 %) is a fundamentally new scientific result that contribute to understanding of the current permafrost state in the region. This research was funded by Russian Science Foundation and Yakutian Science Foundation, grant number 22-17-20040.

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SESSION 12
Periglacial and paraglacial environments in Antarctica

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- **Mauro Guglielmin,** *Department of Theoretical and Applied Science, Insubria University;* mauro.guglielmin@uninsubria.it
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Summary:

Antarctic periglacial and paraglacial environments belong to the most uniques systems on Earth. They are restricted to Antarctic ice-free regions, which are mostly controlled by the occurrence of permafrost. These environments are located mostly in coastal fringes, dry regions in the interior of the continent and scattered nunataks, and represent a rich mosaic of ice-free landscapes that have developed under different climate and topographic conditions. However, their origin, as well as their recent changesremain still poorly investigated and require multidisciplinary scientific research. This session focuses on environmental dynamics prevailing in ice-free regions in Antarctica, and welcomes studies on ground thermal regime of the active layer and permafrost, as well as research focusing on geomorphic, soil and ecological processes in recently deglaciated areas. Contributions providing new multidisciplinary perspectives, including remote sensing and new methods and techniques are also welcomed.

Contaminants in the active layer and permafrost in Barton Peninsula, King George Island (South Shetlands, Antarctic). Preliminary results.

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Abstract

The chemical characterization of frozen soils in the Antarctic is still an understudied subject. Permafrost prevails in most of the ice-free areas of the continent and studies about its content in trace elements are scarce. The geographic location of the South Shetlands archipelago dictates that permafrost is near its climatic boundary and its thaw may lead to the remobilization of trace elements. Our project's objective is to collect and chemically characterize active layer, transient layer and permafrost samples and analyse their content in specific key inorganic pollutants (e.g., Arsenic (As), Cadmium (Cd), Lead (Pb), Mercury (Hg). Furthermore, the use of sequential extractions will help us to determine the bioavailability of these compounds and assess the impact they may have in the environment. Permafrost thermal regimes are characterized using data from the PERMANTAR network boreholes. Electrical resistivity tomography (ERT) surveys are used to detect permafrost and ground moisture spatial distribution and to evaluate their impacts on contaminant mobility. The spatial analysis is supported by very high-resolution satellite imagery analysis and UAS orthomosaics and digital surface models, used to map vegetation and ground surface characteristics. The first sampling campaign was conducted in Barton Peninsula, King George Island. Barton is a recent deglaciated area with low anthropogenic pressure and with no recent volcanic history. More recently, a second campaign was conducted in Deception Island for further comparison between two different environments of the South Shetlands. Deception is one of the most active volcanoes of Antarctica and its activity is a natural source of trace elements. Preliminary results from Barton Peninsula soils do not show concerning concentrations of the measured elements neither an apparent increase with increasing depth in the active layer.

Active layer and permafrost thermal regime in Antarctica: the overview of results in the period 2005-2020

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Abstract

The International Polar Year (IPY) in 2007/08 was a big milestone for the research of the active layer and permafrost in Antarctica. The activities during IPY placed the background for the continuous monitoring focusing on the ground thermal dynamic both in the seasonally thawed active layer and permafrost. Now, 15 years after the IPY, we provide the first comprehensive summary of scientific literature with a major focus on near-surface, active layer and permafrost thermal states across Antarctic ice-free environments, including the sub-Antarctic Islands. The warmest region is the Western Antarctic Peninsula, the mean annual ground temperature is closely below 0°C, and active layer thickness can exceed several meters. This region is presumably formed by discontinuous permafrost; however, more precise evidence about the zonation is missing. The coldest Antarctic region is in the McMurdo Dry Valley and Transantarctic Mountains, where the ground temperature can drop up to -35 °C and the active layer thickness reach only several centimetres. The general climate drives the high variability of the ground thermal regime and active layer thickness. However, specific factors like snow, lithology, moisture or vegetation can also lead to distinctive variability on a local level. Importantly, our results showed the warming tendency of ground temperature in most sites during 2005-2020.

Interannual variability of soil thermal conductivity on the Abernethy Flats (James Ross Island) in the period 2014–2022

Michaela Knazkova (Masaryk University) and Filip Hrbacek (Masaryk University).

Abstract

Thermal properties of soil, in particular its thermal conductivity, greatly influence the thawing propagation rates and active layer depth in permafrost regions. Soil thermal conductivity can either be determined under laboratory conditions or calculated from experimental data using numerical models. Soil texture, soil density and volumetric water content represent the primary controlling factors driving changes in soil thermal conductivity. Here, we analyse air and ground temperature, soil heat flux and soil moisture data obtained over a total of eight Antarctic summer seasons (2014–2022) in the Abernethy Flats on James Ross Island. Based on half-hourly ground temperature and soil heat flux measurements, we employ a numerical model based on Fourier law of heat conduction to determine soil thermal conductivity and investigate how it is affected by changes in soil volumetric water content and in turn how it translates into the changes in active layer thickness. The average soil thermal conductivity for the studied period was 0.65 $W.m^{-1}K^{-1}$ and it ranged between 0.43 and 0.74 $W.m^{-1}K^{-1}$ in the upper (5–20 cm) layer of soil. While higher soil thermal conductivity caused by an increase in soil moisture may lead to increased rates of thaw propagation and a possibility of heat transfer reaching a greater depth, the amount of available heat still is a considerable limiting factor. Therefore, a steady rise of soil thermal conductivity due to an increase of soil moisture over the period 2014–2019 has not generated a considerable increase in active layer depths. However, mean annual ground temperatures started to exhibit a rising trend in the last three seasons, coupled with a dramatic increase in active layer thickness, which has reached its maximum of over 90 cm in the season 2021/2022. This is even despite a slight decrease in soil thermal conductivity since 2019.

Where is the permafrost on King George Island (South Shetland Islands)?

Marek Kasprzak (University of Wroclaw), Mateusz Strzelecki (University of Wroclaw), Grzegorz Rachlewicz (Adam Mickiewicz University), Anna Zmarz (University of Warsaw) and Robert Bialik (Institute of Biochemistry and Biophysics, Polish Academy of Sciences).

Abstract

Numerous permafrost studies conducted on the Antarctic Peninsula and surrounding archipelagos have been published in recent years. We aimed to determine whether perennial ground freezing also occurs near the Arctowski Polish Antarctic Station on King George Island. Despite more than 70 years since the station was established, such information has not been verified. Using electrical resistivity tomography (ERT), we imaged the subsurface structure and, indirectly, its thermal conditions in the glacial-ice-free areas – uplifted marine terraces, slopes and mountain ridges (Squa Ridge, Penguin Ridge) – taking into account slope aspects and hydrological situation. We conducted ground temperature measurements to a depth of 1.5 m at Cape Rakusa Point and water temperature in shallow lakes behind beach berms at Shag Point Peninsula. Interpretation of the inversion models derived from ERT indicates that most of the oasis subsurface is free of ground ice during the warm season, and there is undoubtedly no permafrost. We point to the possibility of shallow (up to 10 m) ground freezing at the foot slopes, where the meltwaters concentrate, on shaded sections of the slopes and inside the moraine ridges in front of the local glacier (the example of Glacier Ecology). Interpreting geophysical data is difficult due to the high lithological variability of the volcanic and sedimentary bedrock. The permafrost has not been found in boreholes drilled into solid rock. Its presence is also not possible on the surface of the marine terraces at the Arctowski Station, where the groundwater table is just below the terrain surface. Stagnant water in shallow lakes periodically reaches 10 °C. At the level of the low marine terraces, the subsurface is also thermally affected by seawater. Permafrost formation under King George Island conditions also faces the significant obstacles of average annual temperatures higher than −2 °C and frequent snowmelt (including mid-winter).

A new CALM grid site in Continental Antarctica (North Victoria Land)

Stefano Ponti (University of Insubria) and Mauro Guglielmin (University of Insubria).

Abstract

The circumpolar active layer monitoring (CALM) network proposed a standardized methodology to monitor the active layer thickness (ALT) for long time to record the impacts of the climate change. Here we want to introduce a new CALM grid site installed in Continental Antarctica. In January 2019 a suitable non-glaciated place was chosen in Boulder Clay (Northern Foothills, North Victoria Land, Antarctica), a glacial ablation-sublimation till area almost adjacent to a previous CALM grid installed in 2001. The quadrat was designed with a 100-meter-long side, having a total of 121 nodes, with an inter-node spacing of 10 m. At 20 randomly distributed nodes 1 m deep boreholes were drilled and equipped with thermistors that record the temperature at 1 hour of interval at 2, 20, 30 and 60 cm of depth. This allows to extrapolate the depth of the 0 °C isotherm and assess the ALT. To validate the extrapolations, at the warmest period of the year also the classic frost probe penetration test was conducted at each node. The surficial grain size and albedo were measured at each node upon a 1 m plot. Moreover, the snow cover thickness has been monitored since 2019 with a frost probe at each node and, in addition, 2 time-lapse cameras were installed at the grid vertices in 2020. These, continuously taking 1 image every 4 hours, are able to detect the snow pack thickness at each node by knowing the height (pixel) of reference points. To assess the continuous spatial distribution of the topography, snow cover and surface temperature, at least one UAV photogrammetric survey has been being taken every year since 2019 with RGB and thermal cameras.

Validation of ERA5-Land reanalysis for monitoring permafrost dynamics on James Ross Island, Antarctica

Lucia Kaplan Pastíriková (Department of Geography, Faculty of Science, Masaryk University), Filip Hrbáček (Department of Geography, Faculty of Science, Masaryk University) and Michael Matějka (Department of Geography, Faculty of Science, Masaryk University).

Abstract

Polar ecosystems in high latitudes are among the most sensitive areas of the world that are currently threatened by climate change. It is important to study the change that occurs in these areas, which also affects permafrost in periglacial areas. The study sites (3 AWSs in a vertical gradient from 10 to 330 meters) are located on the Ulu Peninsula, in the northern part of James Ross Island, Antarctica. When studying the components of the cryosphere, regular monitoring of individual properties is crucial. Ground temperatures at depths of 5, 50, and 75 cm have been measured at sites since 2011, while air temperature began to be measured in 2004 (AWS-Johann Gregor Mendel). The main objective is to use the ERA5-Land reanalysis, which provides suitable parameters (e. g. air temperature, ground temperature) since 1950, with a horizontal resolution of 0.1°, i.e. 9 km. The reference period of measured data and reanalysis data for air temperature (2004/05 - 2020/21) shows a relatively strong correlation of 0.81 (RMSE 1.79) and for ground temperature (2011/12 - 2020/21) a correlation of 0.83 (RMSE 3.54). More accurate results can also be obtained on the basis of data correction from a reanalysis using regression, the average bias value for the reference period is 1.7 °C (AT) and 4.6 °C (GT). After validation, it can be seen from the differences between the data that ERA5-Land shows a more oceanic climate (than in reality), which is related to the underestimated temperatures in the summer season. These temperatures have a significant effect, especially on the active layer; therefore, we use the correction of the time series from the reanalysis for further use in the historical modelling of the permafrost table temperature, which is the subsequent subject of research.

Advances in differentiating surface covers within ice-free areas of the northern Antarctic Peninsula region

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Abstract

Ice-free areas within the Northern Antarctic Peninsula (NAP) region face both the threats of climate change and the impacts of increasing human activities. Higher temperatures and a greater frequency of precipitation occurring as rain rather than snow, accelerated permafrost and snow melting as well as land surface degradation processes increase erosion, weathering rates, and re-mobilization of minerals, nutrients and pollutants. The objective of this work was to characterise, using remote sensing techniques, different soil and surface covers on Deception Island, a volcanic island within the South Shetlands archipelago. The study included multisource data using spectral field and laboratory measurements obtained with a field spectroradiometer (ASD FieldSpec3) within selected test sites during field campaigns in 2017 and 2018 and compiled into the Northern Antarctic Peninsula region SPECtral library (NAPSPEC). Furthermore, multi- and hyperspectral satellite data from Landsat-8 (20/02/2020) and PRISMA (15/01/2023) sensors, respectively, were used to map the different surface covers within selected sectors. Results showed that dominant volcanic deposits interrelated with periglacial, aeolian and hydric processes were spectrally well differentiated using the field spectroradiometer. This allowed to thereafter classify pre-caldera deposits of hydrovolcanic tephra, post caldera deposits from more recent eruptions as well as alluvium deposits using both the hyper- and multispectral data. Pre-caldera spectra have a higher spectral reflectance as the outcrop material and weathered deposits are brighter, whereas the post-caldera deposits are in general much darker. High spectral resolution data was able to detect disturbed areas caused by slope movement or human activities around the research stations due to freshly eroded and compacted surface material. This integrated methodology using remote and proximal sensing techniques will be key to monitor the variability of land surface covers of periglacial and paraglacial environments within the framework of our recently initiated new project (GEOCHEM).

Cryogrid potential for modeling permafrost temperature in Maritime Antarctica (King Sejong Station borehole, Barton Peninsula, King George Island)

Joana Baptista (CEG/IGOT-ULisboa), Gonçalo Vieira (CEG/IGOT-ULisboa), Sebastian Westermann (Department of Geosciences, University of Oslo), Miguel Ángel de Pablo (Departamento de Geología, Geografía y Medio Ambiente. Universidad de Alcalá.) and Hyoungseok Lee (Korea Polar Research Institute (KOPRI).

Abstract

The thermal dynamics of permafrost is crucial for the ecosystems in the ice-free areas of the Antarctic Peninsula, where a strong long-term warming trend has been detected with an increase of 3.4 ºC in the MAAT since 1950. The consequences of this warming on past and future permafrost degradation are still not fully understood, mainly due to the short time span of borehole time series, only available after the mid to late 2000's. The Cryogrid community model is an adaptable toolbox for simulating the ground thermal regime and the ice/water balance for permafrost. A modular structure allows different combinations of classes that represent the surface conditions with or without the presence of snow and classes that represent the subsurface materials. Here we used permafrost temperature data from a borehole with 13m depth, installed in 2019 in Barton Peninsula (King George Island) to assess the Cryogrid potential and limitations. To evaluate the performance, the model was first used in its basic version with the class GROUND_freeW_ubtf, which considers a temperature boundary condition and was forced with air temperature observations. This approach allowed the definition of the parameters used on the version forced with ERA5 data that was run with different stratigraphy classes to find the more suitable structure for the borehole site. GROUND_freeW_ubtf_snow class associated with a representation of a surface with high mineral content and low water and soil content showed the best performance. This assessment was done through the comparison of model runs with observational data. This research was funded by PERMANTAR (PROPOLAR/FCT) and CEG/IGOT (UIDP/00295/2020). Joana Baptista is funded by the Fundação para a Ciência e a Tecnologia with a doctoral grant (2021.05119.BD). KOPRI is thanked for its logistical support.

Antarctic active layer: temperature changes and freeze / thaw dynamics.

Wojciech Dobiński (Uniwersytet Śląski w Katowicach).

Abstract

By definition the active layer (AL) always accompanies the permafrost (PF). In order to determine its thermal variability and freeze taw dynamics, it is necessary to determine the medium covered by the PF. In Antarctica, this is a problem because opinions about PF area, vary between 0.022 x 106 to 14 x 106 km^2. There are three possible cases of this discrepancy: 1. Traditional PF encompass an ice-free periglacial area: ca. 22,000 – 280,000 km^2, 2. PF covers the entire ice sheet as the lightest rock of the lithosphere (ca. 13,900,000 km^2) 3. PF covers the base of the ice sheet, because the temperature there can never be higher than for the pressure melting point (ca. 12,400,000 km^2)
AL is defined on the basis of the phase change of water, but its limit is often considered to be the temperature of 0oC on the permafrost table. Therefore, we can consider both thawing and freezing as activity, as well as temperature variability in the permafrost medium thermal profile. The latter reaches the level of zero annual amplitude (ZAA). with the exception of 3, in the other cases AL occurs both: as thermal and water phase change. In a glacial environment, it is the amount of surface ablation. The current definition of AL based on seasonal phase change is not compatible with the definition of permafrost based on negative temperature of the medium. This situation forces the separation of active, cryotic permafrost at the contact with AL, which seasonally thaws and freezes without the temperature rising above 0ºC. Definition of AL based exclusively on temperature variability in the medium eliminates this problem while unifying the geophysical understanding of both AL and PF.

SESSION 13

Permafrost and Society: how do changes in permafrost systems interact with social and cultural dynamics, economies, industries, and food systems

Conveners:

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Summary:

Near-surface permafrost degradation entails cascading effects, often with a severe impact on ecosystems and communities. Simultaneously, permafrost degradation is influenced by changes in vegetation, key animal species, and diverse human activities. While research efforts on geocryological and biophysical changes in permafrost systems are intensive, less is known on how these changes modify livelihoods, social and cultural dynamics, economies, industries, and food systems. In addition, we need to ask how economic activities – among them agriculture, animal husbandry, and extractive industries – have and are modifying permafrost landscapes. Transdisciplinary approaches are needed to understand how these systemsinteract, and how different processes aggravate or mitigate each other. This session aims to bring together scientists spanning multiple disciplines, e.g., physical, and social sciences, engineering, and life sciences, to come to a more nuanced understanding of the nexus of permafrost and land use in different regions of the northern hemisphere. Topics of interest in the context of changing permafrost systems include but are not limited to:

- The history and future of permafrost landscapes as cultural landscapes
- Settlements, buildings, infrastructure, engineering, architecture, and material culture
- Food systems for commerce and/or subsistence, including permafrost-agroecosystems based on farming, horticulture, floriculture, pastoralism (animal husbandry and reindeer herding), hunting and food-gathering activities
- Perceptions of environmental and socio-economic change in permafrost areas, and strategies of future land use
- Other economic activities, including local businesses as well as large-scale industrial activities of national and global economic significance

We welcome contributions using a range of methodological approaches including field-based observations, interviews, surveys, remote sensing, GIS, and modelling. Central to this endeavor is co-production of knowledge with Indigenous and local communities and scholars in all fields of science.

Increases in climate-related highway maintenance costs (1995–2022) throughout Yukon associated with recent climate change in a permafrost environment

Astrid Schetselaar (Carleton University) and Christopher Burn (Carleton University).

Abstract

Yukon's Transportation Maintenance Database records daily operator time and expenses for 61 activities on the 20 maintenance sections of the territorial highway network. The data are for 1995–2022. Four specific activities: snow clearing, icing control, washout repair, and landslide removal are directly climate related. The dominant activities vary around the network with physiographic context but in all maintenance sections climate-related expenses have increased, particularly since 2006. For Yukon's entire highway network, climate-related expenses have risen by $300,000 (constant $) per year over the last 16 years, or by about $4.8M in total. These expenses have become a greater proportion of the total operation and maintenance budget, increasing from 25 % to 44 %. Over the 465 km of the Dempster Highway, for example, constructed entirely in a permafrost environment, climate-related maintenance costs have increased by 53 % since 2006. Different maintenance activities are required in three distinct landscapes along this road. In the southern Klondike section, icing control is a major activity and expense due to the discontinuous permafrost, and has cost $100,000 annually since 2006. In the central Ogilvie section, the highway traverses steeply sloping terrain where slides and washouts have increased in frequency. Maintenance costs associated with these events have tripled in the last decade compared to the two previous decades and have been $2.5M in total since 2012. In the northerly Eagle Plains section, the dominant cost is snow removal due to unobstructed winds in a tundra environment where snow drifts frequently accumulate on the road. Snow removal costs in this section have increased by about 60 % since 2006. These results indicate that in a permafrost environment, the nature of surface and terrain conditions influences hazard management. They also demonstrate direct costs due to climate factors over several years.

The Permafrost-Agroecosystem Action Group: first results and future goals

Melissa Ward Jones (University of Alaska Fairbanks), Prashant Baral (International Center for Integrated Mountain Development), Nils Borchard (German Agricultural Society), Susan Crate (George Mason University), Bruce Forbes (University of Lapland), Benjamin Gaglioti (University of Alaska Fairbanks), Glenna Gannon (University of Alaska Fairbanks), Stephanie Grand (University of Lausanne), Joachim Otto Habeck (Universität Hamburg), Benjamin Jones (University of Alaska Fairbanks), Mikhail Kanevskiy (University of Alaska Fairbanks), Timo Kumpula (University of Eastern Finland), Amina Maharjan (International Center for Integrated Mountain Development), Nicholas Parlato (University of Alaska Fairbanks), Christopher Poeplau (Thünen Institute of Climate-Smart Agriculture), Mindy Price (University of California - Berkeley), Yuri Shur (University of Alaska Fairbanks), Tobias Schwoerer (University of Alaska Fairbanks), Andrew Spring (Wilfrid Laurier University), Jakob Steiner (University of Graz &International Center for Integrated Mountain Development), Jens Strauss (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Fulu Tao (Natural Resources Institute Finland & Chinese Academy of Sciences), Merritt Turetsky (University of Colorado Boulder), Mathias Ulrich (German Environment Agency), Adrian Unc (Memorial University of Newfoundland & McGill University), Mariana Verdonen (University of Eastern Finland) and Torben Windirsch (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research).

Abstract

Permafrost-agroecosystems encompass northern social-ecological systems which include both cultivation of arable permafrost-affected soils, and animal husbandry practices. These heterogeneous food and cultural systems are being affected by a warming climate. Examples include increasing opportunities for growing crops through longer growing seasons, as well as impacts on animals' local and long-distance migratory movements and their food sources. Furthermore, climate change driven permafrost thaw and thaw accelerated by land clearance is rapidly changing the biophysical and socioeconomic aspects of these systems. Therefore, an international collaboration encompassing experts from North America, Europe and Asia is working on increasing our understanding of permafrost-agroecosystems and contributing to the adaptation, resilience, and sustainability strategy of these rapidly evolving systems.
The International Permafrost Association Permafrost-Agroecosystem Action Group is composed of ~30 members from 7 countries. The objectives of our action group are to share knowledge and build networking capacities through meetings and webinar presentation as well as to collaborate on publications and produce the first geospatial dataset of permafrost-agroecosystems. Our poster presentation provides an overview of the group's activities including providing case studies from a range of high-latitude and high-altitude areas as part of a group manuscript in preparation and an update on our mapping activities.

The combined effects of climate change and infrastructure development on permafrost degradation in Point Lay, Alaska

Benjamin Jones (University of Alaska Fairbanks), Jana Peirce (University of Alaska Fairbanks), Billy Connor (University of Alaska Fairbanks), Mikhail Kanevskiy (University of Alaska Fairbanks), Yuri Shur (University of Alaska - Fairbanks) and Tracie Curry (Northern Social-Environmental Research).

Abstract

The Native Village of Point Lay (Kali) on the North Slope of Alaska has been identified as the second most permafrost thaw-affected community in the State. Issues associated with thawing permafrost and thermokarst have increased during the last decade resulting in the failure of critical infrastructure and increasing risks to life, health, and safety. We have been working closely with village community members as well as regional governance bodies to observe, study, and discuss the effects of thawing permafrost on homes and other critical infrastructure in the village. During our research, we have (1) studied permafrost properties and ground-ice conditions in three main terrain units, (2) mapped the community with a UAV to quantify the effect of thermokarst on village infrastructure, (3) conducted visual assessments on the effects of thawing permafrost on piling foundations, (4) interviewed residents on their observations and experiences of permafrost thaw to better understand the impact of landscape changes, and (5) shared research findings with local and regional engineers and planners to inform community-based decisions.
Most residential buildings in the village of ~330 people are built on pilings to reduce heat transfer to the ice-rich permafrost beneath the community, but nearly a third of pilings supporting village homes are founded in wedge ice. These homes have become increasingly unstable as thaw subsidence has reduced pile embedment from ~3 meters to as little as 1 meter. Underground water main breaks caused by differential subsidence as well as widespread surface water ponding due to failed culverts appear to have greatly accelerated ice-wedge thermokarst throughout the village. Our assessment of ground-ice content and comparative permafrost changes in the village and an adjacent undeveloped area showed that while climate warming has contributed to permafrost thaw in Point Lay, adverse impacts of infrastructure have also been a major driver of subsidence.

The possibility to ensure remote settlements food security by making the sun to cool the ice cellars and the permafrost to heat the greenhouses

Egor Loktionov (Northern (Arctic) Federal University), Elizaveta Sharaborova (Ecole Polytechnique Federale de Lausanne), Alexander Klokov (Bauman Moscow State Technical University), Alexey Maslakov (Lomonosov Moscow State University) and Ksenia Sotnikova (Lomonosov Moscow State University).

Abstract

The dependence of the remote settlements on supplies from the mainland has been becoming increasing over years for the sake of modern life comfort. Fuel and food are the most critical of these supplies. The dependence on fuel has been decreased recently in some areas with introduction of renewable energy sources. While for the food security the main issue is storage capacity. The traditional ice cellars, shallow ones particularly, have been degrading fast due to the global warming, thus, increasing the dependence on reefer containers powered by electricity. Interruptions in energy supply or refrigeration unit breakdown lead to losses of tons of food quite fast. For fresh fruits and vegetables preservation, refrigeration is not an option anyway; delivery (mainly aerial) is very expensive; production on site demands energy and is rather tricky. We have suggested a concept that could help to preserve the high storage capacity ice cellars while making temperature below -10ºC to ensure food quality. The heat diverted by a solar and wind powered heat pump from the ice cellar could be used to warm the greenhouses, and excessive electricity - to provide additional lighting. Our experiment has shown the yield of tomatoes and cucumbers could be increased by multifold in this way.

Thawing permafrost poses environmental threat to thousands of sites with legacy industrial contamination

Moritz Langer (Department of Earth Sciences, Vrije Universiteit Amsterdam), Thomas Schneider von Deimling (Permafrost Research Section, Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Sebastian Westermann (Department of Geosciences, University of Oslo), Rebecca Rolph (Permafrost Research Section, Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Ralph Rutte (Freelancer), Sofia Antonova (Permafrost Research Section, Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Volker Rachold (German Arctic Office, Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Michael Schultz (GIScience, Heidelberg University), Alexander Oehme (Permafrost Research Section, Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research) and Guido Grosse (Permafrost Research Section, Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research).

Abstract

Industrial contaminants accumulated in Arctic permafrost regions have been largely neglected in existing climate impact analyses. Our research has identified about 4,500 industrial sites where potentially hazardous substances are actively handled or stored in the permafrost dominated regions of the Arctic. Furthermore, we estimate that between 13,000 and 20,000 contaminated sites are related to these industrial sites. Ongoing climate warming will increase the risk of contamination and mobilization of toxic substances since about 1,100 industrial sites and 3,500 to 5,200 contaminated sites located in regions of stable permafrost will start to thaw before the end of this century. This poses a serious environmental threat, which is exacerbated by climate change in the near future. To avoid future environmental hazards, reliable long-term planning strategies for industrial and contaminated sites are needed that take into account the impacts of climate change.

Exploring Traditional Knowledge of Permafrost Change in the Gwich'in Settlement Area and Inuvialuit Settlement Region

Emma Street (University of Victoria) and Trevor Lantz (University of Victoria).

Abstract

Temperature increases four times faster than the global average are transforming permafrost landscapes in ways that impact local livelihoods, ecosystems, and infrastructure. This project seeks to better understand the implications in Gwich'in and Inuvialuit communities in the western Canadian Arctic. Using semi-structured interviews and ethnographic mapping in collaboration with land users, the goals of this project are to: (1) document Traditional Knowledge pertaining to permafrost, (2) map evidence of permafrost change in Gwich'in and Inuvialuit communities, and (3) work with local Hunters and Trappers Committees and Renewable Resource Councils to co-develop projects that are responsive to local needs and will inform decision making. Interviews for this project began in Paulatuk, Fort McPherson, and Inuvik in 2022. This presentation describes the Two-Eyed Seeing and community-driven participatory research methodologies that are driving this project and highlights some initial research findings. Findings from this study will contribute to permafrost knowledge and help amplify community needs related to permafrost change.

Drivers of dryness? Exploring the interaction of permafrost and land use in northern Mongolia

Joachim Otto Habeck (Institut für Ethnologie, Universität Hamburg), Avirmed Dashtseren (Permafrost Division, Institute of Geography-Geoecology, Mongolian Academy of Sciences) and Gansukh Tsogterdene (Permafrost Division, Institute of Geography-Geoecology, Mongolian Academy of Sciences).

Abstract

The interaction of permafrost and animal husbandry has recently been explored at several sites in Eurasia: such studies sketch out diverse effects of mobile pastoralism on permafrost dynamics and vice versa. However, regarding the interplay of farming and permafrost dynamics, literature is almost absent for Eurasia. To fill this gap, we conducted preliminary fieldwork in March 2019 in northern Mongolia: here, crop farming complements mobile pastoralism. We conducted interviews with land users in Khuder (Selenge Aimag) and documented vegetation and landscape features along a 2-km transect through the valley where Khuder is located. We pursued the hypothesis that tillage (ploughing) has led to changes at micro- and meso-level in this region at the border between continuous and discontinuous permafrost. Crop production was relatively intensive c. 30 to 60 years ago and continues at present, but its effect on permafrost degradation seems to be small. The number of herd animals have increased tenfold within the last three decades, but mobile pastoralism seems to have no significant effect on permafrost, either. Instead, extensive (and partly illegal) logging can be identified as the main driver of permafrost degradation in this region. This will lead to significant reduction of soil moisture, possibly resulting in rapidly worsening conditions for animal husbandry and agriculture in this and other areas of northern Mongolia.

Hazard mapping in the discontinuous permafrost zone of Fairbanks, Alaska, USA

Louise Farquharson (University of Alaska Fairbanks), Dmitry Nicolsky (University of Alaska Fairbanks), Anna Varvak (Soka University of America), Monika Calef (Soka University of America), Jennifer Schmidt (University of Alaska Anchorage), Vladimir Romanovsky (University of Alaska Fairbanks), Thomas Douglas (US Army Cold Regions Research and Engineering Laboratory Fort Wainwright) and Benjamin Jones (University of Alaska Fairbanks).

Abstract

As ground temperatures continue to warm at earth's high latitudes, permafrost thaw, ground-ice melt, and associated ground settlement pose significant hazards to northern communities and industry. Thaw of permafrost soils can decrease bearing capacity while settlement due to ground-ice melt can cause ground collapse (thermokarst) and changes in local hydrology that can lead to flooding. Here, we present a preliminary permafrost hazard map for the Fairbanks North Star Borough (FNSB), located in an area of discontinuous permafrost in Interior Alaska, USA. The FNSB is a region of ~20,000 km^2 with a population of ~100,000 and home to two military bases, several large gold mine operations, a University and the Trans Alaska Pipeline. To create the permafrost hazard map we combined ground-ice distribution with projections of permafrost thaw. We established the ground-ice distribution for a representative sub-sample ~ 2000km^2 of the borough using geologic maps showing the distribution of ice bearing units, industry bore holes and well logs, and manually digitized thaw features using a lidar digital elevation model. To extrapolate ground-ice values to the entire Borough we utilized a gradient-boosted decision tree aggregate model extent. This model used the units mapped in the sub-region to predict which ground-ice category an area would have based on a range of features including topography and vegetation. To establish areas where permafrost, and therefor ground-ice, is completely absent across the FNSB we numerically modelled the ground thermal regime using the Geophysical Institute Permafrost Model 2.0 (GIPL 2.0). For projections of ground temperature we combined the GIPL 2.0 model with a high-resolution ecotype-based approach. Temperature dynamics, talik development and the potential for thermokarst degradation is estimated for IPCC Representative Concentration Pathway scenarios 4.5 and 8.5. The modelling results show widespread thermokarst and talik formation across the region in 2020-2030, which is corroborated by present-day observations.

Microplastics in Snow in Antarctica

Evrim Celik Madenli (Suleyman Demirel University) and Sarper Sarp (Swansea University).

Abstract

Even though small plastic particles have been reported in the oceans as early as the 1970s, the research on microplastics started in 2004. Microplastic research in polar regions started 10 years after. Because there is not any nearby urban settlement, microplastic accumulation likelihood in the polar regions has been mostly ignored. Compared to the Arctic, the number of the studies in microplastics in Antarctica is far more less. The presence and impact of microplastics in Antarctica have not yet been fully explored and further studies are needed. This study aims to investigate microplastics in snow samples in the Antarctic. The samples were collected in Horseshoe Island during the Turkish Antarctic Science Expedition. Microplastics were determined using Fourier Transform Infrared Spectrophotometer, Scanning Electron Microscopy - Energy Dispersion Spectrometer, Dynamic Light Scattering, light microscopy, gas chromatography-mass spectrometry coupled pyrolysis, and gas chromatography-vacuum ultraviolet spectroscopy. This study is carried out under the auspices of the Presidency of the Republic of Turkey, supported by the Ministry of Industry and Technology, coordinated by TUBITAK MAM Polar Research Institute, and supported by a grant (122Y197) from the Scientific and Technological Research Council of Turkey, through the Support Program for Scientific and Technological Research Projects.

Numerical simulation of thermal regime of permafrost soils around ice cellar of Lorino indigenous community, Chukotka Autonomous Okrug, Russia

Ksenia Sotnikova (Faculty of Geography, Lomonosov Moscow State University, 119991 Moscow, Russia), Alexey Maslakov (Faculty of Geography, Lomonosov Moscow State University, 119991 Moscow, Russia) and Dmitry Evlanov (LLC STC Simmakers, 121205 Moscow, Russia).

Abstract

The modern-day climate warming in the Arctic has affected the state of permafrost and active layer and, consequently, the facilities constructed in frozen ground including ice cellars - a natural means of preserving food in conditions of transport isolation and total energy dependence on imported fuel. Modeling of thermal regime of permafrost soils around underground storages facilities plays an important role in the preservation of ice cellars, since this allows us to assess the impact of predicted climate changes and the effectiveness of various preventive measures to maintain the stability of ice cellars. In this investigation, we made an effort to simulate and predict the thermal regime of permafrost around the ice cellar, located in the community of Lorino, Chukchi Peninsula, NE Russia. Numerical simulation allowed to predict that the climate-induced changes of thermal state of permafrost around the ice cellar will result in noticeable but not critical changes in soil temperature for stability of the facility by the middle of the 21st century. The mean annual ground temperature will increase by no more than 1.0°C, whereas the maximal depth of seasonal thawing of the soil above the storage facility will increase on 1.2 to 2.5 m. In addition to predicting the dynamic of the thermal regime of permafrost soils due to climatic changes, an assessment of measures to manage the permafrost conditions was conducted.

Food Life History in Use of Natural Freezing and Snow - Traditional Preservation and Storage from the North to Japan -

Kazuyuki Saito (JAMSTEC), Michael Koskey (University of Alaska Fairbanks), Go Iwahana (University of Alaska Fairbanks), Yoko Kugo (University of Alaska Fairbanks), Yu Hirasawa (East Asia University), Shirow Tatsuzawa (Hokkaido University) and Theresa John (University of Alaska Fairbanks).

Abstract

This paper introduces and reports the results of the preliminary results on the “Food Life History of the North” project, focusing on varieties and commonness of the issues of cold storage that use the natural cold environment extending from Siberia and Alaska, the “divided twins” in Beringia, to the middle latitudes, namely Mongolia and Japan. Along the latitudinal and climatic gradient, the underground thermal states change from continuous and discontinuous permafrost in the higher latitudes to seasonally frozen ground. The ecosystem and major harvests also change accordingly. Consequently, the types and purposes of storage vary as well, from permanent cellars for all-season usage for food and ice for drinking to temporal pits for occasional storage on hunting, and to ice or snow houses that hold winter-time ice or snow for cool storage or use of ice to the next warm seasons. The usages and practices of their cold storage are consonant, directly or indirectly, with their lifeway and culture, but have been pressured under multiple environmental changes both in human societies and nature; modernization (e.g., use of electricity, global supply chains, monetary and market economy, changes in dietary) on one hand, and climate changes (warming and wetting) on the other. The related issues include security and sovereignty of food and energy, health, traditional and scientific knowledge, rituals and tourism, sustainability and resilience, autonomy, and worldviews. We conducted preliminary research in the above-mentioned areas for current issues in use such as dysfunctions or abandonment of cold storage facilities through questionnaires, recordings (oral interviews), literature, and aerial surveys. We will present the results from our preliminary surveys, and the overall outlook of the continued work in the areas extending from Beringia to the mid-latitudes. This project is conducted partly as a feasibility study at the Research Institute for Humanity and Nature (Japan), and as a project of the National Science Foundation (NSF 2133706, USA),

Forecast of economic damage from permafrost degradation in the coastal zone of the Pechora and Kara Seas

Svetlana Badina (Lomonosov Moscow State University).

Abstract

According to modern scientific forecasts, global climate change will lead to permafrost degradation with subsequent massive deformations and destruction of fixed assets in a significant part of the Russian Arctic to the second half of the 21st century. The coastal zone requires special attention, since the bulk of economic activity is concentrated within a relatively narrow strip of coastal land. The purpose of this research is to estimate two main types of economic damage from permafrost degradation, typical for the coastal zone of the Pechora and Kara Seas: 1 – destruction and deformation of buildings and structures, taking into account future investment projects; 2 – disappearance of a significant area of coastal lands as a result of thermal abrasion processes. Currently, there is no reliable and comprehensive information about the value of buildings and structures at risk area, as well as about the value of land plots. Consequently, in order to solve the tasks set, our own methods for assessing the probable economic damage were created. Based on publicly available information and additional author's calculations, a database of cadastral values of land plots and buildings located on the coastal zone of the study area was compiled. Integration of these data into the coastline retreat forecast up to 2050 made it possible to estimate the amount of probable economic damage for various coast sections. It was found that under a moderate warming scenario, the minimum direct damages from the loss of land area until 2050 will be about $48 million for the Pechora Sea coast and $57 million for the Kara Sea coast (in 2022 prices). Calculations showed that in the municipalities of the Nenets and Yamalo-Nenets Autonomous Okrugs, which have access to the sea, the maximum damage to buildings and structures due to permafrost degradation by 2050 could be more than $50 billion. The research was funded by Russian Science Foundation, grant no. 22-17-00097.

This abstract participates in the Outstanding PYRN Oral Communication / Poster Award.

Key risks of permafrost thaw in Arctic coastal Areas and Inuvialuit & Gwich'in First Nation knowledge holders' perceptions of a thawing relation

Susanna Gartler (University of Vienna).

Abstract

This paper introduces the outcomes of a trans-disciplinary risk analysis of permafrost thaw in Arctic coastal regions conducted within the Nunataryuk project and explores related understandings and perceptions of Indigenous land users and knowledge holders in Northwestern Turtle Island (North America). The highly localized, heterogeneous physical processes of thawing ground pose five key hazards to local populations: infrastructure failure, disruption of mobility and supply, a potential decrease in water quality, challenges for food security and exposure to infectious diseases & contaminants. All hazards have significant implications for health and wellbeing of both humans and their ecosystems, while also affecting recreation and being in nature, financial security, Arctic (Indigenous) cultures and languages, and fate control. People living on and with permafrost face numerous uncertainties in their everyday lives. In addition to a comprehensive, transdisciplinary risk analysis (drawing on a combination of scientific, local and Indigenous knowledges), semi-structured narrative interviews were conducted with Inuvialuit and Gwich'in First Nation citizens. Rivers, sea ice, lakes and the Arctic Ocean, as well as roads, trails and the tundra itself, and their susceptibility to minor changes in temperatures play a crucial role in the maintenance of historically highly mobile Inuit and First Nation ways of life. Through the ethnographic interviews uncertainties in relation to increased permafrost thaw and ways of navigating them become clearly visible, speaking to the resilience of Arctic Indigenous societies on the one hand, as well as to the loss of fate control in terms of climate changes on the other.

Towards a panarctic coastal settlements vulnerability and risk assessment framework based on satellite data.

Rodrigue Tanguy (b.geos Austrian Polar Research Institute), Bartsch Annett (b.geos Austrian Polar Research Institute), Barbara Widhalm (b.geos Austrian Polar Research Institute), Clemens Baeckmann (b.geos Austrian Polar Research Institute), Aleksandra Efimova (b.geos Austrian Polar Research Institute), Ingmar Nitze (Alfred Wegener Institute), Anna Irrgang (Alfred Wegener Institute), Pia Petzold (Alfred Wegener Institute), Gonçalo Vieira (Institute of geography and spatial planning - University of Lisbon), Julia Boike (Alfred Wegener Institute) and Julia Martin (Alfred Wegener Institute).

Abstract

Under a context of unprecedented and rapid temperature increase of the Arctic region, coastal communities are exposed to greater vulnerability from permafrost degradation, flooding events, and amplified coastal erosion, affecting infrastructure stability and indigenous livelihood. Pan-arctic coastal infrastructures were mapped from Sentinel-1/2 in imagery and shorelines change rates were retrieved for the 2000-2020 period from Landsat imagery using Deep Learning /Machine Learning methods. Permafrost (active layer thickness and ground temperature) time series are available from ESA CCI+ Permafrost. These Pan-arctic datasets were compared to high-resolution local data from satellite, aerial, in situ data and drone imagery for validation process. Combined, these datasets are used to assess pan-arctic coastal settlements vulnerability and risks associated to shoreline change rates. This work is part of the ESA EO4PAC project aiming to provide a range of satellite derived information, including coastal changes and infrastructure in the proximity, for the next generation of the Arctic Coastal Dynamic Database (ACD; Lantuit, et al. 2012).

A web-based portal for serving geospatial information on permafrost disturbances to permafrost communities

Tillmann Lübker (Alfred Wegener Institute for Polar and Marine Research), Ingmar Nitze (Alfred Wegener Institute for Polar and Marine Research), Sebastian Laboor (Alfred Wegener Institute for Polar and Marine Research), Anna Irrgang (Alfred Wegener Institute for Polar and Marine Research), Hugues Lantuit (Alfred Wegener Institute for Polar and Marine Research) and Guido Grosse (Alfred Wegener Institute for Polar and Marine Research).

Abstract

Permafrost is warming at a global scale, yet land surface change associated with abrupt permafrost thaw strongly affects permafrost communities and Arctic research stations at the local scale. In the ERC PETA-CARB, ESA CCI Permafrost, and NSF Permafrost Discovery Gateway projects, remote sensing time series were used to detect and map permafrost disturbances at high spatial resolution across large regions to quantify landscape change, hydrological dynamics, and permafrost vulnerability. The multitude of geospatial datasets that were produced in these projects provide useful information also for local scales. Hence, the question arises how such large and complex science datasets can be made available for permafrost communities and Arctic research stations to deal with the issues and challenges they experience with land surface disturbances and permafrost thaw at the local scale. The geospatial datasets are published according to the FAIR principles and are available to the research community via well-established channels such as the GTN-P database, the PANGAEA world data centre, and the geodata portal Arctic Permafrost Geospatial Centre (APGC). Currently, the scientific data is not readily designed and presented to be interpreted by non-scientists and non-experts. We are designing a tailored web-based portal specifically targeting non-scientific user communities, stakeholders, and rightsholders. We will develop interactive maps and adequate cartographic visualizations for near real-time information on land surface changes, hot spots of disturbances, and potential areas of active permafrost thaw. While focusing on the local scale, the data will be explorable up to the panarctic scale and may open new avenues for understanding permafrost change for the general public. Through planned consultations with local permafrost communities and stakeholders we aim to ensure that their actual information needs are met.

SESSION 14
Open session on rock glaciers

Conveners:

- **Cécile Pellet.** *Department of Geosciences, University of Fribourg;* cecile.pellet@unifr.ch
- **Line Rouyet.** *NORCE Norwegian Research Centre AS, Tromsø;* liro@norceresearch.no
- **Yan Hu.** *Institute of Environment, Energy and Sustainability, the Chinese University of Hong Kong;* huyan@link.cuhk.edu.hk

Summary:

Rock glaciers are characteristic landforms associated with mountainous periglacial landscapes and generated by gravity-driven creep of (ice-rich) frozen ground (permafrost). Their location, characteristics and evolution are controlled by a combination of environmental (e.g. internal structure, topography, lithology, debris loading) and climate-dependent factors (e.g. thermal and hydrological regimes). Rock glaciers are highly relevant in various fields of research, such as geomorphology, hydrology, geohazards, paleo-permafrost and climate impact studies. Despite their significance, their complex interactions with environmental variables and the impact of climate change on their evolution remain incompletely understood. In this open session, we welcome contributions from the entire rock glacier community reflecting the different focuses and ranging from observations to modelling, from geophysical to remote sensing methodologies, from site-specific to regional studies in diverse geographic regions of the World. We would especially like to stimulate discussions about innovative methodologies and interdisciplinary approaches, aiming to improve the understanding of past and/or present processes and to assess future rock glacier evolution.scholars in all fields of science.

Prediction modelling of rock glacier distribution in Norway

Karianne Lilleøren (University of Oslo), Bernd Etzelmuller (University of Oslo) and Harald Hestad (Universtity of Oslo).

Abstract

Based on an existing rock glacier inventory, we have fitted a statistical model to predict where and at what time periods rock glaciers have existed in Norway. Knowledge on rock glacier activity and distribution is valuable to understand and explore the development of permafrost throughout the Holocene. The prediction model uses explanatory variables like air temperature, direct solar radiation, topographic roughness and curvature to model potential areas for rock glacier existence at present, but also during other time periods of the Holocene and late-Pleistocene. The latter has been explored by adjusting the mean annual air temperature in the model to different climatic conditions during the Younger Dryas (YD), the Holocene thermal maximum (HTM) and the Little Ice Age (LIA).

Our model indicates that at present, intact rock glaciers exist at 300 to 400, 600 to 800, and 1300 to 1500 meters above sea level in Finnmark, Troms and southern Norway, respectively.

The adjusted model runs predict that rock glaciers could have existed in 1) low-lying, coastal areas in a YD climate, 2) areas at or inside the YD ice sheet margins in an LIA climate, and 3) at high elevation continental areas during the HTM. From these results, we suggest that rock glaciers that were predicted to have existed in the YD were probably also initiated during this time period and remained active a couple of thousand years until they turned relict before or during the Preboreal or the HTM. Rock glaciers attributed to an LIA climate were probably formed after the HTM, and rock glaciers associated with an HTM climate have likely existed continuously since the YD, throughout the HTM and until today as either active or inactive landforms.

Rock-glacier evolution over Holocene time scales : a new modelling approach

Benjamin Lehmann (ISTerre University Grenoble Alpes), Robert S. Anderson (INSTAAR, Colorado University) and Pierre G. Valla (ISTerre University Grenoble Alpes).

Abstract

Rock glaciers are among the most common cryospheric landforms in high and mid-altitude mountain ranges. On time scales ranging from years to millennia, their activity strongly influences the hydrology and geomorphology of alpine environments. Because they represent a visible expression of mountain permafrost and a considerable storage for water in the form of ground ice, rock glaciers are important forms in the geomorphological and hydrological evolution of mountain systems, especially in the context of the current climate crisis. Also, rock glaciers reflect paleoclimatic conditions and can be considered as important players in the erosional processes affecting high mountain slopes. However, our understanding of rock-glacier dynamics at different time scales still requires improvement for a better assessment of their current to future evolution. In this study, we use a numerical modelling approach developed to connect the multiple timescales mentioned above and to quantitatively assess the physical processes operating in rock-glacier dynamics and long-term landscape evolution (Anderson et al., 2018). In this approach we employ a 2D flowline model of the evolution of a rock glacier - headwall system according to the elevation distribution and the longitudinal horizontal distance. In this approach, the rock glacier gains mass thanks to rock-debris and snow avalanches, creeps downvalley through internal ice deformation, while the mass loss is controlled by climatic forcings and their interactions with the different vertical components of a rock glacier, from rock debris, interstitial ice mixed with debris and pure ice. The model is first used for synthetic numerical simulations, investigating the rock-glacier response times to different situations (climate change or variations in rock-debris input, etc.), and is then tested against real case conditions for the Vallon de la Route rock-glacier system (Ecrins massif, western European Alps) where we acquired constraints on both the geometry of the landforms, the modern field displacement, and the integrated Holocene activity from geochronology (Lehmann et al., 2022). Our ability to model the temporal evolution of the rock glacier-headwall system over Holocene time scales will improve our understanding of how high mountain landscapes react to both long-term and short-term climatic fluctuations.

Anderson, R. S., Anderson, L. S., Armstrong, W. H., Rossi, M. W., & Crump, S. E. (2018). Glaciation of alpine valleys: The glacier – debris-covered glacier – rock glacier continuum. Geomorphology, 311,127–142. https://doi.org/10.1016/j.geomorph/2018/03/015

Lehmann, B., Anderson, R. S., Bodin, X., Cusicanqui, D., Valla, P. G., and Carcaillet, J. (2022). Alpine rock glacier activity over Holocene to modern timescales (western French Alps). Earth Surface Dynamics, 10, 605–633. https://doi.org/10.5194/esurf-10-605-2022

Cataloguing of rock glaciers in dissimilar regions of the Mackenzie Mountains: Testing for possible semi-automated detection of rock glaciers using topographic data

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Abstract

Rock glaciers have been the subject of extensive research in recent years, due to their potential to serve as indicators of past and present climate conditions and their potential impacts on water resources. Compilation and analysis of collected data on the location, size, and characteristics of rock glaciers within the Mackenzie Mountains was used to build a rock glacier catalogue that will serve as a valuable resource for future research and monitoring efforts. The research also aims to map the spatial distribution of rock glaciers using optical imagery and to develop a semi-automated detection model using Generalized Additive Models (GAMs) in R. The model will incorporate attribute data, such as solar radiation, aspect, topographic position index, slope, elevation, and lithology as controls for rock glacier development. Topographic data was collected in multiple regions of the Mackenzie Mountains and extracted using a 30m digital elevation model (DEM). The results of this study have the potential to improve our understanding of rock glacier distribution and dynamics in the Mackenzie Mountains and could also be applied to similar mountainous regions.

Flow Velocity Measurements on Hochebenkar Rock Glacier

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Abstract

Rock glacier kinematics have increasingly drawn the interest of the scientific community in the past two decades, as many rock glaciers in the Alps have shown accelerating trends. This study investigates rock glacier destabilization based on the results of a unique in situ and remote sensing-based monitoring network focused on the kinematics of the rock glacier in Äußeres Hochebenkar (Austrian Alps). At this site in-situ measurements of block displacement have been carried out since the 1950s. Here, they have been combined with 14 digital surface models covering a 68 year time period. These surface models are derived from historical aerial imagery and recent airborne and uncrewed aerial vehicle-based laser scanning (ALS, ULS). Using image correlation techniques, we derive velocity vectors from the digital surface models, thereby adding rock glacier-wide spatial context to the point scale block displacement measurements. We investigate both the flow velocity, surface elevation change and overall rock glacier destabilization, as well as potential rotational components. The time series shows two cycles of destabilization in the lower section of the rock glacier. The first lasted from the early 1950s until the mid 1970s. The second began around 15 2017 after approximately two decades of more gradual acceleration and is currently ongoing. Both destabilization periods are characterized by high velocities and the development of morphological destabilization features on the rock glacier surface. Acceleration in the most recent years has been very pronounced, with velocities reaching 20-30m/a in 2020/21. These values are unprecedented in the time series and suggest highly destabilized conditions in the lower section of the rock glacier, which shows signs of translational as well as rotational, landslide-like movement. Due to the length and granularity of the time series, the cyclic destabilization process at Äußeres Hochebenkar rock glacier is well resolved in the dataset.

New insights into mountain permafrost occurrence and characteristics in the Southern Carpathians through geophysical surveying, temperature and surface velocity measurements

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Abstract

Because the mountain cryosphere is changing rapidly due to ongoing climate changes, the study of mountain permafrost has become more relevant in the last decades. However, in marginal periglacial environments (such as the Southern Carpathians), where permafrost occurrence is patchy and site-specific characteristics highly control permafrost preservation, detailed information on permafrost occurrence and characteristics still needs to be improved. This paper aims to present the main permafrost-related findings in the Southern Carpathians, which were obtained in the framework of the ClimaLAND project (2020-2023). Recent geophysical measurements (electrical resistivity tomography – ERT and refraction seismic tomography - RST) confirmed that the frozen layers reach only a few meters thick in the Galeșu (Retezat Mountains) and Pietroasa (Făgăraș Mountains) rock glaciers. Petrophysical 4-phase modelling based on co-located ERT and RST profiles indicates the highest ice content (~ 50 %) at 5-10 m depth in both rock glaciers . The layer showing ice-rich permafrost is between 5 m (Galeșu) and 8-10 m (Pietroasa) thick. Because the deforming frozen layers are very thin, the observed surface displacements rates are extremely low (1-3 cm/yr) in most of the rock glaciers in the Retezat Mountains. Ground-surface thermal (GST) measurements were used to examine the energy exchange fluxes at sites where permafrost occurrence is likely. Very low ground surface temperatures during late winter were recorded at the surface of slow-moving rock glaciers, suggesting permafrost conditions. Permafrost occurrence in the Southern Carpathians is limited to elevations > 2000 m, characterised by coarse openwork debris and reduced solar radiation income.

Unveiling the origin of rock glaciers in the Tröllaskagi peninsula (Iceland) through high-detailed geomorphological mapping: Lambárdalur and Fremri-Grasárdalur cirques

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Abstract

In this work, a detailed geomorphological map of two glacial cirques (Lambárdalur and Fremri-Grasárdalur) located in Tröllaskagi peninsula (northern Iceland) has been produced. Our purpose is to investigate the origin of a remarkable diversity of rock glaciers in these small cirques. According to previous research, most of the glacial and periglacial landforms were generated after the main deglaciation of the valley (~11 ka). This cartographical project has combined field work (summer of 2022), visual inspection of stereo pairs from 2019, and manual and digital (2D) mapping. The final design was digitized over a high-resolution Digital Surface Model (2 m cell size) and was supported by a 3D view of the study area. The main geomorphological units identified in both cirques are five debris-covered glaciers systems (two in Lambárdalur and three in Fremri-Grasárdalur). Their upper sectors still preserve small debris-free ice surfaces, separated from the debris-covered sectors by elongated depressions. The frontal sectors of these debris-covered glaciers have turned into glacier-derived rock glaciers, some of them with well-developed ridges and furrows, but others only with incipient crests. Smaller talus-derived rock glaciers connected to the talus and former collapsed debris-covered glaciers have also been mapped in the lateral walls of the cirques. Most of them are embryonic landforms, except for one tongue-shaped rock glacier in the Fremri-Grasárdalur cirque. Digital visualization techniques and the high-detailed map allowed us to infer several recent deglaciation phases based on the relative position of the formations: 1) glacial retreat towards the cirque head; 2) the formation of a first generation of debris-covered glaciers at the cirque bottom (now collapsed) and talus-derived rock glaciers in the lateral sectors; 3) the subsequent formation of a new generation of debris-covered glaciers, whose fronts evolved to glacial-derived rock glaciers, and new talus-derived rock glaciers at the foot of the headwalls.

Nautárdalur rock glacier (Northern Iceland) dynamics between 1994 and 2021 through the analysis of aerial photographs

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Abstract

The aim of this work is to study the surface dynamics of the Nautárdalur rock glacier, located in the eastern sector of the Tröllaskagi peninsula (Northern Iceland) by comparing historical aerial photographs from 1994 and 2021. This rock glacier is about 605 m long and extend between 1190 and 990 m a.s.l., where its steep front (over than 65 m-high) is located. Previous research on the displacement of the rock glacier surface from 1977-1994, was done with theodolite measurements of fixed control points distributed along three transects perpendicular to the glacier. In this work, we have used a digital photogrammetric workstation to (i) identify and locate the xyz coordinates of several boulders confidently identifiable on aerial photographs from 1994 and 2021, and (ii) plot the contour lines from both dates (2 m interval). A total of 261 boulders were identified on both images; and used to obtain the displacement vectors and elevation changes over this time interval. To constrain the horizontal/vertical displacement uncertainties, additional 57 stable relief elements were identified outside the rock glacier. The results show a mean horizontal displacement of 3.64 m over this 27-year interval, accounting for a mean velocity of 0.135 m yr-1, with a range of 0.006-0.464 m yr-1. Horizontal displacement barely has been detected at the lateral ridges of the glacier, while it increases towards the central sector and the frontal parts, where maximum instability (>0.3 m yr-1) was measured. Overall vertical displacement is largely negative, with a boulder subsidence between -0.25 and -7.09 m over the 27-year interval. The highest negative values are also clustered in the rock glacier front, where 95 % of the surface is sinking. Compared to previous research, we report a more limited flow than previous works, but agree on that the frontal sector is the most active of the rock glacier.

Mapping and inventorying rock glaciers on the Tibetan Plateau from Planet Basemaps using deep learning

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Abstract

Rock glaciers are geomorphologically valuable indicators of permafrost distribution and form potentially important hydrological resources in the context of future climate change. Despite the widespread distribution of permafrost on the Tibetan Plateau and its reputation as the "water tower of Asia", this region lacks a complete inventory and systematic investigation of rock glaciers. In this study, we develop a deep-learning-based approach for mapping rock glaciers on the Tibetan Plateau. A powerful deep learning network, DeepLabv3+, is trained using Planet Basemaps as training imagery and multi-source rock glacier inventories as training labels. The well-trained model is then used to map new rock glaciers. The visually consistent and cloud-free properties of Planet Basemaps are crucial for developing comprehensive maps of rock glacier distribution; and the rock glacier inventories from multiple regions can improve the volume and diversity of the training dataset. The deep learning mapped results present strong identification and acceptable boundary delineation of rock glaciers, indicating that the deep learning model could serve as a useful tool for facilitating the inventory of rock glaciers over vast regions. Based on the deep learning outputs, we compile 4233 rock glaciers on eight subregions of the Tibetan Plateau, which are widespread in the surrounding regions while being scarcely distributed in inner areas. Talus- and glacier-connected rock glaciers are two major classes, which are dominant on the southeastern and densely distributed on the northwestern Tibetan Plateau, respectively. The regions with steep slopes are favored by rock glacier clusters with high density, and glacier-abundant regions tend to breed large rock glaciers. The proposed rock glacier mapping method effectively speeds up inventorying efforts, which will be used to map and inventory rock glaciers on the entire Tibetan Plateau. The complete inventory will offer a significant contribution to the global catalog and serves as a benchmark dataset for modeling and monitoring the state of permafrost in a changing climate.

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Timing of the partial transformation of the glacier fronts into rock glaciers in a paraglacial context in the Svarfaðardalur cirques, Northern Iceland

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Abstract

In this work, the evolution of three small glacial cirques in the Svarfaðardalur area (Vatnsdalur, Búrfellsdalur and Teigardalur), in the Tröllaskagi peninsula, (Northern Iceland) is studied. Firstly, we conducted the geomorphological mapping of each cirque, and a number of glacial and periglacial features have been identified, namely: push moraines built by debris-free glaciers, debris covered glaciers, and rock glaciers. Strikingly, this great variety of landforms was observed along the same glacier front, despite its small size (~ 2 km long). To reconstruct and understand the spatiotemporal patterns of this evolution, multitemporal aerial photographs (from 1946 to 2019) and dating through lichenometry and cosmic-ray exposure dating (36Cl) have been used. Exposure dating of prominent push moraines in the tributary valleys show that the glaciers reached their maximum Holocene extent during the Preboreal (11.5-11.3 ka). Since then, the glaciers dramatically shrunk and retreated during the mid-Holocene. The reconstructed spaciotemporal pattern indicate Neoglacial (from ~ 4 ka) advances that approached the Preboreal positions during the Late Holocene. Many of these Late Holocene advances were more extensive than those of the Little Ice Age (LIA). They must have been driven by climatic causes, though some of the moraines and advances were result of surging processes. Some sections of the glaciers were transformed: some evolved into rock glaciers and/or debris-covered glaciers, and in both cases remained static since then. The rest of the glacier sections still remain debris-free, and seems sensitive to climatic oscillations as they advanced and especially retreated over the last decades. The current study shows that a single glacier can be partially transformed into a rock glacier in a paraglacial context, while the rest of the glacier keeps its debris-free glacier dynamics.

Towards practical guidelines for Rock Glaciers inventories (RoGI) : a new 'user-friendly' GIS tool for training the community.

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Abstract

Rock glaciers are creeping permafrost landforms that constitute an essential geomorphological heritage of the mountain periglacial landscape. They are often used as a proxy for permafrost occurrence. Rock glacier inventories are therefore valuable to complement direct measurements and models in mountains where the permafrost distribution is highly heterogenous due to topographic variability and local conditions.

In a context where open access and high-quality remotely sensed data is constantly increasing, there is a need for the scientific community to develop standard guidelines for rock glacier inventories (RoGI). The International Permafrost Association (IPA) Action Group on Rock Glacier Inventories and Kinematics (RGIK) has worked for five years since its initiation at the European Conference on Permafrost (EUCOP5 2018) in Chamonix. The RGIK community has especially focused on the definition of guidelines for the generation of rock glacier inventories (RoGI).

The proposed poster will present and promote a new QGIS tool developed in the framework of the RGIK Action Group in order to provide an "all-in-one" training exercise. This exercise aims to put into practice the RGIK guidelines for the identification, delineation and characterization of rock glaciers. It will be freely downloadable online at the time of the EUCOP conference (www.rgik.org).

The GIS tool proposes a dataset in the Goms region (Switzerland) with ortho-imagery, InSAR data (for kinematic attribute), hillshade (multiple aspects) and vector layers (primary markers and outlines) for the inventorying process. These vector layers are pre-formatting and allow a semi-automatic filling of attributes in a dedicated dialog box. The GIS Tool is provided with all needed instructions, references to key documents and "GIS Tips". This first GIS Tool in Goms region will serve as template for other examples in different regions of the world.

Prospective use of Schmidt-hammer in relative-age dating of rock glaciers (northern Iceland)

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Abstract

In this study we apply Schmidt-hammer relative dating to the glacial and periglacial landforms in the Lambárdalur and Fremri-Grasárdalur cirques (Tröllaskagi peninsula, northern Iceland) to understand the glacial-to-periglacial transition inferred from geomorphological mapping. Both cirques host debris-covered glaciers, two in Lambárdalur and three in Fremri-Grasárdalur. Those formations show clean ice in their highest sectors and turn into rock glaciers in their frontal and, occasionally, lateral parts. Collapsed debris-covered glaciers and talus rock glaciers are present in lower parts of the cirques, while erratic boulders and polished thresholds occurs at their junction with the main valley. To reconstruct the glacial-to-periglacial transition, the mapped landforms were surveyed with the Schmidt-hammer in 34 survey points selecting 30 blocks in each station and performing three impacts in each boulder. The mean rebound (R-) values show relevant differences amongst the geomorphological units. Thresholds and erratic boulders at the mouth of the cirques show the lowest R-values (51-56). Slightly higher R-values (56-61) are observed in talus rock glaciers and collapsed debris-covered glaciers. Debris-covered glaciers show R-values of 59-62 at their frontal parts (already transformed in glacial-derived rock glaciers). R-values of 61-67 were measured in their middle parts, and 69-71 close to the debris-free ice sectors. These data show different phases of the cirque deglaciation: 1) glacial retreat from the main valley towards the headwalls; 2) formation of debris-covered, now collapsed, and talus rock glaciers in the lower and lateral parts of the cirque; 3) the formation of a younger and extensive generation of debris-covered glaciers in the upper parts of the cirques and rock glaciers derived from them; 4) recent glacial advances of the debris-free sectors overlapping the debris-covered ones. Future ^{36}Cl cosmogenic-ray exposure dating could provide more information on the deglaciation pattern of these cirques, including the origin and evolution of rock glaciers.

Deciphering seasonal surface dynamics of rock glaciers in the Central Alps using DInSAR time series analysis

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Abstract

Permafrost is currently undergoing strong changes due to rising ground and air temperatures in mountainous regions. Surface movement is one key indicator for the existence of mountain permafrost that results in the formation of characteristic landforms such as rock glaciers. As such, continuous observation of rock glacier movements can indicate ongoing changes in permafrost affected mountain environments. Recently, the International Permafrost Association started to promote Differential SAR Interferometry (DInSAR) for the detection of permafrost-induced displacements. DInSAR uses the phase difference between two Synthetic Aperture Radar (SAR) acquisitions to detect distance changes of the surface towards the sensor and is capable of detecting relative displacements of a few millimetres along the so-called Line of Sight (LOS). Recent studies highlight the high potential of Sentinel-1 C-Band SAR for monitoring rock glacier kinematics; however, the applicability of DInSAR especially for smaller areas and locations with heterogeneous displacement patterns is still unassessed. We address this shortcoming by generating and analysing five years of Sentinel-1 DInSAR time series to detect small-scale displacement patterns of four [one] high alpine permafrost environments located in Grison, Switzerland [Tyrol, Austria] on a weekly basis. Our approach is based on a semi-automated procedure using open-source programs such as SNAP (SeNtinel Application Platform) by ESA and PyRate by GeoScience Australia. The workflow provides data with a ground sampling distance of 5m, and as such allows capturing small-scale variations of surface deformations. We compared the aggregated DInSAR displacement with movement derived from feature tracking by using high-resolution airborne orthophotos and found good agreement between these two independent approaches (Pearson R: 0.45 – 0.8, RMSE: 4.3 – 11cm/a). Moreover, the DInSAR time series unveils spatio-temporal variations and distinct seasonal movement dynamics, which enhances the monitoring of permafrost creep and degradation and, thereby, helps to assess the future evolution of permafrost under changing climatic conditions.

Is the present global warming transforming the debris free glaciers into rock glaciers or debris covered glaciers in the Tröllaskagi Peninsula, Northern Iceland?

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Abstract

In this study we analyse the evolution of five debris-free glaciers in the Tröllaskagi peninsula, Northern Iceland. Previous research has shown that most of the 160 glacier existing now in the area, were debris-free glaciers at the beginning of the Holocene. However, except for the five ones studied here, the glaciers in the area eventually evolved to rock glaciers or debris-covered glaciers during the mid-Holocene. The aim of the study is to verify whether the current intense warming is increasing the debris-cover of the referred glaciers as their volume decreases and the vertical walls of the cirques are getting more exposed, and therefore enhancing the slope processes. For this purpose, the extent of these glaciers, as well as their area covered by debris, have been delimited and measured over multi-temporal aerial photographs (1945, 1984, 1995, 2005, 2016 and 2019). These data have been compared with the recent climatic trends from the Akureyri weather station (1945-2019 series). The results show that the studied glaciers have shrunk between 6 % and 14.8 %, compared to their extent in 1946, especially in the last two decades, characterized by a sustained warming. During this time, all glaciers have also undergone an increase in the extent of their debris-covered surface, between 0.6 and 8.2 %. The glacier with the smallest debris cover increase corresponded to that with the largest frontal retreat since (492 m), while the glacier with the greatest debris-covered area has advanced 110.4 metres from its position in 1946. On the other hand, the glaciers that have increased their debris surface are closely related to the vertical development of their adjacent deglaciated walls. If the current climatic trend continues in a paraglacial context, these glaciers will tend to become debris-covered glaciers or rock glaciers.

Inventory of rock glaciers in the Alt Pirineu Natural Park (Central Pyrenees)

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Abstract

This communication presents a detailed inventory of the distribution of rock glaciers and protalus lobes existing in the Alt Pirineu Natural Park (800 km^2), southern Central Pyrenees. These geomorphological features were identified using high-resolution optical and infrared orthophotos (25 cm), Google Earth 3D images and a digital terrain model (2x2 m) interpolated from airborne laser scanning (LIDAR). For a better understanding of the origin and development of these features, we also included an accurate characterization of the distribution and morphometrical properties of protalus lobes and debris-covered (paleo)glaciers identified in the Natural Park. We mapped 133 rock glaciers covering a total area of 5,8 km^2, 59 protalus rampart (total area of 0,3 km^2) and 82 debris-covered glaciers (total area of 4,5 km^2). The majority of rock glaciers are classified as relict, and are located between 1643 and 2550 m. Only six rock glaciers at elevations between 2560 and 2800 m were identified as potentially active. The elevation difference of the rock glacier fronts (ca. 1200 m) suggests that their formation and development is associated with different morphogenetic phases, from the onset of the last deglaciation to present-day dynamics. They are mostly distributed in northern slopes (68.4 % of the total), show an average surface of 4.3 ha (sizes between 0.3 and 40.4 ha) and an average length of 202 m (between 45 and 985 m). The most extensive landforms correspond to polymorphic features, with a complex distribution of furrows and ridges, and occasionally include overlapping features related to different generations of rock glaciers. They are frequent in slates and quartzites settings, very abundant in granitic massifs and absent in areas alternating limestone and slate rocks. Based on geomorphological and morphostratigraphic criteria, we interpret that 60 % have a cryogenic origin and only 8 % are glacigenic, while the other 32 % of the features developed from debris-covered glaciers.

A novel combination of geophysical techniques for monitoring ice and water contents in ice-rich alpine rock glaciers

Alexander Bast (WSL Institute for Snow and Avalanche Research SLF, Alpine Environments and Natural Hazards), Chasper Buchli (WSL Institute for Snow and Avalanche Research SLF, Management of Facilities Davos / Experimental Facilities), Jacopo Boaga (Department of Geosciences, University of Padova), Mirko Pavoni (Department of Geosciences, University of Padova), Samuel Weber (WSL Institute for Snow and Avalanche Research SLF, Alpine Environments and Natural Hazards) and Marcia Phillips (WSL Institute for Snow and Avalanche Research SLF, Alpine Environments and Natural Hazards).

Abstract

Active rock glaciers characterise the face of mountain permafrost and have been in the focus of research for decades. In the European Alps, the creep rates of rock glaciers drastically increased. That galloping is attributable to climate change, the associated rise in temperature and, thus, to changes in the unfrozen water content within the permafrost. Although research has recently gained much knowledge, there is still a gap in the quantitative assessment of the waters' role in rock glaciers. To meet this challenge, we drilled three vertical boreholes in close vicinity at the Schafberg rock glacier (46°29'50.391" N, 9°55'34.779" E; 2'750m asl) in August 2020, recorded their stratigraphy, and equipped one of the boreholes with temperature sensors and piezometers for water pressure (measuring interval 2h), and the other two with ERT multi-core cables (24 electrodes, 0.5 m spacing). A resistivity meter collects daily data for cross-borehole electrical resistivity (ERT) soundings (dipole-dipole skip two array; 1'494 data points/d). The ERT models confirm the recorded, locally heterogeneous stratigraphies. While ground temperatures below 4.5 m depth are close to 0 °C throughout the year, the ERT data show lateral and vertical differences caused by varying water-ice ratios. Most striking are the low seasonal resistivity changes in areas characterised by wet sludge layers. These contain ice crystals, evidencing the substantial content of unfrozen water that can occur in rock glaciers close to their melting point. Piezometer data likewise indicate differences in water and ice contents by seasonal pressure variations in the wet layers. Our contribution highlights the novel application of combined borehole temperature, piezometer and cross-borehole ERT data to gain new insights into rock glaciers' water and ice contents and to detect changes in ice-rich permafrost to contribute towards a better understanding of climate-related factors driving rock glacier kinematics and water availability.

A rock glacier inventory integrating geomorphological mapping and Sentinel-1 satellite SAR interferometry in western South Tyrol, Italy

Francesco Brardinoni (University of Bologna), Aldo Bertone (University of Bologna), Nina Jones (Gamma Remote Sensing AG), Volkmar Mair (Ufficio Geologia e Prove Materiali, Provincia Autonoma di Bolzano), Riccardo Scotti (Servizio Glaciologico Lombardo) and Tazio Strozzi (Gamma Remote Sensing AG).

Abstract

Geomorphologic rock glacier inventories, traditionally compiled through visual inspection of optical imagery and limited confirmatory fieldwork, are critical tools for constraining over large spatial scales the topographic and climatic thresholds associated with (current or past) mountain permafrost. This procedure, however, which operationally involves rock glacier identification, manual delineation and a qualitative assessment of activity (i.e., intact and relict), yields a certain degree of variability among operators. In this context, satellite radar interferometry (InSAR), by detecting cm-to-m rates of surficial deformation over seasonal to annual scales, affords a more reliable, quantitative way for evaluating rock glacier activity. In this work, starting from the compilation of a geomorphologic rock glacier inventory (n = 789) in western South Tyrol, we integrate relevant kinematic information exploiting Sentinel-1, InSAR data acquired between 2018 and 2019, with interferograms computed over 6, 12, 24, 30, 36, 42, 330 and 342 days. Our methodological approach follows Bertone et al (2022). On the interferograms, we have identified and mapped 656 moving areas (MAs). Of these, 640 fall within 326 morphological rock glacier polygons, and 16 belong to 14 additional rock glaciers, previously undetected. Based on MAs spatial distribution, we have classified 340 "moving", 319 "not moving", and 144 dynamically "undefined" rock glaciers, due to decorrelation. With reference to the geomorphologic inventory, InSAR analysis allowed confirming that 76 % (n = 246) of the rock glaciers previously interpreted as intact, do exhibit movement, and that 60 % (n = 278) of the relict ones, do not. Concurrently, we could reclassify 121 rock glaciers, clarifying that 41 of those interpreted as intact, do not move, and that 80 of the relict-labelled ones do. As a result of this reclassification, we find that the altitudinal mismatch between intact and relit rock glaciers shrinks substantially, holding direct implications for modelling the spatial distribution of permafrost.

Application of differential interferometric synthetic aperture radar (DInSAR) to study of the rock glacier dynamics on the Tröllaskagi Peninsula, North Iceland

Claudia Giménez (Departamento de Geografía. Universidad Complutense de Madrid, Spain), Nuria De Andrés (Departamento de Geografía. Universidad Complutense de Madrid, Spain), Thomas Schmid (Centro de Investigaciones Energéticas Medio Ambientales y Tecnológicas (CIEMAT), Madrid, Spain), Luis Miguel Tanarro (Departamento de Geografía. Universidad Complutense de Madrid, Spain) and David Palacios (Departamento de Geografía. Universidad Complutense de Madrid, Spain).

Abstract

The Tröllaskagi Mountains (northern Iceland) are home to hundreds of glacial cirques, with vertical and very unstable walls. In many of these cirques there are currently small glaciers, mostly debris-covered, and rock glaciers, with little known activity. Remote sensing techniques using synthetic aperture radar (SAR) have proven to be suitable for quantifying the flow of rock glaciers. The objective of this work is to apply differential interferometry (DInSAR) to estimate deformations experienced in 15 rock glaciers and the stability of cirque walls in Tröllaskagi mountains for the summer periods of 2020 and 2021. SAR images in wide-swath interferometric (IW) C mode as level 1 SLC products with a 12-day time baseline and VV polarisation were obtained with the Copernicus Sentinel-1 satellite. These images (7 from 25/06 to 12/08/2020 and 7 from 02/06 to 13/08/2021) were used to produce the final interferograms. Open-source software Sentinels Application Platform (SNAP version 8.0) of the European Space Agency and the SNAPHU algorithm for phase unwrapping. was used to process the data Preliminary results show that there was a loss of materials on the slopes, as well as vertical displacements in the rock glaciers. The rock glacier with the greatest subsidence show mean displacement values of -0.072 m to -0.044 m from 25/06 to 12/08/2020 and -0.094 m to -0.05 m from 02/06 to 13/08/2021. These values, compare with results from previous studies over the same area showing similar displacements, applying photogrammetry in aerial photography from 1980 to 1994. Furthermore, slope deformations have been detected at the head of the glacier cirques, with mean values of -0.049 m from 25/06 to 12/08/2020 and -0.070 m from 02/06 to 13/08/2021 and, interpreted as losses of material due to intense periglacial and slope processes.

Extracting rock glacier time-series velocity maps from Landsat imagery and inversion methods

Diego Cusicanqui (ISTerre (CNRS | UGA), Pascal Lacroix (ISTerre (CNRS | UGA) and Xavier Bodin (Laboratoire EDYTEM (CNRS / USMB).

Abstract

Rock glaciers dynamics have recently gained relevance because their kinematics has been promoted as a new parameter of the Essential Climatic Variable (ECV-Permafrost) by the International Permafrost Association (IPA). Monitoring rock glacier kinematics is important because it sheds light on the physics of rock glacier creep and its response to climate change. However, monitoring their dynamics using optical remote sensing data is a challenging tasks because surface kinematics are rather low (between a few cm to a few meters per year) and therefore needs very high resolution datasets.

Here we present a methodology adapted from landslides monitoring, to extract surface kinematics time-series of rock glaciers using Landsat imagery. This methodology is based on the 15m resolution Landsat7/8 legacy (since ~1999) from where one image pear year (with limited snow cover) is selected. Next, surface displacements fields of all possible pairs are obtained from feature tracking image correlation to take advantage of the information redundancy, and then used into inversion algorithm which aims to reduce the uncertainties of surface displacements time series. Finally, constant-directional filters allows us to extract coherent moving areas.

We test our algorithm on a ~2000 km^2 area in the Tapado rock glacier area over the time-period 1999-2022. The moving areas detected with optical imagery are concentrated on the most active parts of the rock glaciers. By comparison with previous inventories realized on this area, our results show that rock glacier can be detected with this algorithm and their displacements time-series can be assessed. We compare our Landsat kinematic results with high resolution imagery datasets (Geoeye//Pleiades) over an area of 206 km^2, showing a very good coherence over rock glaciers. This robust methodology offers new possibilities on monitoring rock glacier dynamics using freely available remote sensing datasets, over large regions.

Towards regional-scale and consistent rock glacier inventories using deep learning

Benjamin Robson (University of Bergen), Shelley MacDonell (Waterways Centre for Freshwater Management), Daniel Thomas (University of Bergen), Adina Racoviteanu (Université Grenoble Alpes) and Daniel Hölbling (University of Salzburg).

Abstract

Rock glaciers are an important component of the cryosphere and are one of the most visible manifestations of permafrost. While the significance of rock glacier contribution to streamflow remains uncertain, their hydrological role is likely to be important in certain parts of the world. High-resolution remote sensing data has permitted the creation of rock glacier inventories for large regions. However, due to the spectral similarity between rock glaciers and the surrounding material, the creation of such inventories is typically conducted based on manual interpretation, which is both time consuming, subjective and dependent on access to sufficiently high resolution imagery.
Several studies have shown that there is a high degree of subjectivity in manually delineating rock glacier outlines, which highlights the need for new methods to complement and validate traditional approaches. However, machine learning based inventories, for example, are vulnerable to untrustworthy training and validation data.
Here we will present preliminary results from rock glacier mapping exercises in both the Andes of South America and High Mountain Asia, using a variety of remote sensing datasets. While our methodology is not yet capable of producing fully automated rock glacier inventories, we show it can reduce the amount of work required to produce regional inventories.

Annual kinematics and elevation changes of an active rock glacier quantified from UAV-based monitoring

Sebastián Vivero (Department of Geosciences, University of Fribourg) and Christophe Lambiel (University of Lausanne).

Abstract

There exists a necessity to increase our understanding of rock glacier dynamics over relatively short periods due to rapid permafrost degradation and its associated effects on the stability of mountain periglacial slopes. Despite the recent acceleration of rock glacier velocities, particularly in the European Alps, data on annual and inter-annual thickness and volume changes remain scarce. Repeated uncrewed aerial vehicle (UAV) surveys combined with structure-from-motion (SfM) photogrammetric techniques were used to determine the surface kinematics, elevation and volume changes of the Les Cliosses rock glacier in the Western Swiss Alps. Accompanying GNSS surveys provided the necessary ground control and check points for processing and validating the UAV-SfM products. The use of automatic image-matching algorithms resulted in average surface velocities ranging from 0.24 m/yr (2016–2017) to 0.4 m/yr (2019–2020). Between 2016 and 2021, detailed digital elevation model (DEM) differencing revealed mean annual changes in thickness between –0.05 ± 0.02 m/yr (2016–2017) and +0.014 ± 0.008 m/yr (2021–2021). Throughout the entire period (2016–2021), the estimated net volume change at the rock glacier is -1509 ± 223 m^3, suggesting that sediment efflux and ground ice melting are considerably more significant than sediment influx and ice aggradation from the upslope area. The enhanced analysis using multitemporal and high-resolution topographic datasets has revealed the presence of distinct rock glacier lobes of different activity embedded into one another, which could not be accurately identified before with more traditional in-situ measurements and observations. Our complementary results on elevation and surface velocity changes demonstrate the importance of detailed and regular high-resolution monitoring for understanding the rapid evolution of active rock glaciers under current permafrost degradation.

A Rock Glacier Inventory of the Central Alaska Range, Alaska

Kaytan Kelkar (University of Alaska, Fairbanks), Louise Farquharson (University of Alaska, Fairbanks), Margaret Darrow (University of Alaska, Fairbanks), Daniel Mann (University of Alaska, Fairbanks), Simon Zwieback (University of Alaska, Fairbanks) and Denny Capps (National Park Service).

Abstract

Rock glaciers are striking periglacial landforms that consists of a perennially frozen rock/ice matrix that gradually undergoes displacement on permafrost affected slopes. Ongoing warming of air and ground surface temperatures is driving a shift in mountain permafrost thermal regimes. Rock glaciers provide valuable insight into the health and conditions of mountain permafrost through changes in creep rates and the occurrence of destabilization events. As such rock glaciers in a warming climate can pose a threat to vital infrastructure in mountain terrain. Identifying rock glacier extent and monitoring rock glacier kinematics is therefore key in predicting permafrost-related geohazards in mountain communities.

Here we present a rock glacier inventory for a subsection of the central Alaska Range, an area of discontinuous permafrost in the Subarctic. We build upon initial efforts by Wahrhaftig and Cox (1959) to explore what influence slope, aspect, elevation, permafrost distribution, and geology exert over rock glacier location, morphology, and movement, including destabilization.

We manually mapped periglacial talus derived rock glaciers using medium to high resolution spectral satellite imagery in ArcGIS Pro. Each rock glacier was manually delineated and categorized into lobate, tongue-shaped, and spatulate morphology classes. Slope aspect, and elevation were derived from the 5-m resolution Arctic digital elevation model (DEM) of the study area. To gain an initial estimate of glacier movement and destabilization locations, we conducted InSAR analysis using C-band (wavelength 5.6 cm) Sentinel-1 data between January 1, 2015 to September 30, 2022. Our workflow included 12-day short temporal baselines to determine creep and rate of rock glacier movement.

Results from this study provide critical baseline data on rock glacier location and dynamics in the central Alaska Range that can be used to infer permafrost conditions and to identify the location of potential mountain permafrost hazards.

This abstract participates in the Outstanding PYRN Oral Communication/Poster Award.

La Paúl Rock Glacier (Pyrenees). Changes and evolution during the last two hundred years

Enrique Serrano (University of Valladolid), Adrián Martínez-Fernández (CENIEH), José J. de Sanjosé (University of Extremadura), Manuel Gómez-Lende (University of Cantabria), Manuel Sánchez-Fernández (University of Extremadura), Alfonso Pisabarro (University of Leon) and Alan Atkinson (University of Extremadura).

Abstract

La Paúl rock glacier is located on the NW side of the Posets massif (3375 m a.s.l.). It is a Holocene debris rock glacier deformed by the advance of Posets and La Paúl glaciers during the LIA. The tongue has a 400 m length oriented to the North, and the front reaches 2800 m a.s.l. Studies on permafrost locate the permafrost environments in the North face of the Posets massif above 2750 m. Three geomatic techniques to know motion and dynamic were applied. From 2013 to 2022, studies on displacement have been made by means of the GNSS-RTK; from 2016 to 2021, motion and deformation analysis were performed using Terrestrial Laser Scanning (TLS) devices; and from 2020 to 2022, Structure from Motion (SfM) photogrammetric surveys have been carried out using Unmanned Aerial Vehicles (UAVs). Previous studies on the ground thermal regime, the basal temperatures of snow (BTS measurements), and geoelectrical sounding show the presence of a frozen body. GNSS measurements show displacements higher than 32 cm a-1, and a small thinning, around 2 cm a-1. TLS and SfM show a glacier where the maximum changes are located at the root, agreeing with the higher slope, and in the front, both with displacements greater than 40 cm a-1. The central axis has shifts between 30 and 40 cm·a-1. Although the displacements are slower on the lateral sides, they show different behaviours on the West and East sides. The West edge, where the La Paúl glacier eroded the rock glacier until around 170 years ago, has displacements between 10 and 40 cm^{-1}. In contrast, the displacement on the East side shows moderate activity (< 10 cm a-1). The rock glacier shows full activity, with little thinning and greater activity in the area affected by erosion in the 19th century.

Rock Glacier Velocity as a new product of the Essential Climate Variable Permafrost

Yan Hu (The Chinese University of Hong Kong), Lukas U. Arenson (BGC Engineering Inc.), Chloé Barboux (University of Fribourg), Xavier Bodin (Laboratoire EDYTEM, CNRS), Alessandro Cicoira (University of Zurich), Reynald Delaloye (University of Fribourg), Isabelle Gärtner-Roer (University of Zurich), Andreas Kääb (University of Oslo), Andreas Kellerer-Pirklbauer (University of Graz), Christophe Lambiel (University of Lausanne), Lin Liu (The Chinese University of Hong Kong), Cécile Pellet (University of Fribourg), Line Rouyet (NORCE Norwegian Research Centre), Philippe Schoeneich (Université Grenoble Alpes), Gernot Seier (Aeronautical Innovation & Research Laboratories Austria) and Tazio Strozzi (Gamma Remote Sensing).

Abstract

"Rock Glacier Velocity (RGV)" was recently accepted by the Global Climate Observing System as a new product of the Essential Climate Variable Permafrost. Our contribution synthesizes knowledge on rock glacier kinematics(general mechanical behavior) and velocities (quantifiable variable) to assess the scientific relevance of RGV. We aim to gain perspectives on the global and regional patterns of rock glacier velocities across temporal scales as revealed by observations. We conducted the systematic review with reference to the PRISMA 2020 Statement to facilitate a transparent review. Among the 105 core articles from the period 1919–2022 reviewed in this work, we found that: (1) existing studies have a near-global, yet uneven, regional coverage as the majority of the papers (54 %) describe rock glaciers in Central and Southern Europe; (2) with a rapid increase in the number of publications during recent decades, most of the studies were published since the 1990s (90 %); and (3) Spaceborne/Airborne/UAV-borne remote sensing is the most frequently employed approach (45 %) for measuring rock glacier velocities followed by close-range remote sensing (40%) and in-situ (15 %) techniques. At a global scale, rock glacier kinematics is primarily characterized by a (multi-) decennial acceleration trend with regional variabilities in terms of onset timing and magnitude. This long-term pattern is found on rock glaciers in areas where observations are available, especially since the 2000s, such as the European Alps, High Mountain Asia, the Rocky Mountains, the Andes, and Scandinavia. A pronounced seasonal rhythm – velocities commonly reach the maxima between late summer to early winter and minima in late spring – occurs on many, yet not all, monitored rock glaciers. With the increasing availability of continuous observations during the past two decades, a synchronous kinematic pattern at the inter-annual scale is identified in the European Alps at the regional scale despite apparent differences in local topo-climatic conditions.

This abstract participates in the Outstanding PYRN Oral Communication / Poster Award

A Very-Low Frequency Survey on the Rainbow Ridge Rock Glacier, Alaska

Kaytan Kelkar (University of Alaska, Fairbanks), Nicholas Hasson (University of Alaska, Fairbanks) and Sergei Rybakov (University of Alaska, Fairbanks).

Abstract

Rock glaciers are unique periglacial landforms which are an indicator of mountain permafrost conditions. The current warming trend of air and ground surface temperatures is modifying the thermal state of mountain permafrost. These changes are deforming periglacial slopes and leading to accelerated rock glacier creep which poses a threat to infrastructure in mountain terrain. To better understand rock glacier creep, an interpretation of the internal structure of rock glaciers is needed. Here, we present our preliminary findings from the first Very-Low Frequency (VLF) electromagnetic (EM) survey of electrical resistivity (ohm-m) on a rock glacier in Alaska.

We conducted three VLF surveys on the Rainbow Ridge rock glacier (RRRG). Two surveys were completed longitudinal to downslope movement and one transect was completed transverse to flow. The RRRG is a tongue-shaped rock glacier emanating from a west-facing cirque accessible from the Richardson Highway, Alaska.

Our preliminary findings suggest that there is saturation within the rooting zone and toe of the rock glacier. The VLF surveys show a distinctive area with flowing water within the rock glacier. We hypothesize that this runoff in the long-term will cause a slope detachment resulting in cascading periglacial hazards. To supplement this VLF investigation we propose to conduct Differential Global Positioning Systems (DGPS) measurements and install temperature sensors during future field seasons. A comprehensive monitoring plan is required for the RRRG, because it will potentially impact the Richardson Highway in the near future.

This work will provide valuable data for future rock glacier dynamics and morphometric studies in the Alaska Range. Furthermore, our findings will address the need to better understand mountain permafrost conditions and locate potential periglacial hazards.

How kinematics attributes improve geomorphological interpretation of rock glacier? Insights from the revision process of the French rock glaciers inventory

Xavier Bodin (Laboratoire EDYTEM (CNRS / USMB), Agziou Julia (Laboratoire PACTE (CNRS / UGA), Duvanel Thibaut (Laboratoire EDYTEM (CNRS / USMB), Diego Cusicanqui (ISTerre (CNRS / IRD / UGA), Thomas Echelard (Cartodia) and Schoeneich Philippe (Laboratoire PACTE (CNRS / UGA).

Abstract

We revised the rock glacier mapping inventory of the French Alps, which was initially completed in 2016 (Marcer et al., 2017) based on geomorphological criteria observed on air-photos. Following the recommendation of the IPA Action group “Rock glaciers Inventories and Kinematics”, we upgraded this inventory by incorporating an evaluation of the landform activity derived from remote sensing data (interferograms computed from Sentinel-1 images, and displacement fields extracted thanks to spatial correlation of airborne and spaceborne images) and a 1-m DEM.
In the line of Bertone et al. (2022), the detection of moving areas on rock glaciers on the X ascending and Y descending interferograms, covering the snow free period in 2018 and 2019, was simultaneously done by n operators, each one with a specific set of landforms selected randomly and a set of 20-30 common landforms for cross-comparison.
Regarding the optical data, the surface displacements were derived from RGDyn toolchain run over a set of 5-10 ortho-images covering the period between 2012 and 2022. A co-registration and temporal redundancy procedure was applied to consolidate robust field displacements, from which moving areas were extracted for as many as possible rock glaciers. The final revised inventory of rock glaciers has been compared to the initial version, in order to quantify the gain in using kinematic attribute. Regional patterns and main controlling factors of the spatial variability of rock glacier activity are then explored. Finally we discuss how the knowledge of kinematic characteristics and the determination of geomorphological traits are complementary, and how the process of rock glacier mapping can be improved thanks to an optimal combination of methods.

Recent and long-term evolution of two contiguous rock glaciers in the Swiss Alps

Christophe Lambiel (University of Lausanne), Sébastien de Meris (University of Lausanne), Georgina King (University of Lausanne), Sebastián Vivero (Department of Geosciences, University of Fribourg) and Cristian Scapozza (Scuola universitaria professionale della Svizzera italiana).

Abstract

To improve our knowledge of the variation in permafrost creep rates over the Holocene, we combined data on current surface movements with surface dating on two contiguous rock glaciers in the Western Swiss Alps, the so-called YC-B and YC-C rock glaciers. Surface movements have been monitored since 2000 using GNSS measurements, and since 2016 by complementary UAV surveys. We used Optically Stimulated Luminescence (OSL) for dating block samples in the front of both rock glaciers and Schmidt hammer exposure-age dating (SHD) on different transects.

YC-B is a very active landform located on a steep slope directly at the foot of a rock wall. Surface velocities display strong interannual variations, from 0.4 m/a between 2005 and 2007, up to 3.5 m/a in 2020. Cumulative displacements reached up to 50 m in 22 years, and during the last decade, the rock glacier entered in a destabilization phase. The roots of YC-C are occupied by a small debris-covered ice patch and geophysical surveys suggest a high ice content. This landform is much less dynamic, since velocities are comprised between 0.1 and 0.4 m/a in the lowermost sector. During the last 22 years, the cumulative displacement has been up to 6.5 m.

SHD revealed ages of around 7.00 to 9.00 ka towards the front of both rock glaciers, while OSL dating in the front yielded ages of 8.00 to 12.00 ka, indicating therefore Early Holocene ages. The mean Holocene velocity is 0.3 m/a for YC-B and 0.4 m/a for YC-C. There is thus a strong discrepancy between the rock glacier ages and the current surface velocities, especially for YC-B. This indicates a considerable increase in velocities in recent decades and that current creep rates are probably unprecedented. More generally, this raises several questions about the velocity variations of rock glaciers on a Holocene timescale.

Shrinking and thinning of a rock glacier in the edge of permafrost environments (2008-2022): La Maladeta rock glacier (Pyrenees)

Enrique Serrano (University of Valladolid), Manuel Gómez-Lende (University of Cantabria), Adrián Martínez-Fernández (CENIEH), José J. de Sanjosé (University of Extremadura), Manuel Sánchez-Fernández (University of Extremadura), Alfonso Pisabarro (University of Leon) and Alan Atkinson (University of Extremadura).

Abstract

Maladeta rock glacier is located on the N side of the Maladeta massif, the highest massif in the Pyrenees (Aneto, 3404 m). It is a debris rock glacier with a tongue of 210 m length and 45 m width, oriented to the North, and the front reaches 2910 m a.s.l. The rock glacier survey is based on the application of two geomatic techniques between 2008 and 2022. From 2008 to 2022, studies on displacement have been made by means of the GNSS-RTK; and from 2020 to 2022, Structure from Motion (SfM) photogrammetric surveys using Unmanned Aerial Vehicles (UAVs) have been applied. Geomatic measurements show moderate displacements in all body, always less than 15 cm·a-1. The lowest displacement is located at the root (around 5-6 cm·a-1) and the front, except for one of the front rods that fell in 2019, showing more than 15 cm/year displacements. The rock glacier shows an important thinning, mainly in the central portion where the registration data is bigger than 9 cm·a-1 and depressive features point to the melt of the frozen body. They indicate a rock glacier losing its activity, close to a transition from an active to an inactive rock glacier, where the main process is the loss of ice in the frozen body. This dynamic is consistent with the behaviour of the very close Aneto and La Maladeta glaciers. They all show the rapid changes that are taking place above 2800 meters in the high mountains of the Pyrenees.

Updating of the Catalog of active rock glaciers in the Pyrenees

Josep Ventura (Department of Geography, Universitat de Barcelona, Catalonia, Spain), Enrique Serrano (Department of Geography, Universidad de Valladolid, Spain) and Marc Oliva (Department of Geography, Universitat de Barcelona, Catalonia, Spain).

Abstract

This communication presents an updated inventory of active rock glaciers in the Pyrenees. The last catalogue was done in 2016, reporting the existence of 18 active rock glaciers in this mountain range, including both the Spanish and French slopes. All the active landforms were located in massifs of the Central Pyrenees (2,900-3,000 m), in different lithological settings, mostly north-exposed, and with the fronts of the rock glaciers located above 2,500-2,600 m. From W to E, active rock glaciers were identified in: Picos del Infierno, Marcadau, Ardiden, Néouvielle, Batoua, Cotiella, Posets, Maladeta and Besiberri. In this communication, we have updated this list with the location of more potentially active rock glaciers in several more massifs. Based on photo-interpretation in 2D and 3D map viewers with high-resolution aerial images, high-resolution MDT-LIDAR photogrammetry and InSAR satellite interferometry, it has been possible to detect displacement rates in several other rock glaciers in some already listed massifs (Besiberri) and several new ones (Clarabide, Punta Alta-Colomers, Pica d'Estats, Medacorba-Coma Pedrosa and Pessons), located also in the Central Pyrenees. In parallel, we have already started monitoring ground temperature conditions in two of these features, namely the Clot de la Menera (Pessons-Andorra) and in the Clot de Broate (Pica d'Estats). This approach will be complemented with geophysical survey and drilling of boreholes to better understand the distribution and thermal state of permafrost in the Pyrenees.

Rock glacier velocity in the Italian and Swiss Alps from Sentinel-1 satellite SAR interferometry

Nina Jones (Gamma Remote Sensing AG), Tazio Strozzi (Gamma Remote Sensing AG), Rafael Caduff (Gamma Remote Sensing AG), Francesco Brardinoni (Università di Bologna), Aldo Bertone (Università di Bologna), Line Rouyet (Université de Fribourg), Lea Schmid (Université de Fribourg) and Reynald Delaloye (Université de Fribourg).

Abstract

During the last decade, multiple studies have monitored in-situ creep behaviour of active rock glaciers in the European Alps. Whereas the absolute motion rate of a rock glacier is related to a multitude of factors, relative variations over time scales from months to years appear to be particularly dependent on the temperature profile between the permafrost table and the main shear horizon at depth. Changes in rock glacier motion are thus believed to be their most indicative short- to medium-term response to environmental changes and an indicator of mountain permafrost conditions in general. In this context, rock glacier velocity (RGV) has recently been added as a new product to the ECV Permafrost within GCOS.
Satellite radar interferometry (InSAR) has been efficiently used in the past to inventory rock glaciers and estimate their rate of motion. The irregular acquisitions and long repeat-pass intervals of past SAR missions, however, prevented the long-term monitoring of rock glacier velocities. With the Sentinel-1 satellite constellation, specifically designed for SAR interferometry and displacement monitoring, SAR images of the same orbit are regularly acquired every 6-12 days over Europe since 2014 and distributed following a free and open data policy. We analysed the performance of Sentinel-1 InSAR time series for displacement monitoring of representative active rock glaciers in the Italian and Swiss Alps. The line-of-sight displacement in 6-12 days derived from the interferometric pairs is converted to slope-parallel motion rates. Reliable InSAR information can be derived for the snow-free season and in winter during stable, cold conditions. A typical annual cycle of rock glacier velocities with higher values in autumn and lower values in spring could be observed with an estimated accuracy of +/- 0.2 m/yr. Our study provides possibilities on the use of InSAR for the systematic documentation of RGV as a new ECV product.

SESSION 15
Drained Lake Basins in lowland permafrost regions

Conveners:

- **Helena Bergstedt,** *bgeos;* helena.bergstedt@bgeos.com
- **Louise Farquharson,** *Geophysical Institute Permafrost Laboratory University of Alaska Fairbanks*; lmfarquharson@alaska.edu
- **Guido Grosse,** *Permafrost Research Section, Alfred Wegener Institute for Polar and Marine Research Potsdam*; guido.grosse@awi.de

Summary:

Drained lake basins (DLBs) are some of the most common landforms in lowland permafrost regions. DLB formation and drainage can form a complex mosaic on the landscape that reflects asynchronous periods of permafrost aggradation and degradation. The presence of DLBs and their relative distribution on the landscape influence permafrost-region topography, hydrology, carbon cycling, habitat diversity, and can play an important role in human land use practices including agriculture. This session is intended as a forum for current research on DLBs in permafrost-affected landscapes. We seek contributions that reflect diverse scientific fields, approaches, geographic locations and a range of temporal (e.g. decadal to millennial) and spatial scales (e.g., local observation to large scale studies). We particularly encourage contributions that (a) provide data on DLB geology, cryostratigraphy, and geomorphology; (b) outline new strategies to improve process understanding; (c) interface with neighbouring fields of science or apply innovative technologies and methods; (d) investigate model validation, model uncertainty, and scaling issues; (e) couple models of diverse processes or scales, and (g) foster our understanding of the geologic history, current state, and future fate of DLBs and associated permafrost conditions and surrounding terrain.

Land Cover Patterns for Drained Lake Basins across bioclimatic gradients

Clemens von Baeckmann (b.geos), Helena Bergstedt (b.geos), Annett Bartsch (b.geos), Barbara Widhalm (b.geos), Aleksandra Efimova (b.geos), Timo Kumpula (University of Eastern Finnland), Dorothee Ehrich (UiT The Archtic University of Norway), Svetlana Abdulmanova (Russian Academy of Sciences Ural Branch of RAS) and Aleksandr Sokolov (Russian Academy of Sciences Ural Branch of RAS).

Abstract

Thermokarst lakes and drained lake basins (DLBs) play a major role in the geomorphological, hydrological and the ecological development of Arctic landscapes on the circumpolar scale. Associated dynamics such as changes in surface water area and vegetation cover can be monitored consistently from space.
Here, we focus on DLBs representing different bioclimatic zones on permafrost. Existing Landsat trend products going back to 1999 have been combined with a landcover classification based on Sentinel-1 and Sentinel-2. Lakes which remained drained have been identified and visually inspected before final selection. The final, semi-manually selected DLBs were evaluated for annual landcover patterns from 2016 up to present. The landcover classes were derived from a combination of an unsupervised and supervised classification based on Sentinel-1 and Sentinel-2 satellite data following an approach developed within the ESA DUE Globpermafrost and Permafrost_cci projects. ERA5 and in-situ data provide additional information for the selected DLBs.
Improving the knowledge on processes involved in drainage events in the Arctic environment associated with permafrost conditions and surrounding terrain is crucial for numerous applications (e.g., landscape models, carbon cycle processes and local infrastructure stability). This study advances the understanding of DLBs and the corresponding change of biodiversity as well as carbon cycling as is the focus of the Horizon 2020 project CHARTER and ERC Q-Arctic respectively.

Permafrost aggradation in drained lake basins of the forest-tundra transition, Old Crow Flats, Yukon

Pascale Roy-Leveillee (Centre d’études nordiques, Département de géographie, Université Laval) and Fabrice Calmels (Yukon University, Permafrost and Geoscience Research Centre).

Abstract

Lake drainage rates are increasing in many thermokarst lowlands of the circumpolar North, and permafrost aggradation in contemporary lake basins near the discontinuous permafrost zone may slow, halt, or reverse under a warming climate. This project examines talik refreezing patterns in basins drained over the last 50 years in the Old Crow Flats, Vuntut Gwitch’in traditional territory, Yukon. The area is within the forest-tundra transition, in the continusou permafrost zone of northern Yukon. Permafrost aggradation was assessed using electrical resistivity tomography, earth augering, and thermal monitoring in lake basins drained in the 2010s, 2000s, 1970s and in basins that drained hundreds and thousands of years ago. Old basins were underlain by permafrost, which was more than 40 m thick at the oldest basin surveyed (2395 ± 20 years). Basins surrounded by polygonal tundra showed clear permafrost recovery in subaerial portions of the basin, even at sites drained less than 5 years ago where pre-drainage talik geometry was still visible beneath the aggrading permafrost. Basins surrounded by taiga vegetation showed partial and delayed permafrost recovery. No frost was detected along transects in two basins drained for over a decade when surveyed in 2019. After a winter (2020-21) with below average snow precipitation, a solid frozen layer persisted through summer less than 1 m beneath the surface in areas with a cover of Carex spp. and less than 2 m beneath the surface of a mudflat. By August 2022, this solid frost layer had disappeared from the mudflat but persisted and thickened in vegetated areas suggesting the initiation of permafrost aggradation in these modern drained basins. Continued thermal monitoring will help characterize basin floor thermal regime and identify climatic conditions and basin characteristics that favor and/or impede permafrost aggradation in this warming landscape.

Chain reaction drainage of four permafrost region lakes in northern Alaska

Benjamin Jones (University of Alaska Fairbanks), Andrew Parsekian (University of Wyoming), Mikhail Kanevskiy (University of Alaska Fairbanks), Melissa Ward Jones (University of Alaska Fairbanks), Rodrigo Rangel (University of Wyoming), Noriaki Ohara (University of Wyoming), Alexandra Veremeeva (Alfred Wegener Institute), Amy Breen (University of Alaska Fairbanks), Kenneth Hinkel (Michigan Technological Institute), Yuri Shur (University of Alaska Fairbanks) and Qaiyaan Harcharek (North Slope Borough).

Abstract

Despite the well-recognized importance of lake drainage in lowland permafrost region landscapes in the Arctic, direct observations of drainage events remain sparse which limits our understanding of rapid lake drainage processes. Here, we document a cascading lake drainage sequence in northern Alaska following the initial drainage of a lake into a nearby river in early June 2020. We anticipated that the initial isolated lake drainage event may trigger the chain reaction drainage of adjacent lakes, so we began to study the site. We installed water level sensors in each of the adjacent lakes and the recently drained lake basin, conducted UAV surveys to map basin geometries, and performed near-surface geophysical measurements.

In early July 2021, a water level logger deployed in an adjacent lake measured its drainage occurring over the period of one day. The waters flooded the basin of the lake that drained the prior year, triggering further erosion of its drainage outlet. During the fall of 2021, another lake drained. This lake drained into the lake that drained in early July 2021. Finally, the partial drainage of another lake occurred in early July 2022 in less than 24 hours. This lake also drained into the lake that drained in early July 2021, which drained out into the basin of the lake that drained in early June 2020, and ultimately into the nearby river. Thus, the drainage of the initial lake in early June 2020 triggered the drainage of three other lakes over the convening two-year period.

Our observations of the chain reaction drainage of four permafrost region lakes in northern Alaska demonstrate the potential for landscape reorganization through cascading lake drainage. Based on the early season timing of three of the lake drainages as well as field site visits at the fourth lake drainage site in the first few days following the event we infer that underground erosion and ice wedge tunneling is an important drainage mechanism in this region.

Drained lake basins on a panarctic scale

Helena Bergstedt (b.geos), Amy L. Breen (International Arctic Research Centre, University of Alaska Fairbanks), Benjamin M. Jones (Institute of Northern Engineering, University of Alaska Fairbanks), Louise Farquharson (Geophysical Institute, University of Alaska Fairbanks), Juliane Wolter (University of Potsdam, Institute of Biochemistry and Biology), Guido Grosse (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Permafrost Research Section), Annett Bartsch (b.geos), Mikhail Kanevskiy (Institute of Northern Engineering, University of Alaska Fairbanks), Clemens von Baeckmann (b.geos), Timo Kumpula (University of Eastern Finland), Alexandra Veremeeva (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Permafrost Research Section), Gustaf Hugelius (Department of Physical Geography, Stockholm University, Stockholm, Sweden) and Ksenia Ermokhina (Earth Cryosphere Institute, Tyumen Scientific Centre SB RAS, Tyumen, Russia).

Abstract

Lakes and drained lake basins (DLBs) are ubiquitous landforms covering 50 % to 75 % of permafrost lowlands in parts of Alaska, Siberia, and Canada. The mosaic of vegetative and geomorphic succession within DLBs and the distinct differences between DLBs and surrounding areas can be discriminated with remote sensing and used to derive a landscape-scale classification. Depending on the age of a given DLB, surface characteristics detected with remote sensing such as surface roughness, brightness, greenness, moisture, and abundance of ponds may vary. In situ observations of these surface characteristics are crucial for a better understanding of DLBs but can only describe a small percentage of existing DLBs. In addition, spatial heterogeneity within a single basin also depends on time passed since the drainage event occurred. DLBs can be recently drained (young basins, < 50 years since drainage event occurred) up to ancient basins (> 2000 years). Here we compile existing field data on DLBs available for the circumpolar region, assessing the representativeness of past measurements for DLBs on a panarctic scale. A panarctic-scale effort to map and further the understanding of DLB distribution in permafrost regions has been conducted within the International Permafrost Association (IPA) Action Group on DLBs, a bottom-up effort led by the scientific community that includes developing a first panarctic drained lake basin data product based on multispectral remote sensing data (Landsat-8). Comprehensive mapping of DLBs areas across the circumpolar permafrost region and including field data into this approach will allow for future utilization of these data in panarctic models and greatly enhance our understanding of the role of DLBs in permafrost landscapes. Here we present a first effort linking a pan-Arctic DLB data set to existing available in situ information such as vegetation data and soil characteristics. This will improve quantitative studies on landscape diversity, wildlife habitat, permafrost, hydrology, high-latitude carbon cycling, and landscape vulnerability to climate change.

Yedoma-alas landscape elevation changes and their drivers based on Sentinel-1 SAR Interferometry, field data, and high-resolution optical imagery, Bykovsky Peninsula, Laptev Sea region

Alexandra Veremeeva (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Frank Guenther (Neubrandenburg University of Applied Sciences), Tazio Strozzi (Gamma Remote Sensing), Alexander Kizyakov (Lomonosov Moscow State University), Nitze Ingmar (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Cornelia Inauen (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Anne Morgenstern (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Nina Jones (Gamma Remote Sensing), Mikhail Kanevskiy (Institute of Northern Engineering, University of Alaska Fairbanks), Anfisa Pismeniuk (Lomonosov Moscow State University), Mikhail Zimin (Lomonosov Moscow State University), Elizaveta Rivkina (Institute of Physicochemical and Biological Problems in Soil Science, Russian Academy of Sciences) and Guido Grosse (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research).

Abstract

Yedoma landscapes formed by late Pleistocene ice-rich Yedoma Ice Complex deposits cover vast lowlands of NE Siberia, Canada and Alaska. These areas are among the most vulnerable permafrost regions in a warming climate. Widespread thermokarst at the end of the late Pleistocene - beginning of the Holocene led to significant transformation of initial Yedoma plains, which has resulted in the formation of numerous thaw lakes and subsequently drained lake basins (alases). There is a general lack of knowledge of modern Yedoma-alas landscape elevation changes due to thaw processes and their dependence on geomorphological conditions and other characteristics at local scale. The aims of our study are (i) to determine recent Yedoma-alas landscape elevation changes using in-situ measurements and Sentinel-1 satellite synthetic aperture radar interferometry (InSAR) and (ii) to investigate the local-scale geomorphological patterns and drivers of elevation changes and spatial differences based on field and remote sensing data. We used a series of Sentinel-1 images from 2016 to 2021 on the Bykovsky Peninsula (NE Siberia) to compute a mean surface deformation rate. We also conducted an analysis of landscape changes based on optical historical and modern high-resolution remote sensing imagery and machine learning-based classification of robust trends of multi-spectral indices derived from 2000-2022 Landsat data. We detected 18 landform types (seven types of Yedoma uplands and eight types of alases), characterized by different drainage conditions, permafrost characteristics (upper permafrost structure and active layer thickness), microtopography, soils, and vegetation cover. A thaw subsidence trend rather than heaving prevailed on all relief types. Generally, Yedoma uplands are characterized by subsidence rates of about 1 cm/year, with the highest values identified on slopes with initial formation of thermokarst mounds (baydzherakhs) (1.1±0.4 cm/year). Field data, Landsat trend data, and the analysis of optical high-resolution imagery show changes in the current status of landscapes and permafrost conditions, which help to interpret and correct elevation changes obtained with InSAR.

Contemporary formation of ice-wedge pseudomorphs during the expansion of a thermokarst lake followed by lake drainage in Old Crow Flats, Yukon, Canada

Samuel Gagnon (Université Laval / Centre d'études nordiques) and Pascale Roy-Léveillée (Université Laval).

Abstract

Old Crow Flats (OCF) is a 5600 km^2 lake-rich thermokarst landscape in the traditional territory of the Van Tat Gwitch'in First Nation, northern Yukon, Canada. Like other sensitive ecosystems of the Arctic, OCF is changing rapidly due to climate warming, including increased rates of lake drainage. In August 2022, we investigated a lake basin partially exposed to subaerial conditions following progressive drainage between 2016 and 2020, and discovered triangular, downward-pointing, organic matter inclusions in the lakebed, which we interpreted as ice-wedge pseudomorphs (IWP). The majority of IWP reported in the literature are from mid-latitude regions where permafrost no longer exists, but they can also form in present-day permafrost environments and provide invaluable information on the processes of permafrost thaw and wedge-ice melting. However, contemporary IWP as well as their mechanisms of formation remain poorly documented. For this study, we exposed three IWP to describe their morphology and sampled them and the enclosing ground for grain size and carbon content analyses. We used remotely sensed imagery to map lake-bottom polygons, to measure pre-drainage lakeshore erosion rates, and to estimate carbon mobilization rates associated with pre-drainage lake expansion. Measurements of near-shore talik depths prior to drainage were used to estimate rates of ice-wedge degradation. The IWP formed prior to drainage via infilling of the melted ice wedges in the near-shore zone with organic material eroded from the shore bank during lake expansion. This suggests that, with the initiation of permafrost aggradation following lake drainage, the IWP could contribute to sequester carbon that was mobilized from the polygonal tundra to the bottom of the lake prior to drainage. To our knowledge, this study is the first to present the formation process of IWP composed of organic material and to discuss the role of IWP development in carbon sequestration in drained basin soils.

Ecohydrological changes due to channeling of alases and thermokarst lakes in Central Yakutia

Yoshihiro Iijima (Mie University), Takahiro Abe (Mie University), Naoto Omori (Mie University), Hitoshi Saito (Nagoya University) and Alexander Fedorov (Melnikov Permafrost Institute, SBRAS).

Abstract

The ice-rich permafrost layer is subject to massive topographic change due to the ongoing development of thermokarst associated with arctic climate change. Recently, it has been pointed out that the expansion may significantly alter hydrologic processes by developing a network of channels along the polygonal topographic troughs. Once expanded as thermokarst lakes by topographic subsidence, lateral erosion can result in collapse runoff, merging with nearby lakes or draining into lower-elevation valleys and alas. These channelizations, the lake and drained lake basin systems, have been noted as significant changes to the landscape and ecosystems of permafrost regions. The central basin of the Lena River (the Central Yakutia) has developed the Yedma layer within the boreal forest on several river terraces, with a mix of old alas lakes and new thermokarst lakes, especially on the Tyungyulyu and Abalakh terraces. While the lakes in some places were drained and channelized during the 20th century, mainly by anthropogenic changes, climate change since the 2000s has led to progressive lateral thawing and erosion in many places. A comparison of Planet and Worldview satellite images from 2017-2022, together with high-resolution AW3D DSM, shows that thermokarst lakes have been areas of expansion, erosion, and merging were identified. The results showed many thermokarst lakes expanding and combining within the forest. The merging of thermokarst lakes with channeling is expected to expand the water body initially while subsequently causing runoff and desiccation. The spatio-temporal variability needs to be assessed, as it is likely to be associated with the irreversible evolution of ecological and hydrologic processes in the future.

Resolving three-dimensional small-scale heterogeneity of surface and subsurface properties in two drained lake basins on the Tuktoyaktuk Peninsula and in the Caribou Hills, Northwest Territories, Canada

Julius Kunz (Institute of Geography and Geology, University of Wuerzburg), Tobias Ullmann (Institute of Geography and Geology, University of Wuerzburg) and Christof Kneisel (Institute of Geography and Geology, University of Wuerzburg).

Abstract

Thermokarst lakes are common features in ice-rich permafrost regions and frequency of drainage events increases recently due to global warming. The expansion of thermokarst lakes often initiates the degradation of permafrost and the formation of sub-lake taliks. After lake drainage events, these taliks start to freeze and permafrost develops below the drained lake basin (DLB). Permafrost aggradation in both directions, top-down and bottom-up, affects the sub-lake talik depending on its size and hydrological connectivity. In addition, the permafrost aggradation, especially the top-down refreeze, is affected by several other factors like surface hydrology or vegetation growth within the drained lake basin. The current study presents a multi-methodological investigation of two drained lake basins on the Tuktoyaktuk Peninsula and in the Caribou Hills, Northwest Territories, Canada. In one of the two DLBs a broad-based open-system pingo developed whereas a larger residual pond remains in the other DLB. The age of both DLBs is unknown but optical satellite data provide evidence that the drainage events must have taken place before 1966. The focus of the study was on heterogeneities in permafrost characteristics below the former lake floor and their relationships to varying surface characteristics, micro-relief and hydrology. A combined use of quasi-three-dimensional electrical resistivity tomography, frost probing, temperature monitoring, and drone-based structure-from-motion provides complementary datasets suited to investigate the surface-subsurface relationships in the area of the two DLBs. The geophysical data allowed a derivation of high-resolution subsurface models and revealed spatial heterogeneities in permafrost characteristics and partly unfrozen conditions within the DLBs, even long time after the drainage events. These data support the understanding of surface-subsurface interactions during permafrost aggradation in DLBs and provide insights into complex interactions in permafrost environments in the context of global warming.

A glimpse into past, current, and future thermokarst lake drainage across different study areas in the panarctic permafrost region

Guido Grosse (Alfred Wegener Institut for Polar and Marine Research, Permafrost Research Section), Juliane Wolter (University of Potsdam, Institute of Biochemistry and Biology), Benjamin Jones (University of Alaska Fairbanks, Institute of Northern Engineering), Ingmar Nitze (Alfred Wegener Institut for Polar and Marine Research, Permafrost Research Section), Alexandra Veremeeva (Alfred Wegener Institut for Polar and Marine Research, Permafrost Research Section), Matthias Fuchs (Institute of Arctic and Alpine Research, University of Colorado Boulder), Miriam Jones (Florence Bascom Geoscience Center, U.S. Geological Survey, Reston, VA) and Helena Bergstedt (bgeos).

Abstract

Drained Lake Basins (DLB) are abundant in Arctic lowlands and were mostly formed by thermokarst lake dynamics. This includes the formation, expansion, and drainage of lakes, which in many regions happened for multiple cycles, or basin generations, throughout the Holocene. These dynamics have substantial impacts on lowland permafrost landscape characteristics. Thaw subsidence due to thermokarst in the past and present time affects surface morphology and interacts with hydrology, which in turn shapes ecological succession and biogeochemical dynamics. Data on DLB characteristics is still scarce, severely limiting our ability to understand past, current and future dynamics of these regions and what their contributions are to ecological and carbon cycle changes in a rapidly warming Arctic. We collected more than 70 thermokarst DLB cores and exposure samples from multiple study areas across Arctic coastal lowlands (Seward Peninsula, Baldwin Peninsula, Teshekpuk Lake Special Area, central Lena Delta, Bykovsky Peninsula). Radiocarbon age determination was used to establish drainage ages by dating terrestrial organic layers and peat overlying lacustrine sediments. For additional sites, we extracted this information from the literature (Barrow Peninsula, Kolyma Lowland coastal region). In combination with an assessment of DLB coverage for these study areas, the geochronological assessment provides first insights into the landscape-scale timing of past drainages and land surface ages. In addition, we analyzed recent lake changes with remote sensing data to quantify lake drainage dynamics in these study areas for ~1950 to 2022 (~70 years), allowing a comparison of recent drainage rates with past Holocene drainage dynamics. Future drainage rates for the study areas are projected using a simplified modeling approach by combining observed thermokarst lake expansion rates with high-resolution elevation datasets to forecast which lakes have a high probability to encounter topographic drainage gradients and will likely drain within the coming decades. Our study provides a substantial database for thermokarst lake drainage and DLB characteristics that will benefit ongoing upscaling efforts with remote sensing and modeling.

Post-Drainage Evolution of Drained Lake Basins in Old Crow Flats, Yukon, Canada

Danielle Chiasson (Université Laval, Centre d'études nordiques), Pascale Roy-Léveillée (Université Laval, Centre d'études nordiques) and Najat Bhiry (Université Laval, Centre d'études nordiques).

Abstract

Old Crow Flats is a lake-rich thermokarst landscape spanning 5,600 km^2 within the continuous permafrost zone of northern Yukon, Canada. The rate of catastrophic lake drainages has increased over the past decades and contemporary conditions in drained basins have been well documented. However, it is difficult to assess the impacts of warming on contemporary post-drainage basin conditions because there are very few paleo-environmental reconstructions of post-drainage basin evolution prior to anthropogenic climate warming. This study analyzes the evolution of vegetation succession over the last several hundred to thousand years in two old drained lake basins of Old Crow Flats. Peat samples from different components of drained lake basins, such as margins, centres, and near the head of drainage outlets, have been collected to reconstruct local vegetation histories through radiocarbon-dated macrofossil records. These vegetation histories will be compared to documented contemporary post-drainage vegetation succession patterns in the region. In particular, key questions about the evolution of drained basins will be refined, such as the local importance and persistence of remnant ponds and different plant assemblages (e.g., sedge fens, large stands of willows, sphagnum bogs), and the relative timing of surface heaving via permafrost aggradation. Preliminary results from the examination of plant macrofossil records from the margin of drained lake basins suggest the rapid onset and mortality of woody shrubs in the years following drainage, representing a seral stage of succession consistent with observations of vegetation succession in contemporary drained basins. By increasing our knowledge of drained lake basin dynamics under past and current climatic conditions, better predictions can be made for future consequences of warming on sensitive and internationally significant thermokarst lowlands such as Old Crow Flats.

Assessing mercury and methylmercury concentrations in drained basins complexes in Old Crow Flats, Yukon, Canada

Nicole Corbiere (Living with Lakes, Laurentian University), Pascale Roy-Léveillée (Centre d'études Nordiques, Université Laval), Brian A Branfireun (Department of Biology, Western University), Danielle Chiasson (Centre d'études Nordiques, Université Laval) and Nathan Basiliko (Department of Natural Resources Management, Lakehead University).

Abstract

Lakes and drained basin complexes (LDBC) cover nearly one-fifth of the circumpolar North. In these complexes, drained basins accumulate organic carbon over decades to millennia. This stored carbon may be associated with atmospherically deposited mercury (Hg). Accelerated landscape changes in permafrost environments may lead to terrain conditions that favour or inhibit Hg methylation - the transformation of inorganic Hg to methylmercury (MeHg), which bioaccumulates and is a neurotoxin. In LDBCs, lake drainages create mosaics of wet and dry environments that evolve as progressive permafrost aggradation heaves the lake bottom. These environments host different microbial communities and are likely to have different Hg methylation potentials. This study examines the net MeHg production potential in drained lake basins of Old Crow Flats (OCF), Yukon. OCF is a vast thermokarst lowland underlain by continuous permafrost that is a crucial part of Vuntut Gwitchin First Nation's traditional territory. In June and August 2021 and June 2022, soil samples were collected within contemporary and old drained basins, frozen, and sent to the Biotron Centre for Experimental Climate Change Research to quantify total Hg content (THg) and MeHg concentration. Old drained basins had a lower ratio of Hg to soil organic carbon (0.15μg/g) than young drained basins (0.56μg/g). While old drained basins had a slightly higher THg concentration (70ng/g) than young drained basins (61ng/g), younger drained basins had a higher MeHg/THg ratio than old basins (2.0 % vs 0.85 %). Preliminary results suggest that where permafrost fails to aggrade in young drained basins and wet conditions (remnant ponds) persist, extensive sedge growth can occur and lead to higher proportions of methylated Hg. This study will improve our understanding of the impacts of drained basin dynamics on Hg cycling in thermokarst lowlands.

A synthesis of drained lake basin ages for northern permafrost regions

Juliane Wolter (University of Potsdam, Institute of Biochemistry and Biology, Potsdam, Germany), Helena Bergstedt (bgeos, Korneuburg, Austria), Louise Farquharson (University of Alaska Fairbanks, Geophysical Institute, Permafrost Laboratory, Fairbanks, USA), Benjamin Jones (University of Alaska Fairbanks, Institute of Northern Engineering, Fairbanks, USA), Mikhail Kanevskiy (University of Alaska Fairbanks, Institute of Northern Engineering, Fairbanks, USA), Pascale Roy-Leveillee (Université Laval, Department of Geography, Centre d'études Nordiques, Quebec, Canada), Alexandra Veremeeva (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Section Permafrost Research, Potsdam, Germany) and Guido Grosse (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Section Permafrost Research, Potsdam, Germany).

Abstract

Lakes and drained lake basins cover about 50 % of Arctic permafrost lowlands. Lakes may act as carbon source or sink depending on their age and specific environmental setting, but drained lake basins (DLBs) are mostly carbon sinks due to peat accumulation after lake drainage. Investigations into the role of DLB wetlands in regional and global carbon budgets must therefore include information on wetland ages, i.e., the time since lakes drained. However, timing and spatiotemporal patterns of lake drainage are not well constrained due to a scarcity of dated drainage events before the period covered by remote sensing (after ca. 1950). Region-wide quantifications of lakes vs drained lake basins require sampling of DLBs from various Arctic regions to allow geochronological analysis of drainage events using stratigraphic marker horizons and absolute dating methods such as radiocarbon dating. We are developing the first panarctic geochronological database focused on lake drainage ages. Additional dates from the literature are continuously added. We collected permafrost cores and samples from natural exposures from >120 DLBs from Arctic Siberia, Alaska, and northwest Canada and identified drainage events by careful stratigraphic assessment. We then radiocarbon-dated the base of the uppermost peat overlying lacustrine sediments as the onset of terrestrial conditions after lake drainage. We found that the vast majority (>90 %) of latest DLB generation wetlands in the basins are less than 3000 years old. Remote sensing imagery may complement our data, as it shows recent increases in lake drainage, which are not detectable using radiocarbon dating. Our DLB age database will be an important step towards refining estimations of permafrost thaw contributions to landscape age, rates of geomorphic change, and greenhouse gas emissions. For the first time, the regional spatial scale and the Holocene time scale of our synthesis provide representative information for these widespread permafrost landforms.

SESSION 16
Processes in cold rocky landforms

Conveners:

- **Dominik Amschwand,** *University of Fribourg*; dominik.amschwand@unifr.ch
- **Tamara Mathys,** *University of Fribourg*; tamara.mathys@unifr.ch
- **Julie Wee**, *University of Fribourg*; julie.wee@unifr.ch
- **Răzvan Popescu,** *University of Bucharest*; razvan.popescu@geo.unibuc.ro

Summary:

The debris mantle of cold rocky landforms like rock glaciers or undercooled talus slopes insulates and cools the landform, creating relatively stable ground thermal conditions that are remarkably colder than in the surrounding terrain. Such landforms are favourable for azonal, low-altitude mountain permafrost, might persist as warmingresilient habitat islands for cold-loving species, and store subsurface ice. However, knowledge about the unique cooling processes like air circulation and geophysical expertise to estimate the ground ice content are fragmented between different scientific disciplines. Also, our quantitative process understanding of heat transfer across the porous debris mantle is still limited. This hampers projections of the future response of these landforms to climate change and the assessment of their hydrological behaviour. With this session, we encourage contributions from geomorphologists, permafrost hydrologists, ecologists, micro-climatologists, and geophysicists alike to foster the exchange of various research disciplines working on cold rocky landforms.

Detailed surface energy balance measurements on rock glacier Murtèl (Engadine, Switzerland): New views into the interaction between atmosphere and the active layer of the rock glacier

Dominik Amschwand (University of Fribourg), Martin Scherler (University of Fribourg), Martin Hoelzle (University of Fribourg), Anna Haberkorn (GEOTEST AG), Bernhard Krummenacher (GEOTEST AG) and Hansueli Gubler (ALPUG GmbH).

Abstract

The thick debris mantle of rock glaciers stores, converts and transfers heat and moisture in the vast pore space between the atmosphere and the underlying permafrost core. The heat gained from solar radiation is largely re-exported by the turbulent fluxes, thus their balance determines the amount of heat available for ground ice melt and in general determines conductive, convective, and lateral fluxes. However, the precise determination of turbulent fluxes remains challenging because of the rough terrain, the highly permeable debris mantle, and the seasonal snow cover: Unless a thick snow cover prevents any exchange with the atmosphere, air flow extends into the shallow debris mantle or even encompasses the entire air column down to the ground ice table. These complex interactions between debris mantle and atmosphere call for a volumetric approach and complementing subsurface measurements. Here, we present estimates of the surface energy fluxes derived from our large sensor network that were installed in summer 2020 above ground as well as in in natural cavities of the rock glacier Murtèl (Engadine, eastern Swiss Alps), including a sonic anemometer for eddy-covariance measurements. The sensor array complements the automatic weather station operated by the Swiss permafrost monitoring network (PERMOS). We discuss the "surface" temperature and moisture and different stability corrections for the bulk parametrization, the eddy covariance and a simple Bowen ratio approach. The two hydrological years 2020/21-2021/22 with their starkly different weather conditions provide insight into the summertime turbulent flux partitioning (sensible vs. latent flux) and wintertime debris mantle–atmosphere coupling controlled by the snow cover.

Thermal aspects of the Schafstein block accumulation, Central German Uplands

Tim Wiegand (Institute of Geography and Geology, University of Wuerzburg) and Christof Kneisel (Institute of Geography and Geology, University of Wuerzburg).

Abstract

The Schafstein (832 m a.s.l.), a basaltic hill in the Rhoen Mountains, is known for one of the largest and deepest open block accumulations in the Central German Uplands. The lower part of this complex periglacial landform is discussed to be a relict rock glacier and studies indicate the isolated occurrence of species that typically exist in cold climate regions. However, the thermal regime is not fully understood, and assumptions are based on only a few observations published to date. It is claimed that the landform might contain summer or even year-round ice lenses. We aimed for a more systematic investigation of the microclimatic conditions. Therefore, temperatures were registered by data loggers along a profile across the whole slope and at different depths. We combined these observations with a camera monitoring on the snow distribution and geophysical measurements (electrical resistivity tomography and seismic refraction tomography) to address the question of potential low-altitude permafrost occurrences. Ground surface temperature measurements show an inverse thermal gradient, meaning lowest mean annual values in the lowest part of the block-covered slope. Furrows and depressions were identified as the cold spots in winter. In summer, cold air outflows are present along the front of the block accumulation bordering a peat bog. On hot summer days the temperature at the ventilation holes can be up to 25 °C below the air temperature. By correlating channel and air temperatures we defined periods indicative for slowdowns of an internal air circulation. We observed similar phenomena at a talus slope in the Bever Valley, Switzerland for which continuous temperature measurements are available for more than one decade and isolated patches of permafrost have been confirmed well below the timberline.

This abstract participates in the Outstanding PYRN Oral Communication / Poster Award.

Ground temperature monitoring with 2cm-interval chip sensors for detection of ice growth in block slope in Mt. Nishi-Nupukaushinupuri, Hokkaido, Japan

Yuki Sawada (Fukuyama City University), Toshio Sone (Hokkaido University) and Shoichi Mori (Hokkaido University).

Abstract

Block slopes have unique thermal characteristics for permafrost preservation in mountainous areas. Many studies discuss how air circulation contributes to strong cooling of the slope, while few studies pay attention to the ice that fills the voids of the blocky deposits in the slope. Ice formation releases latent heat and raises the temperature up to 0 °C. Thus, ice formation can be detected by temperature sensors. To test this hypothesis, we constructed a temperature monitoring system with chip sensors mounted at short intervals (2 cm) and installed it in the lower part of the block slope, where ice formation and abrasion had been manually monitored in the previous study. The study site is located in the summit area of Mt. Nishi-Nupukaushinupuri (1254 m) in Hokkaido, northern Japan. Sawada and Ihsikawa (2003) monitored changes in ice surface depth at the same site and found that meltwater flows to the lower part of the slopes and refreezes, adding overlaying ice to the perennial ice. Sensors were installed at a depth of -60cm to -210cm in the lowermost part of the block slope. The ice surface was found at -171cm when we installed the sensors on 30 October 2018. Air temperature was monitored in the middle part of the block slope. The monitoring results show an abrupt increase in soil temperature at all depths on 17 April 2019, when the air temperature rose to 13 °C and snowmelt started. The amplitude of the warming was highest (up to 0 °C) in the depth of -180 to -160 cm, where the ice surface was detected in the previous autumn. This abrupt warming in the deeper part indicates ice formation in the spring. In the deeper part, the temperature rose to 0 °C several times until the temperatures between -60 cm and -170 cm accumulated to 0 °C. The series of abrupt changes up to 0 °C in the deeper part clearly shows latent heat release from the ice formation within the coarse blocky deposits. Densely-installed chip sensors can detect phase changes from percolating snow-melt water to superimposed ice within the voids in the block slope.

Permafrost modelling of slopes affected by talus-sourced landslides in northern Iceland

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Abstract

In Iceland, permafrost thaw has been recently recognised as a new triggering factor for landslide occurrence, whose frequency has increased in the last decade. Many of these landslides share the common characteristic of being sourced from ice-cemented talus deposits. While the growing number of rock slope failures has determined a flourishing interest in the study of permafrost in steep rock walls in mountain environments worldwide, the permafrost distribution in talus and loose deposits, its response to warming temperatures in time, and its contribution to the onset of landslides are still largely unknown. Here we investigate the permafrost conditions at three sites of the Tröllaskagi Peninsula in Northern Iceland, where recent landslides characterised by the presence of permafrost molards raised the hypothesis that permafrost thaw in this area is increasing the frequency of talus-sourced landslides. This is notably suggested by the altitude of sources areas that lie between c. 750 m a.s.l and c. 900 m a.s.l., which corresponds to the regional permafrost limit. During summer 2021, we installed temperature sensors at the near surface (from 5 to 50 cm depth) of rock walls and talus of these three sites following altitudinal profiles between c. 650 and c. 1200 m a.s.l. Near surface temperature was measured at a hourly time step and data were retrieved during summer 2022. Temperature data will be used to better characterise the permafrost conditions of the sites and to constrain 2D heat transfer numerical models to discuss the role of permafrost conditions in landslide triggering. Ultimately, such approach could allow to better assess conditions prone to talus-slope destabilisation.
Acknowledgements: This study is funded by the Agence Nationale de la Recherche in the framework of the project ANR-19-CE01-0010 PERMOLARDS

Chimney circulation, thermal regime and internal structure of a low altitude cold talus slope-rock glacier system (Detunata Goală, Romanian Carpathians)

Răzvan Popescu (University of Bucharest, Faculty of Geography), Mirela Vasile (Research Institute of the University of Bucharest) and Alfred Vespremeanu-Stroe (University of Bucharest, Faculty of Geography).

Abstract

Talus slopes are landforms that usually occur in alpine environments but they can also be found at lower altitudes either as relict landforms in the forest area, indicating past colder climates (with intense frost weathering) or still active due to ongoing debris accumulation. In the last decades it was shown that these landforms can sometimes maintain unusual cold ground conditions, persistent ice and sometimes permafrost. The main process leading to cold conditions in talus slopes is the chimney effect, which represents cold air adsorption in the winter and evacuation in the summer in the lower parts, complemented by warm air evacuation in the winter in the upper parts. This assures persistent cold conditions in the lower sectors of the talus slope but persistent warm conditions in the upper ones. However, in spite of the general model of manifestation, the chimney circulation is still insufficiently understood. The aim of this work is to bring new data on chimney circulation process in terms of air currents speed and direction, continuity throughout the year and initiation and cessation in relation to atmospheric and ground temperatures. This is revealed by ultrasonic anemometer measurements in Detunata Goală site (Apuseni Mountains, Romanian Carpathians), a cold talus slope-rock glacier system developed at a mean altitude of 1050 m asl, characterized by multiannual air temperatures of about +7 °C. The scree deposit is relatively shallow (12 m deep) and has low ice content, as inferred from geophysical survey and borehole drilling. Twenty Hobo thermistors (0-15 m depth) placed inside the borehole indicated that the coldest conditions are at 7 m depth and that in the 2021-2022 hydrological year the subzero temperatures at this depth were interrupted only for a few hours by slightly positive temperatures in August indicating seasonal frost at the borehole location but possible permafrost nearby.

Geophysical surveys on coarse-blocky talus slopes – What can we learn about ice content from the ambiguity between ERT and refraction seismic results?

Christin Hilbich (University of Fribourg), Tamara Mathys (University of Fribourg), Coline Mollaret (University of Fribourg), Răzvan Popescu (University of Bucharest) and Christian Hauck (University of Fribourg).

Abstract

The ice content within coarse-blocky talus slopes is currently of growing interest, especially in the context of the role of permafrost for the hydrologic cycle in arid and semi-arid mountain ranges, such as the Central Andes or the Pamir and Tien Shan mountains in Central Asia. Coarse-blocky permafrost landforms are considered to store significant amounts of water, but while active rock glaciers obviously contain massive ground ice, leading to permafrost creep, the role of permafrost and ground ice in talus slopes is less evident. Geophysical methods, such as Electrical Resistivity Tomography (ERT) and Refraction Seismic Tomography (RST) were used extensively to characterise the internal structure of talus slopes. In most cases, resistive anomalies are observed at several meter depth and mostly in the lower part of the talus slope, which is in accordance with the concept of a porous and cold zone subject to internal ventilation as well as with the accumulation of snow at the foot of mountain slopes. However, resistive conditions do not necessarily point to frozen/ice-bearing substrate, they can also simply indicate dry porous conditions. To reduce this ambiguity, RST surveys are often conducted in addition to help discriminating between porous unsaturated (air-filled) and porous saturated (ice-filled) conditions. However, in many cases, observed velocities in talus slopes are very low (< 1000-1500 m/s), even where frozen conditions are expected, causing an ambiguity between the interpretation of ERT and RST (and partly other) data. We here present combined ERT/RST surveys from numerous talus slopes worldwide and investigate potential reasons for this striking ambiguity. We use synthetic modelling to analyse the response to different ice/air ratios in the pore space and try to narrow down the minimum ice content detectable with the RST method. With this we hope to contribute to a better understanding of the low velocities observed in talus slopes, and the question whether they still contain information about ice content.

SESSION 17
Biodiversity and biogeochemistry of permafrost ecosystems and global change

Conveners:

- **Oriol Grau**, *University of Antwerpen*; grau.oriol@gmail.com
- **Olga Margalef**, *University of Barcelona, Catalonia*; omargalefgeo@gmail.com
- **Sergi Pla-Rabés**, *CREAF, Catalonia*; sergiplarabes@gmail.com
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Summary:

The degradation of permafrost and deepening of the active layer has accelerated in subarctic and arctic regions. Air temperatures and snow depth are predicted to continue to increase in many northern regions, so this trend is expected to persist. This has major consequences for biodiversity and the functioning of subarctic and arctic permafrost ecosystems, as most biogeochemical activity occurs in the active layer. Permafrost is present in 25% of the northern hemisphere, and stores large amounts of soil organic carbon (C). The degradation of permafrost is threatening because it may turn some ecosystems from C sinks to C sources, through the accelerated decomposition of C-rich organic matter, and the emission of greenhouse gases, with major consequences on the global C balance, biodiversity and climate. Moreover, despite recent advances in the inclusion of N and P cycles into ecosystem and climatic models, the coupling with nutrient cycles is still a knowledge gap for permafrost soils. In this session we will discuss the impacts of permafrost thaw on biogeochemical and biodiversity changes, as well as the past, current and future changes associated with global change.

Contrasting water chemistry and dissolved gas concentrations in degrading thermokarst water bodies compared with surrounding wetland streams, in Iškoras, northern Norway

Heleen de Wit (Norwegian Institute for Water Research), Jacqueline Knutson (Norwegian Institute for Water Research), Francois Clayer (Norwegian Institute for Water Research) and Peter Dorsch (Norwegian Institute of Life Sciences).

Abstract

Degrading permafrost can lead to profound changes in water chemistry of downstream water bodies, and significantly affect greenhouse gas and organic matter (OM) transport. Here, we present two year of data from a degrading permafrost peat plateau (ca 4 ha) in Iškoras, Northern Norway, located in a 4 km^2 catchment. Thermokarst ponds (TK ponds) and a drainage stream (TK stream) into the downstream wet fen, and the inlet (upstream of permafrost) and outlet stream of the fen (WF stream), were sampled throughout summer season for water chemistry (pH, main cations and anions, silica, nitrate, ammonium, phosphorus, dissolved OM (DOC) and dissolved gases (CH_4, CO_2, DIC, N_2O, O_2). The TK water bodies are acidic (pH<5) compared with the WF streams (pH>6), and are higher in NH_4, DOC and totP but lower in SiO_2 and SO_4. All water bodies are oxic (TK ponds from sphagnum photosynthesis). We attribute high SO_4 and SiO_2 in WF streams to hydrological contributions from mineral soil from higher elevation in the catchment while water chemistry in TK water bodies is controlled by dissolution and mineralization of OM from destabilized permafrost soil. The outlet of the fen was more acidic and had higher DOC than the inlet of the fen, consistent with inputs from degrading permafrost. We suggest that low pH inhibited nitrification of NH4 in the TK water bodies. Dissolved CO_2 and CH_4 in the TK stream was lower than in the TK ponds, possibly from degassing during water flow. We suggest that nutrients, DOC and GHG production in water bodies in thermokarst are controlled by OM inputs from thawing thermokarst and that lateral element export can impact downstream nutrient, DOC and GHG concentrations. These signals are modified by element transport from other part of the catchmet, and by gas evasion during lateral transport.

Interplay between microbial communities, methane flux, and environment in aquatic ecosystems under arctic permafrost context

Arthur Szylit (Laboratoire d'Océanologie et de Géoscience (LOG), Université du Littoral Côte d'Opale), Ludwig Jardillier (Laboratoire Ecologie Systématique Evolution (ESE), Université Paris-Saclay), Urania Christaki (Laboratoire d'Océanologie et de Géoscience (LOG), Université du Littoral Côte d'Opale), Maialen Barret (Laboratoire d'Ecologie Fonctionnelle et Environnement (LEFE) , ENSAT, Université de Toulouse), Léa Cabrol (Instituto de Ecología & Biodiversidad (IEB), Institut Méditerranéen d'Océanologie), Sarah Ollivier (Laboratoire Géosciences Paris-Saclay (GEOPS), Université Paris-Saclay), Antoine Séjourné (Laboratoire Géosciences Paris-Saclay (GEOPS), Université Paris-Saclay), Laure Gandois (Laboratoire d'Ecologie Fonctionnelle et Environnement (LEFE) , ENSAT) and Frédéric Bouchard (Département de géomatique Appliquée, CARTEL, Université de Sherbrooke).

Abstract

Yedoma is an ice-rich Pleistocene permafrost, which for 7 % of the total permafrost area, contains about 30 % of its total carbon stock. The thawing of this carbon stock exposes a large amount of organic matter to various microbial processes in a wide diversity of wetland and aquatic ecosystems that differ in their geological context, morphology, and chemical characteristics. In these aquatic ecosystems, which increase with the permafrost thaw, methanogenic microorganisms form methane from various carbon substrates. A large part of the methane produced is oxidized by methanotrophic prokaryotes under aerobic or anaerobic conditions. Microbial composition has been documented in a small set of these ecosystems, highlighting the putative role of particular taxa in the dynamics of greenhouse gases. However, our understanding of the exact role of the environmental conditions on microbial community composition and, in return, of microbial taxa in the methane fluxes is scarce. Here, we studied the microbial communities in different lakes and water sources of a discontinuous Yedoma near Beaver Creek (Yukon territories, Canada). The preliminary objective is to relate the composition of the microbial communities to the physicochemical properties of the environment in diverse aquatic ecosystems featuring diverse geological origins, depth and sizes. This study is part of the PRISMARCTYC project, which aims to understand the impacts of permafrost thaw in a transdisciplinary approach combining geological, chemical, physical and biological data. In August 2022, water sampled from 13 lakes along a depth profile was collected for 16S rRNA metabarcoding sequencing and for functional genes quantification (mcrA, pmoA). Physicochemical parameters as well as CO_2 and CH_4 concentrations and fluxes were measured in situ at the same depths. We show here how microbial communities structure over the water column are linked with environmental conditions and how this controls methane fluxes in the diverse types of aquatic ecosystems. This abstract participates in the Outstanding PYRN Poster Award.

Iron, manganese and aluminum solubility with permafrost thaw in an Arctic peatland: coupled geochemical and geophysical measurements

Eléonore du Bois (Earth & Life Institute, Environmental Sciences (ELIE), UCLouvain), Maxime Thomas (Earth & Life Institute, Environmental Sciences (ELIE), UCLouvain), François Jonard (SPHERES Research Unit, Earth Observation and Ecosystem Modelling Laboratory, Uliège), Maëlle Villani (Earth & Life Institute, Environmental Sciences (ELIE), UCLouvain), Catherine Hirst (Durham University), Reiner Giesler (Climate Impacts Research Centre, Umeå University), Carl-Magnus Mörth (Department of Geological Sciences, Stockholm University), Erik Lundin (Abisko Scientific Research Station) and Sophie Opfergelt (Earth & Life Institute, Environmental Sciences (ELIE), UCLouvain).

Abstract

With permafrost degradation due to the increase in air temperature in high latitudes, previously frozen soil organic carbon (OC) becomes vulnerable to mineralization which reinforces the global warming through the release of greenhouse gases. Between 30 and 80 % of soil OC in permafrost environments can be stabilized by interactions with mineral surfaces or metals such as iron (Fe), manganese (Mn) and aluminum (Al). The objective in this study is to quantify the influence of permafrost degradation on the solubilization of Fe, Mn, Al and the associated OC released in soil pore water. Along a thaw gradient in Abisko, Sweden (palsa-bog-fen), the following geophysical parameters were collected: elevation, active layer depth, soil water content (SWC), soil temperature and soil electrical conductivity (EC). They were measured continuously for 20 days and coupled with the chemical composition of the soil pore water. The results suggest that (i) at the profile scale, elevation, active layer depth and SWC are relevant geophysical parameters to distinguish palsa from bog from fen; (ii) permafrost degradation leads to the solubilization of iron (1 mg.L-1 for palsa, 10 mg.L-1 for bog and 13 mg.L-1 for fen) and DOC (44 mg.L-1 for palsa, 55 mg.L-1 for bog and 71 mg.L-1 for fen) in soil pore water; (iii) at the slope scale, landscape areas can be classified as palsa, intermediate or fen based on the three relevant geophysical criteria found at the profile scale. The classification can hence be used to identify correlations between iron and DOC (r2 = 0.11 (palsa), 0.22 (bog), 0.60 (fen) and further for Mn et Al. The data support that physical changes in soils caused by permafrost thaw and subsequent changes in SWC from palsa to fen controls the stability of mineral-OC interactions.

Mass-wasting and mercury along the Churchill River in the continuous permafrost zone of Far North Manitoba, Canada

Adam Kirkwood (Carleton University), Pascale Roy-Leveillee (Laval University), Nathan Basiliko (Lakehead University), Brian Branfireun (Western University) and Murray Richardson (Carleton University).

Abstract

Permafrost thaw on hillslopes causes thaw-induced mass wasting features such as retrogressive thaw slumps which have been extensively studied in Northern Canada. Further south, where permafrost is warmer and thawing rapidly, the role of permafrost in mass-wasting processes is understudied. In the continuous permafrost zone of Manitoba (60 oN-56oN), mass wasting features have been observed along the Churchill River, but the failure mechanism, potential role of permafrost thaw, and impacts on the biogeochemistry of the river have not been examined. This study: 1) investigates factors controlling the initiation of failures; 2) assesses the role of permafrost degradation in their occurrence; and 3) assesses the biogeochemical impacts on mercury cycling. Remotely sensed imagery was obtained from 1950, 2005, 2016, and 2022 to compare the occurrence and expansion of slumps to climatic triggers and to calculate area/volume of failures. Ground penetrating radar was run along the intact riverbank adjacent to failures to determine the presence of permafrost in the riverbank. Twenty sediment samples were collected from two representative failures, and 18 water samples were taken along the main channel and tributaries of the Churchill River before and after a series of slope failures along a 50 km transect. Water and sediment samples were analyzed for total- and methyl-mercury (THg and MeHg) concentrations using USEPA methods 1630, 1631, and 7473. Preliminary results reveal that there have been few to no new major failures in the last 5 years. MeHg is below MDL for 50 of 58 samples, and the mean THg concentration is 8.34 ± 3.64 ng/g. There is little variation in filtered THg and MeHg concentrations (mean 1.24 and 0.07 ng/L, respectively) from water samples before and after series of failures, indicating that despite continuous erosion of slump lobes there is little continuous input of Hg to the river after initial failure.

A preliminary study of the biodiversity on the San Felix rock glacier, Cordillera Chila, Peru

Katy Medina (Faculty of Environmental Sciences (FCAM), Santiago Antunez de Mayolo National University (UNASAM), Sofia Rodriguez-Venturo (Faculty of Biological Sciences, National University of San Marcos (UNMSM), Edwin Loarte (Faculty of Environmental Sciences (FCAM), Santiago Antunez de Mayolo National University (UNASAM), Nataly Taco-Taype (National Forestry and Wildlife Service (SERFOR), Hairo León-Dextre (Faculty of Environmental Sciences (FCAM), Santiago Antunez de Mayolo National University (UNASAM) and Miluska Alejo-Mosquera (Faculty of Environmental Sciences (FCAM), Santiago Antunez de Mayolo National University (UNASAM).

Abstract

Rock glaciers are cryospheric landforms developed from accumulations of ice and debris, and are excellent indicators of current or past permafrost. Despite recent research addressing the impacts of climate change, biological characterization in rock glaciers and surface runoff waters from such glaciers is still scarce. The present investigation focused on San Felix rock glacier (cordillera Chila, Peru), where the plant composition on the rock glacier surface and the benthic macroinvertebrate diversity of glacier runoff were studied during the period 2020-2021. It was observed that the vegetation cover was lower in the highest area of the glacier (upper limit) and progressively increased in areas of lower altitude (rock glacier front). Another aspect that was evidenced was the predominance of vascular plant species of the families Asteraceae and Poaceae, and of the lichens of the species Rhizocarpon geographicum, Xanthoria sp. and Lecanora sp. As for the macroinvertebrate communities, a low diversity was evidenced in all the sampling points analyzed (H': 1 - 1. 4), with greater richness and abundance of taxa in the points more distant from the glacier runoff; the Chironomidae (Insecta) family being the most representative at the point closest to the glacier, while the Elmidae (Insecta) and Hydrobiosidae (Insecta) families were the most predominant at the points farthest from the glacier. This study provides preliminary information on the composition of plant species associated with the surface of rock glaciers, which could be used as indicators of the dynamics of these kinds of glaciers; it also provides information on the species diversity of benthic organisms for further studies of ecological evolution in the headwaters in the context of a progressive retreat of rock glaciers in the tropical Andes of Peru.

Increased microbial decomposition associated to warming in Arctic ecosystems

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Abstract

Arctic ecosystems are deeply affected by the ongoing climate warming. One of the consequences of warming of Arctic soils is shrub expansion, which results in higher amount of plant-derived substrates, either as litter or plant-root exudates. Microorganisms play key roles in the carbon cycle and are paramount in tundra soils. Our aim was to investigate the response of microorganisms to decomposition of plant-derived substrates in tundra soils under a scenario of increased summer temperature and increased snow cover conditions via stable isotope probing (SIP). For our study, we used soils from an in situ climate manipulation experiment established in Western Greenland (Disko Island) in 2013 with open top chambers (simulating expected increase in summer temperatures) and snow fences (simulating expected increase in winter precipitation). Soil samples for our experiment were collected in summer 2021 from treatment combination and control soils and used for incubations in the laboratory to study the microbial decomposition of both complex (cellulose) and simple organic compounds (glucose and acetate as model compounds for plant exudates). For tracking decomposition, we used ^{13}C-stable-isotopically labelled compounds and monitored respiration (formation of labelled $^{13}C\text{-}CO_2$) and biomass (incorporation into the DNA) as indicators of substrate decomposition by microbial communities. DNA was extracted after one week and after one month of soil incubation and separated by isopycnic centrifugation into heavy and light ^{13}C-DNA-fractions. Our experiment revealed high 13C-CO_2 production after one week for incubated soils amended with glucose and acetate. Substantially less 13C-CO_2 was produced in incubations amended with cellulose. We also found differences between warmed and control soils, where warmed soils usually showed higher $^{13}C\text{-}CO_2$ production. DNA-SIP showed that 13C was incorporated into the microbial biomass although varied among substrates. We conclude that warming may induce higher respiration of simple carbon compounds and enhance microbial biomass formation from organic matter decomposition.

Methylmercury concentrations in a degrading palsa field near Kangiqsualujjuaq, Nunavik (Canada)

Rose-Marie Cardinal (Centre d'études nordiques, Department of Geography, Université Laval, Québec), Pascale Roy-Léveillée (Centre d'études nordiques, Department of Geography, Université Laval, Québec), Sarah Gauthier (Centre d'études nordiques, Department of Geography, Université Laval, Québec), Michael Kwan (Nunavik Research Centre) and Brian Branfireun (Department of Biology, Western University, Ontario).

Abstract

Palsas, formed in peatlands by the aggradation of segregated ice, are widespread in the discontinuous permafrost zone. Their organic, carbon-rich upper layer is associated with inorganic mercury (IHg) deposited from natural and anthropogenic sources. Permafrost degradation can change environmental conditions that control Hg methylation, an anaerobic microbial process that converts Hg into its organic and neurotoxic form, methylmercury (MeHg). However, changes in mercury methylation concentration through the progressive thaw and stabilization of permafrost features is understudied. In Kangiqsualujjuaq, Nunavik (Canada), palsa fields degrade rapidly and create evolving mosaics of hydrological and ecological conditions through progressive palsa collapse, ponding, and revegetation. This research examines whether the geomorphological and ecological evolution of such a degrading palsa field creates environmental conditions conducive to the methylation of IHg. Remotely sensed imagery from 1964 to 2021 was used to examine geomorphic change and informed the selection of 90 sampling sites, including: palsas (n=13), rim ridges (n=12), and thermokarst depressions at different stages of pond formation and revegetation (n=65). Hydrological and ecological conditions including water depth, vegetation cover, red/ox potential, and organic layer thickness were assessed in the field. Over 150 soil samples were collected along the degradation and revegetation toposequences to characterize THg and MeHg concentrations, as well as related soil chemical parameters (C, N, S). The methylated fraction of THg (%MeHg) was lowest in palsas (0,62 %), followed by rim ridges (2,13%), and highest in thermokarst depressions (6,34 %) where it was also most variable (σ = 5,28). Net methylation concentration varied between stages of pond terrestrialization, and was highest during intermediate successional stages with open water and submerged dead Betula glandulosa (8,02 %) or abundant Cyperaceae spp (8,12 %). This study combines permafrost geomorphology and Hg biogeochemistry to better link the evolution of permafrost landscapes to the impacts of warming on Hg cycling.

Flow-path changes in permafrost soils affect Fe-organic carbon interactions: evidence from silicon isotopes

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Abstract

In a warming Arctic, active layer is thickening and winter conditions can locally not be sufficient to freeze it back entirely. This leaves residual unfrozen soil portions in winter, which can remain unconnected (isolated), or create new lateral subsurface water flow paths (connected). These flow-path changes increase the soil biogeochemical connectivity by contributing to the lateral transfer of nutrients such as dissolved organic carbon (DOC) and iron (Fe). Identifying these flow-path changes is essential given the key role of Fe for soil OC stabilization, and hence permafrost C emissions. We posit that isolated and connected systems can be identified using silicon isotopes (δ30Si): in isolated systems, freezing induces amorphous silica precipitation which preferentially incorporates the light Si isotopes, and the presence of colloidal amorphous silica in soil pore waters (spw; <0.2µm) decreases δ30Sispw; whereas in connected systems, amorphous silica precipitation is not induced. To test our hypothesis, we collected a temporal series of soil pore water from September to November 2021 on a natural gradient of permafrost degradation palsa-bog-fen in Stordalen (Sweden) to measure their δ30Si and Fe and DOC concentrations. Results show that upon freezing: (i) δ30Si remains stable in palsa (~-0.74‰), decreases in bog (from 0.067 to -0.29‰) and increases in fen (from -0.25 to 0.29‰); (ii) concentrations in DOC and Fe are stable in palsa, increase in bog (Fe-oxides dissolution in reducing conditions), and are divided by two in fen (Fe-oxides precipitation and lateral transfer to rivers). These data support changes in water flow-paths in the active layer between systems that are frozen (palsa), unfrozen isolated (bog) and unfrozen connected (fen). The δ30Sispw in fen can be explained by Si adsorption onto Fe-oxides, highlighting the presence of mineral surfaces for OC stabilization. The evolution of Fe-OC interactions in solution with flow-path changes is investigated using geochemical modeling.

This abstract participates in the Outstanding PYRN Oral Communication / Poster Award.

Biogeochemical changes in response to permafrost thaw in subarctic and arctic peatlands

Oriol Grau (University of Antwerpen), Olga Margalef (University of Barcelona), Hans Joosten (Greifswald University), Andreas Richter (University of Vienna), Alberto Canarini (University of Vienna), Inge Van de Putte (University of Antwerpen), Nicolás Valiente (University of Vienna), Victori Martin (University of Vienna), Sergi Pla-Rabés (CREAF), John Couwenberg (Greifswald University), Cornelia Rottensteiner (University of Vienna), Christop Gall (University of Vienna), Pere Roc Fernàndez (CREAF), Josep Peñuelas (CREAF) and Ivan Janssens (University of Greifswald).

Abstract

Climate warming accelerates the decomposition of old organic matter in permafrost peatlands, as the active layer becomes thicker. Permafrost thaw re-activates the cycling of carbon and nutrients, leading to higher availability of essential nutrients such as nitrogen, phosphorus or potassium, and enhances ecosystem productivity and greenhouse gas emissions. It is though unknown whether the mobilisation of nutrients may lead to stoichiometric imbalances in plants and microbes in these fragile ecosystems and whether permafrost thaw may promote shifts in nutrient limitation. Here we compare the results from subarctic palsa mires and arctic polygon mires in Sweden and North America, where we sampled vegetation and soil samples to 1 m depth across several permafrost thaw gradients in discontinuous and continuous permafrost. We analysed C and nutrient concentrations in plants, soils and microbes, as well as microbial enzymatic activity. Our results show that the biogeochemical and stoichiometric changes observed in plants, soil and microbes at different soil layers and across the gradients of permafrost thaw evidence that ongoing and future environmental changes will have a major impact on the functioning of these permafrost peatlands across circumpolar regions.

Influence of geomorphology and permafrost degradation on permafrost porewater DOM composition

Laure Gandois (CNRS, LEFE), Nic Jelinski (University of Minnesota-Twin Cities), Irfan Ainuddin (University of Minnesota-Twin Cities), Megan Andersen (University of Minnesota-Twin Cities), Frederic Bouchard (Université de Sherbrooke), Aurélie Noret (Université Paris Saclay), Sarah Ollivier (Université Paris Saclay) and Antoine Séjourné (Université Paris Saclay).

Abstract

Yedoma is an ice-rich Pleistocene permafrost covering 1 million of km^2 in the Arctic. Yedoma dissolved organic matter (DOM) has been studied in Alaska and Eastern Siberia and has been shown to be potentially highly labile, with a specific composition. In this study, we investigate pore water dissolved organic carbon (DOC) concentrations and DOM characteristics (DOC:DON ratio, optical properties and organic acid concentrations) in a continuous Yedoma permafrost area in the Yukon (Canada), in the surroundings of Beaver Creek. This study is part of the PRISMARCTYC project aiming at better understanding the impacts of permafrost thaw on soils, groundwater fluxes and carbon cycle. In this area, characterized by a complex glacial and periglacial history, the ice-rich Yedoma permafrost is unconformably overlain by Holocene permafrost of different ice and organic content. In August 2022, permafrost cores were sampled in various locations representing different soil types, geomorphological context and permafrost degradation levels. Porewater was extracted on the sampling day using rhizons. Pore water was analyzed for dissolved carbon and nitrogen, water stable isotopes and small organic acid concentrations. Preliminary results showed a wide range of DOC concentrations, from 12 to more than 200 mg.L-1, the highest concentrations being measured in thermokarst gully exposures. No trend could be observed with depth for aromaticity and molecular weight of DOM. Contrastingly, in all cores, the contribution of microbial-derived DOM, as revealed by the fluorescence index value, increased with depth. All cores showed a decreasing trend in $\delta^{18}O$ of water, potentially related to the age of permafrost ice. Additional results will be incorporated after finalization of the analysis before the conference, to better constrain the potential effects of geomorphological context and recent permafrost degradation on DOC and DOM dynamics in permafrost soils of the Yedoma domain.

Sediment profile characterization of small thermokarst peatland lakes in the Taiga Plains

Cristian Estop Aragonés (University of Münster), Mckenzie A. Kuhn (University of New Hampshire), Klaus-Holger Knorr (University of Münster) and David Olefeldt (University of Alberta).

Abstract

Small peatland lakes and ponds formed following permafrost thaw (thermokarst lakes) are landscape features with the largest CH_4 emissions and high rates of biogeochemical cycling. While physical and biological controls are usually related with net CH_4 emissions, sediment geochemistry may also reflect lake biogeochemical processes and control CH_4 release but this is commonly not documented. Additionally, both thaw and groundwater connectivity may further influence sediment characteristics but little information is available. Here we present surface sediment geochemistry profiles from representative small (4000 to 20000 m2) thermokarst peatland lakes in the Taiga Plains ecozone (Canada) affected by different groundwater connectivity. Sediment cores were collected at the thawing edges and at the center of the lakes. Elemental content of C, N, P, Fe, S, Ca among others and isotopic content of ^{13}C, ^{15}N, ^{34}S as well as organic matter humification indices were quantified at 2 cm resolution scale along with additional analysis of water chemistry and gas exchange. Higher electrical conductivity and sulfate concentrations, lower elevation as well as greater content of Ca, Mg, Na, K, Cl and S in sediments indicated greater groundwater influence in one lake. Preliminary results indicate contrasting Fe and S content that align well with dissolved iron and sulfides porewater profiles. Observed differences in ^{13}C, ^{15}N, ^{34}S could be related by differences in pH and speciation of dissolved inorganic carbon species, relative differences in contribution of allochthonous and autochthonous sediments and differences in S redox cycling, respectively. Differences in Fe redox chemistry and Ca availability may also influence P content, which decreased with depth and dictated N:P ratio increasing depth trends. Lower humification was observed in the thawing edge profiles. Sediment geochemical data needs to be put in context with water redox chemistry and CH_4 production and emission in these lakes.

Variability of iron involved in organic carbon protection in thawing palsa mires across northern Scandinavia

Anne Eberle (School of Earth Sciences, University of Bristol), Fin Ring-Hrubesh (School of Earth Sciences, University of Bristol), Hanna Lee (Department of Biology, Norwegian University of Science and Technology – NTNU, Trondheim), Angela Gallego-Sala (Geography Department, College of Life and Environmental Sciences, University of Exeter), Richard D. Pancost (Organic Geochemistry Unit, School of Chemistry and School of Earth Sciences, University of Bristol) and Casey Bryce (School of Earth Sciences, University of Bristol).

Abstract

In a warming Arctic, permafrost thaw will potentially unlock huge amounts of carbon for microbial decomposition, increasing greenhouse gas emissions from soils. A large proportion of affected carbon is currently preserved in permafrost peatlands, including palsas (frozen peat mounds). However, controls on the extent of greenhouse gas production during permafrost thaw in peatlands, are still a big uncertainty in climate projections. One mechanism for protection of organic matter is association with iron minerals, which can protect soil organic carbon against microbial degradation. In Stordalen mire, a palsa mire in northern Sweden, up to 20 % of organic carbon was found in association with iron minerals in oxic peat layers. However, when palsas thaw and collapse into waterlogged peatlands, reducing conditions cause microbial iron reduction and dissolution of minerals, releasing the associated carbon. In addition, iron can be involved in carbon metabolism as an electron donor and a nutrient. Little is known about how the impact of iron on protection of organic matter varies across palsa mires, or how this is impacted by palsa collapse. We sampled peat cores and pore water from eight thawing palsa mires in Norbotten, Sweden, and Finnmark, Norway. We quantified iron-carbon associations across the different sites, identifying that both peat depth and the composition of the underlying material is a strong predictor on release of iron and carbon following palsa collapse. Understanding these changes and differences between peatlands will help to predict the role of permafrost peatlands for carbon emissions triggered by permafrost thaw across northern Scandinavia.

SESSION 18
Studying past environments to understand current permafrost dynamics

Conveners:

- **Sergi Pla-Rabés.** *CREAF, Catalonia, Spain; sergiplarabes@gmail.com Santiago Giralt. GEO3BCN-CSIC*; sgiralt@geo3bcn.csic.es
- **Dermot Antoniades.** *Laval University;* Dermot.Antoniades@cen.ulaval.ca
- **Julia Gracia-Oteyza.** *Universitat de Barcelona;* juliaoteyzaciria@gmail.com
- **Olga Margalef.** *Universitat de Barcelona;* omargalefgeo@gmail.com

Summary:

Over the last several decades, permafrost regions have undergone accelerated climate and environmental changes that are modifying the biogeochemistry and the biodiversity of inland ecosystems (terrestrial and aquatic), resulting in dramatic socio-economic consequences. Permafrost degradation is predicted to continue into the coming decades as climate models project further increases in air temperatures and changes in precipitation regimes. The scarcity of long-term and spatial instrumental data hampers the study of permafrost dynamics as past responses to climate changes remain poorly understood. In this regard, lakes located in permafrost regions and their sediment records can serve as sentinels of environmental change recording and integrating signals of environmental and societal change at local and global spatial scales and annual to millennial temporal scales. Studies of these records may provide the linkage between recently observed patterns and the natural responses of terrestrial ecosystems to past and present climate variability. This session welcomes abstracts studying inland environmental archives, such as lake sediments, peatland, fluvial/alluvial, and periglacial deposits. The primary purpose of this session is to report the latest developments in understanding past environments in permafrost regions and identify gaps and areas for future research.

Cryofacies of massive ice of the western sector of Russian Arctic

Nataliya Belova (Lomonosov Moscow State University, Faculy of Geography; Earth's Cryosphere Institute, Tyumen Scientific Centre SB RAS), Lev Kuzyakin (Lomonosov Moscow State University, Faculy of Geography) and Anfisa Pismeniuk (Lomonosov Moscow State University, Faculy of Geography).

Abstract

The north of Western Siberia is the main area of massive ice bed distribution in the Russian Arctic. Their origin is most often associated with permafrost aggradation in the Pleistocene. This aggradation could be either a result of the ice sheets recession or a result of the freezing of sediments that have risen above the sea level as a result of its relative fall. Despite numerous and effective geochemical methods for studying massive ice, the reconstruction of freezing conditions and ice formation mechanisms requires, first of all, a detailed description of both the macrostructure of ice bodies and ice cryofacies. Here we present typical cryofacies of massive ice beds, studied in thin sections of ice monoliths in the cold laboratory of the Faculty of Geography, MSU. Massive ice monoliths were collected during expeditions of the Earth's Cryosphere Institute and Faculty of Geography, MSU, in 2019-2022. The "upper" massive ice from the Marre-Sale area, western Yamal, has cryofacies similar to those in massive ice in lake sediments on the right bank of the Norilskaya River. Large ice crystals (up to 10 cm) and a few suspensions of fine debris (but with large blocks of clay at Norilskaya River) can indicate ice formation during the slow freezing of the enclosing deposits under stable freezing conditions. Layered massive ice near Amderma, Yugorsky Peninsula (>4.5 m thick, overlayed by marine clays), and massive ice near the Vaskiny Dachi research station in Central Yamal (>3 m thick, overlayed by continental sediments) are characterized by a large variety of cryofacies. Crystal size depends on the content of mineral inclusions. A variety of cryofacies indicates the formation of these massive ice beds in changing freezing conditions. The study was supported by the Russian Science Foundation project No. 23-27-00218.

A 14,000-year record of mercury concentration from a lake sediment core in the continuous permafrost region of Central Yakutia (Sakha Republic)

Lara Hughes-Allen (Universite Paris-Saclay), Frederic Bouchard (Universite de Sherbrooke), Boris Biskaborn (Alfred Wegener Institute (AWI) and Jeroen Sonke (Geosciences Environnement Toulouse (GET).

Abstract

In a warming Arctic, heavy metals, including mercury (Hg), are released from frozen soils to the atmosphere as increasing temperature and other disturbances cause permafrost thawing. Hg further enters hydrological ecosystems (streams, lakes, wetlands) and food chains. Studying past permafrost Hg dynamics, via natural archives of Hg accumulation, as a function of climate and environmental change may help understand ongoing and future Hg trajectories in warming permafrost landscapes. In this study, we present the results of Hg concentration and stable isotope analysis of a 7 m-long sediment core (spanning the last 14,000 years) from Lake Malaya Chabyda within the Central Yakutia region. The results of the Hg analyses are combined with published results of a multiproxy biogeochemical analysis, including organic carbon (OC) concentrations and accumulation rates, on the same sediment core. Our results indicate high rates of Hg accumulation (> 1 ug Hg m-2 yr-1) between ~ 10,000 cal BP and 8,000 cal BP, which corresponds to a period of high OC accumulation (> 80 g OC m-2 yr-1). It is possible that the peak in Hg accumulation is related to increases in primary productivity within the lake, resulting from changing climatic conditions and nutrient availability. Fluctuations in Hg concentrations and Hg isotope signatures in the sediment core indicate that climate and landscape conditions are important drivers of Hg dynamics in permafrost aquatic environments.

Tracking climate-driven changes in carbon dynamics in the Mackenzie Delta region using compound-specific radiocarbon analysis

Julie Lattaud (ETHZ), Timothy Eglinton (ETHZ), Negar Haghipour (ETHZ) and Lisa Bröder (ETHZ).

Abstract

The Arctic is undergoing accelerated changes in response to ongoing alterations to the climate system (Arctic report card 2019), and there is a need for local to regional scale records of past climate variability in order to put these changes into historical context. As for much of the Arctic, the Mackenzie Delta region (Northwestern Territories, Canada) is expected to undergo marked environmental perturbations, such as permafrost thaw and earlier melting of river ice. The Mackenzie Delta is populated by numerous small shallow lakes that are classified as no-, low- and high-closure lakes, reflecting varying degrees of connection to the river main stem, and as a result, have different sedimentation characteristics. As a consequence of climate change, the annual flood pulse (freshet) may decline, potentially resulting in the disconnection of some lakes from the river, leading to their subsequent desiccation (Lesack et al., 2014; Lesack & Marsh, 2010). In contrast, an invigorated hydrological cycle, abrupt permafrost thaw and enhanced thermokarst-related processes might lead to additional lake formation and deepening of already formed lakes. In this study, we examined sediment cores originating from several lakes within the Mackenzie Delta, representing the three types of connectivity to the river (Lattaud et al., 2021). Radiocarbon and stable carbon isotopic signatures of two groups of compounds - fatty acids and isoprenoid and branched glycerol dialkyl glycerol tetraethers (GDGTs) - are employed as tracers of carbon supply to, and cycling within the different lakes. Short-chain fatty acids as well as GDGTs serve as putative tracers of microbial production while long-chain fatty acids originate from higher terrestrial plants. The carbon isotopic signatures are used to distinguish between the relative importance of carbon inputs derived from in situ production, as well as from proximal (lake periphery) and distal (Mackenzie River) sources to the different lakes in the context of their degree of connectivity. Down-core molecular ^{14}C measurements provide insights into the temporal evolution of the lakes and influence of carbon from modern, pre-aged (permafrost) and fossil (petrogenic) sources, providing context for their response to past and future climate change.

Optically stimulated luminescence ages for relict frost wedges in the Bohemian lowlands, Czech Republic

Tomáš Uxa (Institute of Geophysics, Czech Academy of Sciences, Prague), Marek Křížek (Faculty of Science, Charles University, Prague), David Krause (Faculty of Science, Charles University, Prague; Krkonoše Mountains National Park Administration, Vrchlabí) and Piotr Moska (Institute of Physics – Center for Science and Education, Silesian University of Technology, Gliwice).

Abstract

Cold climates prevailed in Central Europe throughout most of the last glacial period, which led to the growth of permafrost. Prolonged low temperatures and rapid temperature drops in frozen substrates caused their thermally induced contraction, which resulted in massive ground cracking over extensive areas and the development of frost wedges that are therefore excellent indicators of past presence of at least discontinuous permafrost. But while the distribution of relict frost wedges is relatively well known, their chronology is still poorly established, which inhibits our knowledge of the last glacial permafrost evolution there. This is especially true for the Czech Republic where most of the research on frost wedges took place in the 1950s and 1960s when modern numerical dating methods were not yet available. Here, we present optically stimulated luminescence (OSL) ages for seven relict frost wedges situated at four study sites in the Bohemian lowlands, Czech Republic (13°22'–16°00' E, 50°00'–50°30' N, 230–350 m asl). The OSL ages indicate that the frost-wedge development (~permafrost occurrence) peaked during the Last Glacial Maximum and that its latest phase took place during the early Late Glacial, which is consistent with similar Central-Western European records and other palaeo-environmental archives. The collected OSL ages provide the first extended dataset on the chronology of relict frost wedges in this overlooked area in the middle of Central Europe, which is essential for reconstructing regional permafrost evolution or for validation of models of past permafrost dynamics.
The research is supported by the Czech Science Foundation, project number 21-23196S.

Permafrost and depositional setting in the Beenchime-Salaatinsky Crater, Northern Yakutia

Georg Schwamborn (Istanbul Technical University, Eurasia Institute of Earth Sciences), Ulli Raschke (Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover), Ali Mohammadi (Istanbul Technical University, Eurasia Institute of Earth Sciences), Anatoly Zhuravlev (Diamond and Precious Metal Geology Institute, Yakutsk), Nikolai Oparin (Diamond and Precious Metal Geology Institute, Yakutsk), Andrei V. Prokopiev (Diamond and Precious Metal Geology Institute, Yakutsk), Boris Biskaborn (Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Potsdam), Christoph Manthey (Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Potsdam) and Lutz Schirrmeister (Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Potsdam).

Abstract

The Beenchime-Salaatinsky Crater (BSC) is a multi-million-year-old and fairly weathered ring structure with 8 km in diameter in Northern Yakutia (Russian Arctic). It is poorly understood in age (>65 ma or ~40±20 ma), in origin (kimberlitic vs. meteoritic), and in sub surface geometry, all of which waits to be fully disclosed. Scientifically exploiting the site in greater detail promises for a better understanding of long-term environmental dynamics from an area, which likely never was glaciated and where permafrost is presumably thickest (>1 km) in the northern hemisphere. After a pilot campaign and near-surface geological sampling this study presents results from (i) microscopical studies of bedrock material to enlighten the BSC origin and (ii) extracting biotic and abiotic proxy data from the sedimentary basin fill. Universal stage polarized-light microscopy for the first time shows an impact related shocked quartz mineral with PDF (planar deformation features), which is a high priority feature arguing for a meteoric impact. Precambrian and Palaeozoic zircon grains (U-Pb dated) from crater rim and crater floor bedrock remnants exhibit distinct traces of freeze-thaw stress under permafrost conditions, when inspected using SEM, CL, and BSE imagery. Permafrost studies in the BSC include sediment dating (using ^{14}C AMS), reconstructing fluvial-alluvial transport dynamics (grain size composition, TOC/TN, $d^{13}C$) and ground ice formation back to MIS 3 (dD, dO). This late Quaternary history also holds a thermokarst lake development starting during the early Holocene Thermal Maximum and late Holocene ice wedge growth in an ice-rich peat environment. The thickness of Quaternary deposits has yet to be defined, this is also true with detecting structures of the crater base below the basin fill. This requires deeper geophysical investigations (e.g. geoelectrics, gravity measurements) and deeper drilling.

Long-term perspectives on the landscape evolution in permafrost-ice regions of NE Greenland

Julia Garcia-Oteyza Ciria (Department of Geography, Universitat de Barcelona), Marc Oliva (Department of Geography, Universitat de Barcelona), David Palacios (Department of Geography, Universidad Complutense de Madrid), Jose María Fernández-Fernández (Department of Geography, Universidad Complutense de Madrid), Irene Schimmelpfenni (Aix‐Marseille Université, CEREGE), Santiago Giralt (Geosciences Barcelona (GEO3BCN-CSIC), Dermot Antoniades (Department of Geography & Centre for Northern Studies, Université Laval, Quebec, Canada), Sergi Pla-Rabes (Center for Ecological Research and Forestry Applications (CREAF), Spain), Marcelo Fernandes (Centre for Geographical Studies, IGOT, Lisbon, Universidade de Lisboa), Nuria Andrés (Department of Geography, Universidad Complutense de Madrid), Vincent Jomelli (Aix‐Marseille Université, CEREGE) and Aster Team (Consortium: Georges Aumaître, Karim Keddadouche).

Abstract

Although past oscillations of the Greenland Ice Sheet (GrIS) have played a prominent role in global environmental changes, its glacial response to natural variability still needs to be better constrained. Alongside this, the scarcity of long-term data from inland environmental archives still needs to be improved for remote high Arctic areas. The timing of deglaciation also has implications for local terrestrial ecosystems, including permafrost dynamics. This communication focuses on reconstructing the deglaciation history and landscape transformation along the NE GrIS coastal margins (74°N, 20°-22ºE), precisely, in two valleys; Zackenberg Valley and Tyroler Valley. We combine detailed geomorphological mapping, new datasets of 10Be cosmic-ray exposure (CRE) ages from different glacial landforms, and sedimentary lake records from different ice-free valleys in continuous permafrost terrain. The CRE results suggest that: (i) the deglaciation of the upper slopes started by ~13.7–12.5 ka, which accelerated paraglacial slope processes; (ii) the lowest parts of the valley became ice-free during the Early Holocene, at ca. 10-8.5 ka; (iii) The present-day glacier foreland record evidence of Neoglacial advances before ca. 5.9 ka, and two advances during the Little Ice Age (LIA, 0.6 ka, and 0.3 ka), confirming thus that the deglaciation was not a continuous process. Sub-millennial temperature reconstructions from our paleolimnological datasets accompanied these results providing evidence for the onset and development of the local environmental change and the sensitivity of these remote areas. Multiproxy studies of past glacial landscape evolution and environmental response to climate variability can help to better understand how the glacial-periglacial transition occurred in the past, including current dynamics in periglacial landscape configuration in these permafrost environments.

Synthesis of historical thaw records in interior Alaska- back to the future

Thomas Douglas (Cold Regions Research and Engineering Laboratory) and Merritt Turetsky (University of Colorado Boulder Institute of Arctic and Alpine Research).

Abstract

Permafrost degradation has been documented across Interior Alaska using a variety of ground surveys and remote sensing. Changes in surface vegetation, hydrology, and thermokarst extent that can be identified from above ground measurements support results from coring and geophysical investigations that have identified lateral thaw, talik development, and top-down thaw. Since much of the region is remote and inaccessible there is great need to synthesize high resolution measurements and models from focused sites and project them across the broader region. We have been working at a number of thaw observatories where we are coupling surface and subsurface measurements with historical reconstructions using peat records, dendrochronology, or space-for-time substitutions. Our ultimate goal is to learn about the timing, rates, and consequences of thaw. Multiyear active layer monitoring and repeat geophysical measurements such as electrical resistivity tomography reveal small-scale (i.e. meters to centimeters) areas of top-down thaw and have allowed us to reconstruct the sensitivity of thaw to annual and seasonal precipitation patterns. This level of change cannot be represented at that scale using paleoreconstructions. However, reconstructions of peat cores reveal controls on the timing and lateral spread of permafrost thaw in lowland environments. Chronosequence studies in which we have studied sites varying in time following thaw or last wildfire reveal long-term responses in ecosystem and permafrost resilience to disturbance as well as rates of recovery over time. Information across all of these temporal and spatial scales is needed to fully represent the complexity of thaw processes in large-scale models. Different approaches to compiling historical records and rates of change over space and time have their strengths and challenges which we will summarize in this presentation.

Origin of massive ice beds and host Pleistocene sediments at Marre-Sale, Western Yamal, Russia

Nataliya Belova (Lomonosov Moscow State University, Faculy of Geography; Earth's Cryosphere Institute, Tyumen Scientific Centre SB RAS), Radik Makshaev (Lomonosov Moscow State University, Faculy of Geography), Lev Kuzyakin (Lomonosov Moscow State University, Faculy of Geography) and Gleb Oblogov (Earth's Cryosphere Institute, Tyumen Scientific Centre SB RAS).

Abstract

Massive ice beds at the artic coastal lowlands of Western Siberia are mostly relics of Pleistocene epoch. The mechanisms and conditions of the formation of massive ice beds are debatable. To create or prove regional paleogeographic models, detailed comprehensive studies of ice and enclosing deposits with the reconstruction of the history of sedimentation and freezing are necessary. In August 2022, during the Earth's Cryosphere Institute expedition, massive ice and enclosing sediments in the area of the Marre-Sale weather station, previously studied in detail by many researchers, were described and sampled. In the coastal cliff of the Kara Sea, 25 m high, a section of Quaternary deposits with wedge ice and massive ice beds (the "upper" massive ice beds of the Marre-Sale key site) was studied. The upper part of the section is represented by continental sandy deposits, including syngenetic wedge ice up to 12 m in height. Massive ice occurs at a depth of 11–12 m from and is presented by two adjoined lenses 0.4 and 0.75 cm thick. The top and bottom of the ice lenses are inclined, and the contact with the host sands is unconformable – the ice lenses cut the layering of the host sandy stratum. At a depth of 12 m, the massive ice is dissected by the tail of wedge ice. Massive ice beds contain almost no sediment inclusions, and the crystals of ice are big (individual crystals have a size of more than 10 cm), which indicates relatively slow freezing. Such a structure shows that this massive ice was formed earlier than the Late Pleistocene wedge ice during intrasedimental freezing of a water-saturated sandy stratum. The study was supported by the Russian Science Foundation project No. 23-27-00218.

Greenhouse gas trapped in Alaska's permafrost ice wedges

Nikolai Fedorov (Seoul National University, Seoul, South Korea), Jaeyeong Park (Seoul National University, Seoul, South Korea), Neyeon Go (Seoul National University, Seoul, South Korea), Jinho Ahn (Seoul National University, Seoul, South Korea) and Go Iwahana (International Arctic Research Center, University of Alaska Fairbanks, Fairbanks, AK, USA).

Abstract

Under the influence of drastic climate change, scientists pay more attention to the rapid feedbacks of Arctic environments. In particular, rapid degradation of permafrost has been observed, but the future predictions are still limited due to lack of understanding of the process. To evaluate the dynamics, as an important environmental archive, Ice wedges were used to study paleoclimate and paleoenvironments during the Late Pleistocene and the Holocene. Especially, stable water isotopes, greenhouse gases (GHG) composition, soil contents and chemistry can provide records of past environmental changes. This study focuses on the gas geochemistry of three ice wedges in the North Slope and interior Alaska (CRREL Tunnel), covering carbon dioxide (CO_2) methane (CH_4) and nitrous oxide (N_2O) as well as N_2-O_2-Ar composition. The greenhouse gas concentration was measured by a wet extraction technique at Laboratory of Ice Core and Paleoclimate at Seoul National University, South Korea. For all three ice wedge sites, the GHG mixing ratios vary 0.5 % to 88.79 % for CO_2, 376.55 ppm to 25.55% for CH_4, and 0.25 ppm to 31.23 ppm for N_2O. All of three ice wedges showed higher of CO_2 and CH_4 ratios compared to atmospheric ratios. The molar ratios of $\delta(O_2/Ar)$ and $\delta(N_2/Ar)$ vary between -98.34 % ~ -14.99 % and -60.56 % ~ 1.93 %, respectively, indicating that some of the ice was formed by freezing of liquid water. During the presentation, we will compare the Alaska data with those from the Central Yakutia and Kolyma river Basin in Northeastern Siberia. Our paleoenvironmental approach can help us better understand the evolution of Beringia since the Last Glacial Maximum.

"This abstract participates in the Outstanding PYRN Oral Communication / Poster Award"

Coldspots of European Mid-Mountains (the Karkonosze Mts. case study)

Marek Kasprzak (University of Wroclaw), Andrzej Traczyk (University of Wroclaw), Krzysztof Migała (University of Wroclaw), Krzysztof Krakowski (Karkonosze National Park) and Petr Tábořík (Institute of Rock Structure and Mechanics of the Czech Academy of Sciences).

Abstract

We use the term 'coldspots' to refer to specific locations where low ground temperatures can persist. We look for them in the European Mid-Mountains, which are most often overlooked when considering the presence of perennially frozen ground. Meanwhile, in unusual terrain situations, such as under coarse-grained slope covers, in rock clefts or caves, year-round ice and thus low ground temperatures exist. In this study, we consider the case of the Karkonosze Mts., which are the highest range of the Bohemian Massif (1603 m a.s.l.) and the entire Variscan Mountains of Central Europe. This massif bears evident traces of Pleistocene glaciations and processes operating in a periglacial environment. It is characterised by a specific climate with many days with air temperature transitions through 0 °C and a vegetation cover with relict species. Measurements of temperatures carried out within coarse-grained slope covers and GIS modelling of freezing processes prove that even today, despite pronounced climate changes, the persistence of low temperatures near the ground surface is possible. Winter ground freezing has the most substantial effect on the ground in snow deflation zones in the altitude zone of 1250–1450 meters above sea level, lower than the highest mountain peaks in the Karkonosze. These zones coincide with the occurrence of block covers. The granite bedrock's electrical resistivity tomography (ERT) indicated the existence of rock bodies with extremely high electrical resistivity values, imaged 50 m below the ground surface, which can be interpreted as relict permafrost. In the absence of direct thermal measurements, it is impossible to determine conclusively whether these values are due to the behaviour of frozen rock, effectively isolated from atmospheric thermal conditions and liquid waters, or to the characteristics of the bedrock itself. However, due to the existing local terrain, we do not exclude the possibility that this site is where relict permafrost has been preserved.

Permafrost history in Fennoscandian peatlands during the last 6000 years

Marit Hichens-Bergström (Stockholm University, Departement of Physical Geography and Bolin Centre for Climate Research) and A. Britta K. Sannel (Stockholm University, Departement of Physical Geography and Bolin Centre for Climate Research).

Abstract

Peatlands in the permafrost region have acted as long-term net carbon sinks throughout the Holocene and are important soil organic carbon reservoirs. Circum-Arctic warmer air temperatures can cause thawing and degradation of permafrost peatlands, resulting in extensive emissions of climate-forcing trace gases such as CO_2 and CH_4. In order to better be able to project future carbon feedbacks from these ecosystems an increased understanding of the permafrost history is needed. In this study we have conducted high resolution plant macrofossil and geochemical analyses, and AMS radiocarbon dating of active layer cores from four locations in the sporadic permafrost zone, two in northern Sweden and two in Finnmark, northern Norway. The relationship between $\delta^{15}N$ and C/N was used as a supplement to plant macrofossil analysis for interpreting the timing of permafrost aggradation. In the mid-Holocene all four sites were wet fens, and at least three of them remained permafrost-free until a shift in vegetation towards bog species was recorded around 800-400 cal. a BP, indicating permafrost aggradation during the Little Ice Age (LIA). In the uppermost peat layers the C/N ratio was high, supporting that permafrost development and frost heave took place during the LIA. At one site, Karlebotn, the plant macrofossil record also signify a period of dry bog conditions between 3300-2900 cal. a BP, followed by a rapid shift towards species growing in waterlogged fens or open pools, suggesting that permafrost was present around 3000 cal. a BP but thawed and was replaced by thermokarst.

Plant material from the intestinal tract of a frozen steppe bison (Bison priscus) carcass - a window into ice-age environments

Frank Kienast (Senckenberg Research Institute and Natural History Museum, Research Station for Quaternary Palaeontology Weimar) and Pavel Nikolskiy (Geological Institute of the Russian Academy of Sciences, Moscow).

Abstract

A complete mummy of a Late Pleistocene steppe bison (Bison priscus) preserved in permafrost sediments was recovered at a steep frozen bank of the Alazeya River in the Kolyma Lowlands, Yakutia in 2009. Thick deposits of subcutaneous and visceral fat suggest that the bison was in good health at the moment of death, which was result of a predator attack indicated by a large laceration at the underbelly. Direct dating of collagen from bone and skin tissues yielded radiocarbon ages of > 48000 and > 41000 years BP, which together with stratigraphic context suggested that the bison lived during MIS 3. Plant material was taken from the intact intestine for preliminary analyses of the bison's diet using macrofossils. The studied bulk consisted of remains of grass (Poaceae), and as indicated by the preserved fruits of only one grass species, nearly exclusively of alkali grass (Puccinellia sp.). This productive, nutritious grass species usually grows on brackish soil (solonchak) and, together with the other detected facultative halophytes Chenopodium prostratum and Ch. album, it suggests that the bison grazed on a saline meadow shortly before it died. As the coast line, due to eustatic sea level lowering, was shifted hundreds of km north of its current position, the salinification of the ground during the time of the bison's existence must have resulted from aridity. Of particular interest might be a single remain of larch (Larix gmelinii) indicating the presence of trees in today's treeless coastal tundra lowlands. The rapid recolonization of trees at the beginning of the Holocene suggested the existence of cryptic tree refugia in Northern Siberia during Pleistocene cold stages, which is now verified by this macrofossil. Further research will drive the study of the intestinal content forward using a DNA analyses.

Study of massive ice beds on Eastern Chukotka coasts (near the Lavrentiya community)

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Abstract

Massive ice beds are lenticular-shaped ice formations distinguished by the shape. They have a thickness from 0.5 m to 30-50 m and can reach a length of more than 100 m. The term “massive ice” reflects only the morphology of the ice body, while the genesis of such objects remains the subject of scientific debates. Eastern Chukotka is one of the regions of widespread massive ice occurrence. In the vicinity of Lavrentiya community (Chukotka Autonomous Okrug, NE Russia), they have been studying since 2015. During the study period, six massive ice deposits were found and described. To determine the genesis of massive ice, we applied several methods: cryolithological analysis, analysis of the isotopic composition of ice, analysis of the composition of gas inclusions in ice. The latter method has been widely used recently to study formation ice in Yamal region and was used for the first time for Eastern Chukotka. We performed the extraction of gases from ice using the headspacemethod. Gas chromatography analysis of the extracted gas phase was performed in VNIIOkeangeologia. The most important charateristics for determining the genesis of massive ice are the values of methane concentration. The massive ice of Eastern Chukotka is characterized by low methane concentrations. For two massive ice discovered in sediments of the marine and glacial-marine terraces, they are 2-3 ppm, which is close to the values of methane concentration in the air. We assume that these deposits are of buried (glacial or snowpatch) origin. In massive ice bodies in the sediments of the glacial plain, methane concentrations range from 30 to 400 ppm. We conclude that these bodies are most likely of subsurface genesis. Presumably, they were formed during the epigenetic freezing of the deposits of the glacial plain in the Late Pleistocene.

Permafrost-free Miocene: a window to the future?

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Abstract

Speleothems from caves near the Lena River delta in northern Siberia were investigated by the ISOPERM project team members. Today, this area has a mean annual air temperature (MAAT) of -12°C. Active growth of speleothems is linked to time periods when the area was permafrost-free (MAAT of >-2°C), with water seeping freely through the epikarst (Vaks et al., 2013, 2020). Preliminary dates from these deposits yield a late Miocene age, around 9 million years before present, which suggests that a majority of Siberian permafrost was still absent when global mean temperatures were approximately 4.5°C warmer than present. Ice wedge pseudomorphs provide evidence for permafrost during the late Pliocene around 3 Ma (Murton, 2022), but little is known about older time periods. Thus, the late Miocene may represent a window to the future if we pursue a "business as usual" scenario such as the SSP5-8.5 projection of 4.6-5.2°C warming by 2100 (Nazarenko et al., 2022). As part of this ongoing study, we aim to quantify the amount of soil organic carbon (SOC) that could be vulnerable to release from permafrost thaw. Total SOC in the northern permafrost regions (excluding the Tibetan Plateau) is estimated to contain around 813 Pg C (Palmtag et al., 2022a, 2022b). When comparing the GHCN land surface air temperature (Fan and van den Dool, 2008) and SOC datasets, we find that the area of thaw up to a modern-day MAAT isotherm of -12°C near the study site holds an estimated 740 Pg C in the upper 3 meters of soil. The total amount and proportion of carbon that would be emitted to the atmosphere in the form of CO_2 or CH_4 remains unclear (and is a major uncertainty in future climate change projections), but ultimately would be an important feedback contributing to the greenhouse effect.
ISOPERM is a four-year Leverhulme funded project started in 2021, investigating Siberian permafrost stability along a transect from Lake Baikal in southern Siberia to the Laptev Sea coast in northern Siberia. Our team uses speleothem (calcium carbonate cave deposits such as stalagmites and flowstones) and permafrost (ice wedge, pore ice, fossil ostracods and mollusks) archives to reconstruct permafrost and drivers of permafrost thaw.

Citations:
Fan, Y., and van den Dool, H. (2008). A global monthly land surface air temperature analysis for 1948-present, Journal of Geophysical Research, 113, D01103, https://doi.org/10.1029/2007JD008470.
Murton, J. B. (2021). What and where are periglacial landscapes? Permafrost and Periglacial Processes, 32(2), 186-212.
Nazarenko, L. S. et al. (2022). Future Climate Change under SSP Emission Scenarios with GISS-E2. 1. Journal of Advances in Modeling Earth Systems, 14(7), e2021MS002871. https://doi.org/10.1029/2021MS002871
Palmtag J. et al. (2022a) A high spatial resolution soil carbon and nitrogen dataset for the northern permafrost region. Dataset version 1. Bolin Centre Database. https://doi.org/10.17043/palmtag-2022-spatial-1
Palmtag, J. et al. (2022b). A high spatial resolution soil carbon and nitrogen dataset for the northern permafrost region based on circumpolar land cover upscaling. Earth System Science Data, 14(9), 4095-4110. https://doi.org/10.5194/essd-14-4095-2022
Vaks, A. et al. (2013) Speleothems reveal 500,000-year history of Siberian permafrost. Science, 340(6129), 183–186. https://doi.org/10.1126/science.1228729.
Vaks, A. et al. (2020) Palaeoclimate evidence of vulnerable permafrost during times of low sea ice, Nature, 577(7789), 221–225. https://doi.org/10.1038/s41586-019-1880-1

Holocene reconstruction of a palsa mire (Abisko, Sweden, 68ºN) through macrofossil analysis

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Abstract

Peatlands in high latitude regions often co-occur with discontinuous permafrost zones. Vertical peat accumulation in frozen environments can provide very useful multi-proxy records for paleoenvironmental studies, as very detailed historical reconstructions can be conducted thanks to the excellent preservation conditions of the animal and plant remains. We studied a 120 cm peat core extracted from a palsa (peat mound with a permafrost core) on the Storflaket Mire (Abisko, Sweden, 68ºN). This record contains more than 9 kyr of paleoenvironmental information. Mainly focussing on the ecological interpretation of macrofossil remains found throughout the core, we detected noticeable landscape and environmental changes during the Holocene, which could be caused by autogenic and climatic variations. Macrofossils also shed light on the formation process of the palsa and allowed estimating the moment of its elevation and, consequently, the formation of active permafrost. We found evidence of a sharp switch of habitats in the mid-Holocene, from mineral-rich flooded environment dominated by brown mosses (Scorpidium scorpioides and Warnstorfia tundrae) to a drier peatland with highest presence of vascular plants, mainly Cyperaceae. This moment coincides with the appearance of the majority of the vascular plants seeds and roots found along the core. Moreover, mite remains also sustain this habitat-transition hypothesis. We suggest that dryer conditions of the mire topsoil would have triggered permafrost formation, causing the peat surface uplift and its oxidation. This loss of material resulted in a gap between 4020 and 818 cal. yr. BP. The top layer of the record is characterized by dry palsa peat, indicating the functioning of a palsa system since 1100AD. Understanding the dynamics and ecological drivers of peatlands is crucial for predicting the resilience of these systems in front of the current global warming, as well as the impact that their degradation could mean for the atmosphere, biosphere and hydrosphere.

Characteristics of last glacial polygonal sorted patterns from high-resolution airborne data

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Abstract

Sorted patterns are abundant features in past and present periglacial landscapes that greatly affect ecosystem dynamics and are also valuable indicators of past permafrost and climate states, but have so far been investigated mostly by field methods, which are usually challenging due to high time requirements and poor pattern visibility from a ground perspective. Here, we demonstrate that the region-wide high-resolution digital elevation model (DEM) and aerial photographs with a resolution of 0.5 m and 0.2 m, respectively, allow to reliably map and analyse large sets of last glacial sorted nets at one site in the Krkonoše Mts., Czech Republic, and to determine many of their geometric parameters, which would be difficult in conventional field surveys. Basic remotely sensed parameters such as length, width, and diameter of the sorted nets differ by less than ~13 % from the field-based values measured at the same study site, whereas the height is ~35% lower. Most remotely sensed parameters of the sorted nets typically require ~30–100 observations for the absolute percentage error to be constantly below 5 % of the mean parameter value. It can be expected that a higher-resolution DEM would further reduce both the deviations and the number of observations needed. Besides that, the remotely sensed diameter of the sorted nets can also be used to estimate the thickness of the past active layer over permafrost, which was nearly 1 m at the study site during the Last Glacial Maximum and the mean annual air temperature likely declined by at least ~5–8 °C compared to the modern climate. Consequently, remote sensing can bring a wealth of new information on sorted patterns and their characteristics, and aid in past permafrost and climate modelling.

The research is supported by the Czech Science Foundation, project number 21-23196S.

Western Beringia and beyond - three decades of German-Russian paleoenvironmental research on Siberian permafrost

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Abstract

With first joint fieldwork on Taymyr Peninsula during mid-1990s, a successful cooperation of German, Russian, and further international partners on permafrost and Quaternary palaeoenvironments in Siberia was started and resulted in extensive joint research for 3 decades. Studies of permafrost deposits and ground ice provided insights on past environmental and climatic changes, covering several hundreds of thousands of years into the past. They provide multi-proxy evidence for multiple glacial/interglacial cycles and different periods of past climate change or stability in Arctic land environments. Study objects were natural permafrost exposures along coastal sections, thaw slumps, and river banks, studied mostly during summers, complemented by permafrost cores from land, lake and sea ground drilled mostly in spring. Exposure geometry and stratigraphic horizon thickness have been surveyed using laser tachymetry, other measuring equipment, and drones. Based on multi-proxy analyses, mid- and late Quaternary periods were studied, resulting in >300 scientific papers. The approach includes geomorphic studies, various geochronological analyses, analysis of frozen sediments (for ice, carbon, nitrogen, and carbonate contents, grain-size parameters, magnetic susceptibility, heavy mineral compositions), ground ice (stable water isotopes, major ions) and of numerous fossil bioindicators, to reconstruct the Quaternary paleoenvironmental change. Oldest permafrost horizons were dated from the Batagay mega-thaw-slump (Yana Uplands) to about 650 ky with luminescence dating. Here and elsewhere, records of Eemian and Holocene interglacial periods, and environmental conditions associated with it were targeted. Many sites with late Pleistocene Yedoma Ice Complex have been explored. Lateglacial and Holocene warming induced enormous periglacial landscape changes by widespread permafrost degradation and substantial paleoecological changes. For vast Siberian areas where glacial records are not available, we aim on the establishment of permafrost as paleoclimatic archive, emphasizing peculiarities of permafrost age control and record resolution and stressing the great potential for understanding climate variability on glacial-interglacial timescales in Western Beringia.

SESSION 19

Carbon stocks, soil properties, greenhouse gas fluxes and atmospheric feedbacks of permafrost regions

Conveners:

- **Matthias Siewert.** *Department of Ecology and Environmental Science, Umeå University;* matthias.siewert@umu.se
- **Gustaf Hugelius.** *Department of Physical Geography, Stockholm University;* gustaf.hugelius@natgeo.su.se
- **Claire Treat.** *Alfred Wegener Institute Helmholtz Center for Polar and Marine Research;* Claire.treat@awi.de

Summary:

This session brings together research that aims to better quantify the role of permafrost regions in the global carbon cycle and other atmospheric feedbacks. Studies have shown that soils, peatlands, Yedoma and deltaic deposits in the circumpolar permafrost region store around half the global soil organic carbon (SOC). Much of this carbon has accumulated since Pleistocene times and is protected from decomposition and erosion by waterlogging and low temperatures close to or below the freezing point. Increasing atmospheric temperatures and changes in hydrologic conditions risk to remobilize this carbon and generate emissions of carbon dioxide (CO_2) and methane (CH_4). Also other greenhouse gases such as nitrous oxide (N_2O) are increasingly recognized in their importance. The magnitude of potential feedback effects with the atmosphere are still under debate, including the effect of increased greenhouse gas fluxes from permafrost landscapes on the global radiation balance and changes in source and sink budgets of landscapes through vegetation growth and other mechanisms. We invite all contributions that broadly address these topics. This may include studies that (1) quantify stocks of carbon and nutrients related to greenhouse gas fluxes and vegetation productivity such as nitrogen (N) and phosphorus (P) in soils, peatlands and sediments of the permafrost region. (2) Contributions that aim to better understand source and sinks of greenhouse gases in permafrost landscapes or (3) provide long-term assessments of greenhouse gas flux dynamics. As well as (4) simulations of past, present and future feedbacks of permafrost regions with the atmosphere. Contributions may provide a microbial to global perspective and use a wide range of methods including field observations, laboratory analyses, manipulation experiments, remote sensing data or numerical modeling.

High methane production in drained lake basin wetlands in northern Alaska

Juliane Wolter (University of Potsdam, Institute of Biochemistry and Biology), Benjamin M. Jones (University of Alaska Fairbanks, Institute of Northern Engineering, Water and Environmental Research Center (WERC), Matthias Fuchs (University of Colorado Boulder, Institute of Arctic and Alpine Research), Ingeborg Bussmann (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Section Shelf Sea System Ecology), Josefine Lenz (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Permafrost Research Section), Isla H. Myers-Smith (University of Edinburgh, School of GeoSciences), Torsten Sachs (Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences), Jens Strauss (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Permafrost Research Section) and Guido Grosse (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Permafrost Research Section).

Abstract

Wetlands in drained lake basins are important elements of the Arctic carbon budget. They may store large amounts of carbon while also producing substantial amounts of greenhouse gasses. After lake drainage the former lake bottom is colonized by pioneer graminoids, succeeded by moss-sedge-dwarf shrub vegetation, producing a typical peat sequence. However, post-drainage organic matter dynamics are not well studied. We hypothesize that vegetation composition reflects both succession and surface wetness, which in turn determine soil organic matter content and methane production. We propose that vegetation types detected by remote sensing-based landcover classification may be used to extrapolate methane production and organic matter composition across drained lake basin landscapes. We investigated (i) plots along a temporal drainage gradient, surveying vegetation, surface sediment, and pond water. We then used (ii) landcover classification of main eco-hydrological classes to (iii) upscale from plot to basin scale. We found that vegetation and organic matter changed markedly between recently drained basins and older age classes. Overall, vegetation composition differed more between eco-hydrological classes than between age classes. Surface sediments had very high water contents (>80 %), suggesting largely anaerobic conditions favouring methane production. Methane concentrations were indeed relatively constant throughout, and particularly high in sediments beneath few centimetres of water ("wet patches", up to 200 µmol/L) and in pond water (up to 22 µmol/L). Landcover classification yielded seven classes including five classes we also identified using statistical clustering of vegetation data plus a water class and a bare ground class. We found that 67 % of basin areas were occupied by wet patches with especially high methane production. Our study shows that remote sensing-based landcover classifications are useful for quantifying wet-vs-moist patches and high-vs-moderate methane production in Arctic drained lake basins. The study highlights the potential for future upscaling of methane emissions from these abundant wetland environments.

The controls on carbon mineralization in permafrost peatlands following thermokarst formation

Konstantinos-Marios Veziourakis (Department of Ecology and Genetics/Limnology, Uppsala University), Liam Heffernan (Department of Ecology and Genetics/Limnology, Uppsala University) and Lars Tranvik (Department of Ecology and Genetics/Limnology, Uppsala University).

Abstract

Permafrost peatlands accumulate and emit globally significant amounts of organic carbon and greenhouse gases. Under rapid climate warming, thaw leads to thermokarst formation in permafrost peatlands resulting in drastic shifts in temperature, waterlogging and oxygen availability. Within permafrost peatland complexes, this drastic shift in ecological conditions form distinct terrestrial (thermokarst bogs) and aquatic (thermokarst ponds) ecosystems underlain by previously frozen organic matter of similar age and composition. To examine how post-thaw ecosystem trajectories constrain peat decomposition, we ran a one-year oxic incubation (10ºC and 20ºC) with samples from the active layer, permafrost lens, and previously frozen peat along a permafrost thaw gradient (peat palsa, thermokarst bog and thermokarst pond) at four different sites in northern Scandinavia. Concomitant CO_2 and O_2 gas measurements allowed us to assess not only the magnitude of carbon mineralization at different thaw features, but also the performance of the decomposer communities calculating the respiratory quotient (RQ), defined as the molar ratio of produced CO_2 and consumed O_2 during the microbial mineralization of organic matter. We also measured the nominal oxidation state of carbon (NOSC), the bulk energy content of organic matter and the potential enzyme activity. Preliminary findings suggest that mineralization rates are highest in the upper layer of the previously frozen material under thermokarst bogs and ponds. Moreover, RQ seems to decrease over time at 20ºC, compared to its relatively stable pattern in the lower temperature, indicating a potentially enhanced microbial buildup. We argue that the mechanisms that regulate RQ following permafrost thaw will provide insights to the organic matter decay and persistence across ecosystems boundaries.

Carbon and nitrogen stocks distribution in vegetation and soil across different environments near Abisko, Northern Sweden.

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Abstract

Arctic environments undergo significant climatic changes that affect, among others, hydrology, soil processes, and plant communities of these systems. At large scale, tree-line and shrub cover expand northward, although permafrost thawing, increased snow cover and raised soil water content can promote herbaceous covers at the local scale. Our study evaluated plant community composition and carbon (C) and nitrogen (N) stocks across soil and vegetation in two mire and heathland sites at Abisko, northern Sweden. Results showed that differences in vegetation communities within and between sites imply little to no changes in total aboveground biomass and associated elemental stocks (140.1 ± 56.9 gC.m-2 and 3.7 ± 1.5 gN.m-2). However, major shifts in the distribution of short-lived (e.g. leaves) and long-lived (e.g. woody) biomasses and associated stocks were highlighted, with an increase from 1 % to up to 40 % of long-lived biomass in dryer environments. Regarding soils, C and N stocks did not echo plant communities and varied mainly at large scale between the mire (47.1 ± 9.1 kgC.m-2 and 2.6 ± 0.4 kgN.m-2 for palsa subsite; 20.2 ± 6.9 kgC.m-2 and 0.9 ± 0.4 kgN.m-2 for bog subsite) and the heathland (5.8 ± 1.4 kgC.m-2 and 0.21 ± 0.02 kgN.m-2 for dry heathland and forest understorey), and were driven mostly by soil density, soil depth, and water content. Those results suggest that large-scale shrubification is likely to increase the overall C and N stocks in these ecosystems through an increase in long-lived biomass proportion, and while the proportion of ligneous/herbaceous species seems to be a good indicator of biomass and stock distribution, soil stocks appear not to be well predicted by it.

Soil organic carbon and nitrogen stocks in lowland coastal tundra along the Canadian Beaufort Sea coast

Julia Wagner (Department of Physical Geography and Bolin Centre for Climate Research, Stockholm University), Justine Ramage (Department of Physical Geography and Bolin Centre for Climate Research, Stockholm University), Annett Bartsch (b.geos GmbH), Michael Fritz (Alfred Wegener Inst., Helmholtz Centre f. Polar & Marine Research), Juliane Wolter (Alfred Wegener Inst., Helmholtz Centre f. Polar & Marine Research; Univ. of Potsdam, Institute of Biochem. and Biology), Hugues Lantuit (Alfred Wegener Inst., Helmholtz Centre f. Polar & Marine Research) and Gustaf Hugelius (Department of Physical Geography and Bolin Centre for Climate Research, Stockholm University).

Abstract

Approximately 22 % of the earth´s terrestrial area is defined as the permafrost region. This region stores ca.1400-1600 Pg of soil organic carbon (SOC) which is approximately half of the carbon stored in all soils globally. While estimations of SOC stocks exist on a pan-arctic scale, they remain highly uncertain and there is a need for assessments on smaller scales, focusing on specific landforms and regions. Furthermore, recent studies have highlighted the need for development and application of machine learning methods to aid estimation efforts. We present a regional assessment of carbon and nitrogen stocks along the Canadian Beaufort Sea coast focusing on coastal catchments west of the Mackenzie River delta. The study synthesizes data from different sources to estimate SOC and nitrogen stocks for the study area. This estimation is based on machine learning methods in combination with environmental variables derived from remote sensing data. We apply the random forest algorithm and ensemble learners. Random forest has been proven to deliver the most accurate results as an individual algorithm. Ensemble methods can improve performance and reduce potential errors by averaging the classifier outputs. The results generated from ensemble learners are not limited by the constraints of the respective model and potential artefacts produced by the model. We are planning to present the methodology and preliminary results of the study. Our study delivers a contribution to fill a research gap by providing a regional estimation of SOC and nitrogen stocks for the Canadian Beaufort Sea coast based on novel machine learning methods.

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Predictive mapping of soil properties beyond carbon: the Alaska Soil Data Bank project

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Abstract

More than 70% (approximately 300 million acres) of the unmapped soils in the United States lie in permafrost-affected areas of the US state of Alaska. This project aims to harness disparate legacy datasets for permafrost and non-permafrost affected soils to support digital soil mapping of soil classes and diverse soil properties. The curation of novel soil point data not contained in established databases represents a major opportunity to expand the available data for digital soil mapping efforts in permafrost-affected regions such as Alaska. This legacy data ranges in scope from point observations of permafrost depth or organic layer thickness to full morphological descriptions and a wide range of soil properties. This dataset will be used in conjunction with existing data in the US Department of Agriculture soil survey database (NASIS) to produce statewide predictive maps of Alaska soil classes and properties at fine scales (10-30m resolution), and apply a novel approach to digital soil mapping (using landscape segmentation analysis) for Katmai National Park and Preserve in southern Alaska.

Exploring shoulder season greenhouse gas production along a permafrost thaw transect in sub-arctic Finnish Palsas

Mackenzie Baysinger (Alfred-Wegener-Institut (AWI)), Katharina Jentzsch (Alfred-Wegener-Institut (AWI)), Timo Kumpula (University of Eastern Finland), Mélissa Laurent (Alfred-Wegener-Institut (AWI)), Susanne Liebner (GeoForschungsZentrum Potsdam (GFZ)), Jakob Reif (Alfred-Wegener-Institut (AWI)), Jens Strauss (Alfred-Wegener-Institut (AWI)), Mariana Verdonen (University of Eastern Finland) and Claire Treat (Alfred-Wegener-Institut (AWI)).

Abstract

The future of terrestrial carbon found in permafrost is not yet well understood, but this soil carbon may be a potential significant contributor to positive-feedback loop of climatic warming. In the (sub) arctic, the annual freeze-thaw cycles and thick peat accumulation harbor ideal conditions for palsa formation. Although, a recent study at our site in Arctic Lapland found that the area of the carbon-rich palsa mounds have already decreased by -77 % to -90 % since 1960.
Here, we investigate potential greenhouse gas (CO_2, CH_4, N_2O) production from a palsa sampled along a transect with 60+ years of documented thaw. During the annual cycle of freeze-thaw, one of the largest unknowns in the life cycle of a palsa mound is the biogeochemical cycles during the shoulder season. This transition time between growing, and non-growing seasons that have previously been assumed to be times of relative dormancy for GHG flux in high-latitude wetlands. However, recent studies find that there is in fact a significant amount of GHG flux during this time.
We aim to isolate shoulder season variables (increased N from plant senescence, temperature change) and explore how they each affect the potential CO_2 and CH_4 production using ex-situ incubations, coupled with microbial community cell counts sampled in tandem. Here, we test whether N addendums increase the GHG, as n-poor habitat has been shown to respond with increased microbial activity to the release of this metabolic bottleneck. In addition to the N-treatments, the samples will also be separated into three incubation temperature groups (4 , 15, 20 C) to be able to link increasing temperatures with the N response. Overall, we aim to fill knowledge gaps on these habitats response to changing climatic conditions, and use our findings to better earth system models permafrost carbon predictions.

Carbon stocks and potential greenhouse gas production of permafrost-affected active floodplains in the Lena River Delta

Tanja Herbst (Alfred Wegener Institute (AWI), Matthias Fuchs (Alfred Wegener Institute (AWI) and Claire Treat (Alfred Wegener Institute Helmholtz Center for Polar and Marine Research).

Abstract

Arctic warming increases the degradation of permafrost soils, making large deposits of formerly frozen organic matter vulnerable to microbial decomposition and releasing methane (CH_4) and carbon dioxide (CO_2) to the atmosphere. The active floodplains in Arctic river deltas are highly dynamic permafrost environments but little is known about their C stocks and potential loss with permafrost thaw. This study aims to determine soil organic carbon (SOC) stocks, accumulation rates, and the potential CH_4 and CO_2 release under aerobic and anaerobic conditions from the active floodplains of Kurungnakh and Samoylov Island in the Lena River Delta, Siberia. The mean SOC stocks were 12.89 ± 6.02 kg C m-2 with ~40 % stored in the upper 30 cm but were highly heterogeneous with depth-distribution. The estimated SOC pool for the active floodplains in the entire Lena River Delta was ~114 ± 53 Tg C. Total anaerobic CH_4 emissions ranged from 0.03 ± 0.01 to 176.95 ± 13.35 µg CH_4-C gsoil-1. The active layer samples did not reach a steady state during incubation period, and the permafrost layer samples showed a 30-day lag phase. CO_2 emissions (9.14 ± 1.31 to 417.33 ± 31.39 µg CO_2-C gsoil-1 anaerobically and 17.47 ± 1.57 to 856.12 ± 61.37 µg CO_2-C gsoil-1 aerobically) were two times higher under aerobic conditions than under anaerobic conditions, but both treatments showed a similar pattern during incubation. This comprehensive study provides valuable information on the carbon stocks and carbon release from active floodplains in the Lena River Delta and highlights the need to include these dynamic permafrost environments in future estimates of the permafrost carbon climate feedback.

Alpine permafrost – a CO_2 source upon climate warming?

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Abstract

Cold regions will experience the most pronounced warming under ongoing climate change affecting the global carbon cycle. Whereas the permafrost carbon climate feedback has been studied in high latitude regions, mountain permafrost in temperate climates remains little investigated. Paleosols, found in e.g., solifluction lobes, blockfields, or rock glaciers, might provide a carbon source that could be released during permafrost warming. To investigate alpine permafrost as a potential CO_2 source, we measured soil organic carbon (SOC) stocks and CO_2 fluxes in-situ at ice-poor and -rich permafrost sites in the Swiss Alps. The ice-poor site at 3100 m a.sl. on a mountain ridge consists of a few decimeters of debris, covering a dark and fine-textured substrate, which contains degraded soil organic carbon (0.8 % SOC, >1.4 kg C/m^2, high δ13C of -23.2 ‰, narrow C/N ratio of 10.7). Radiocarbon contents and CN analysis of rocks will give further insight into the age and origin. Regardless of its origin, this substrate released 0.2-0.5 % of its SOC stock within one month upon incubation at 10 and 22°C and, moreover, 2.8 mg CO_2-C/m2/h during in-situ chamber measurements at the end of August 2022. CO_2 flux measurements on four rock glaciers proved to be more difficult because of the blocky surface. We therefore covered an area of 8x10m with an air-tight tarp on wind-calm days for up to an hour, yielding similar CO_2 effluxes as with soil chambers in a validation assay on vegetation-free soil. On rock glaciers, we did not detect any CO_2 release. Overall, these first measurements indicate that SOC in alpine permafrost is prone to be released upon climate warming, however, only in the high alpine ice-poor permafrost region by possibly paleosols. Future carbon measurements of ice, permafrost, and additional paleosol samples will provide further insight into the role of alpine permafrost on the carbon cycle.

Testing the suitability of a low-cost CH_4 sensor for flux chamber measurements in a boreal peatland

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Abstract

Developing low-cost methods for capturing methane (CH_4) emissions is crucial to quantify greenhouse gas (GHG) sources and sinks in northern high latitudes. Wetlands are the largest natural source of atmospheric methane, making them highly relevant for overall GHG budgets. Methane production of Arctic wetlands has been found to be strongly influenced by rising temperatures and wetter conditions. Permafrost thaw has been shown to release significant amounts of CH_4 but the processes leading to this flux are currently poorly understood. Datasets from high-latitude wetlands are limited in their temporal and spatial resolution due to limited access, short-term sampling campaigns and costly expeditions and equipment. As the affordability of high-frequency gas analyzers represents a major constraint for climate research, developing low-cost CH_4 sensors holds great potential for facilitating GHG measurements in these environments. This study aims to test the potential for low-cost CH_4 sensors for flux chamber measurements in Arctic wetlands. The sensors were tested for short-term measurements in a transparent manual flux chamber on various microtopography plots in a boreal bog in July 2022, with a high-frequency Los Gatos Research gas analyzer for reference. The sensors were also tested for longer-term measurements in automated flux chambers at the same site in autumn 2022, with a reference Picarro G2508 gas analyzer. This allowed testing the sensors in different environments and seasons in the wetland. Additionally, cross-calibration measurements before and after field use were made to check the sensors for drift and establish calibration curves. The performance of the low-cost sensors relative to the reference methods under the studied conditions in northern peatlands will be presented. This study aids in developing low-cost methods for measuring CH_4 to overcome financial constraints in environmental research, which can support remote sensing data and climate models by facilitating ground truth measurements at higher temporal and spatial resolution.

Topographic Variability of Soil Carbon and Nitrogen Stocks in Hilly Permafrost Terrain of the Northern Arctic Foothills

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Abstract

Constraining the variability of soil organic carbon (SOC) and total nitrogen (TN) stocks across hillslopes in permafrost-mantled terrain of the low Arctic remains a significant challenge for improving uncertainties in global estimates of permafrost SOC stocks. Despite studies focusing on SOC and TN stocks across regional climate gradients in the northern circumpolar region, the lack of quantitative data across hillslope toposequences introduces large uncertainties in SOC estimates at regional and global scales. Therefore, constraining SOC stocks across permafrost-region hillslopes remains a significant challenge for improving earth system models. We investigated SOC and TN stocks across hillslopes in two locations that make up a portion of the North American Arctic Transect in the Arctic Foothills of Alaska, USA (Happy Valley and Sagwon Hills). SOC and TN stocks were linearly related (R2 = 0.74), and variability was greatest within rather than between hillslope positions, a distinct difference between soils of non-permafrost landscapes. Furthermore, SOC and TN stocks did not generally vary by hillslope position nor were they closely associated with major geomorphic parameters (i.e. slope, curvature) that are typically good predictors of SOC and TN stocks across most landscapes. The landscapes processes unique to permafrost features such as ice wedge polygons, non-sorted circles, and water tracks associated with patterned ground along with soil cryoturbation and variation in ice content across these landscapes contribute to the relatively even distribution of SOC and TN stocks along hillslope positions for both sites.
The high local variability in SOC and TN stocks introduced by patterned ground (in the form of ice wedge polygons, non-sorted circles, and water tracks), in addition to processes of cryoturbation and variability in ice content obscure and confound typical relationships between SOC and TN stocks and environmental co-variates. This work underlines the importance of local toposequence studies to underpin broader regional scale predictive efforts.

Using Earth Observation to determine permafrost degradation and methane emissions from palsa peatlands in Scandinavia

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Abstract

Methane (CH_4) emissions from areas with degrading permafrost result from a complex mixture of micro-topographies and vegetation types that support widely differing CH_4 emissions. We used (i) ultra-high resolution unoccupied aerial vehicle (UAV) data, together with Sentinel-1 and -2 data to extrapolate field measurements of CH_4 emissions from a set of vegetation types that capture the local variation in vegetation on degrading palsa peatlands and (ii) Sentinel-1 data to assess regional palsa degradation across northern Sweden. We show high spatial variability in CH_4 fluxes which related in a predictable way to local variation in vegetation type and that the ultra-high resolution UAV data can map spatial variation in vegetation relevant to variation in CH_4 emissions and extrapolate these across the wider landscape. By way of a soft classification, and simple correction of misclassification bias of a hard classification, the output vegetation mapping and subsequent extrapolation of CH_4 emissions matched closely that generated using the UAV data. InSAR assessment of subsidence show large scale degradation of palsa peatlands with subsidence occurring in 55% of the area of Swedens eight largest palsa peatlands. However, degradation varied over region with the most rapid degradation being in the most northerly sites. We show that InSAR together with the vegetation classification can be used to quantify areas at risk of increased CH_4 emissions. We estimate that a transition of an area currently experiencing subsidence to fen type vegetation would result in an increase in emissions from 116 kg CH_4 season-1 from our 50 ha study area, to emissions as high as 6500 to 13000 kg CH_4 season-1. The key outcome from this study is that a fusion of EO data types provides the ability to estimate ongoing permafrost degradation at regional scales and CH_4 emissions from large geographies covered by a fine mixture of vegetation types that are vulnerable to transition to CH_4 emitters in the near future.

Non-destructive characterization of permafrost physical properties using industrial computed tomography

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Abstract

Permafrost cores provide important data on the distribution and characteristics of frozen ground. The distribution and abundance of ground ice in permafrost is a fundamental property that determines the potential for thaw subsidence and terrain effects of permafrost landscapes. However, most methods to characterize permafrost are destructive and of low resolution. Here, we tackle these limitations of traditional destructive methods using Industrial computed tomography scanning (CT) to systematically log permafrost cores, visualize cryostructures, measure bulk density, and estimate volumetric and excess ice contents non-destructively. The results show strong agreement with traditional destructive analyses as well as recent developments of non-destructive methods such as multi-sensor core logging, demonstrating that these approaches can produce replicable, cost-effective measurements including digital records of permafrost physical properties. Development of these approaches will build more robust permafrost datasets and strengthen efforts to understand future thaw trajectories of permafrost landscapes.

Investigating the lability of organic matter from degrading peatland permafrost, Northern Norway

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Abstract

Permafrost regions are estimated to store twice the amount of carbon currently present in the atmosphere and their degradation can result in further greenhouse gas emissions. In many areas, including Norway, permafrost is rapidly degrading which releases stored organic carbon to decomposition and transport. Thawing of ice-rich soils in areas of low relief commonly generates thermokarst ponds, which expose old carbon to degradation and can become hotspots of greenhouse gas (GHG) emissions. These thermokarst pond systems and surrounding peatlands are hydrologically connected, allowing for the export of organic matter. However, the quantification and timing of these lateral and vertical fluxes are still poorly constrained.
We present our investigations of hydrology and dissolved organic matter (DOM) lability from a thermokarst pond and wetland system in the Iškoras peat plateau, located in Northern Norway. A 12-30 h dark incubation method is used to estimate DOM lability. Between May 2021 and September 2022, we collected water samples and performed dark incubations on 7 occasions from several thermokarst ponds, wetland streams and a lake. These samples were analyzed for greenhouse gas (CO_2, CH_4 and N_2O) and O_2 concentrations. Gas concentrations in water samples and at the end of the dark incubations were analyzed by gas chromatography following headspace equilibrium. High frequency water height and temperature sensors were installed in autumn 2021.
A preliminary analysis indicates that the thermokarst ponds are higher in concentrations of CH_4 than the wetland, while CO_2 concentrations are not as spatially variable. N_2O shows seasonal variability and is likely controlled by vegetative uptake of nitrogen, although there is still high production in the ponds. Results from dark incubations highlight the lability of the organic matter originating from the permafrost plateau. In addition, 35 % of the annual discharge occurs during ice-melt which will be the focus of our May 2023 field campaign.

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CO_2 and methane dynamics in the Siberian tundra, a long-term case study

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Abstract

Siberia has the largest area of permafrost in the world. Compared to Canada, Alaska or Scandinavia, Siberia is understudied in terms of carbon flux studies. Here we present a long-term eddy co-variance study, quantifying greenhouse gas fluxes of an extremely remote Siberian arctic site. With data going back to 2003, this study offers a unique snapshot into the contemporary Siberian arctic carbon cycle. Over a period of more than 15 years, we show that the tundra is a net CO_2 sink, the strength of which is positively correlated to the start of the growing season. Carbon uptake quickly follows snowmelt. As the Arctic is warming, it is predicted that snowmelt will happen earlier in the season, which could thus result in more carbon uptake across the Siberian tundra. However, the site is a net methane source, which might offset any future gains in carbon uptake. Exactly how methane release will react to the future climate is not entirely clear and will most likely depend on changes in hydrology and permafrost conditions across the Siberian Arctic.

Modelling permafrost peatland dynamics and their effect on regional carbon fluxes

Nitin Chaudhary (Lund University).

Abstract

Peatlands are important carbon reserves in the terrestrial ecosystem and have stored around 350-500 Petagrams [1015] of carbon (PgC) over the last thousands of years, comprising around 30 % of the present-day soil organic carbon pool. Around 20 % of peatland areas coincide with permafrost, affecting carbon accumulation rates and biogeochemical processes. Permafrost peatlands contain important soil organic carbon pools averaging around ~277 PgC and are key components of the global carbon budget. Significant fractions of permafrost peatlands freeze and thaw seasonally, while substantial areas remain frozen for the entire year because of prevailing cold climate conditions, influencing their hydrological, structural, and biogeochemical properties. Until the mid-20th century, most of these distinctive permafrost carbon pools remained almost undisturbed, but recently, the ice-rich peatlands are undergoing rapid changes. Climate warming-driven permafrost thawing is changing the fine balance of these pristine landforms. Around 20 % of permafrost peatlands are subjected to abrupt thawed conditions. During this ice-degradation process, many permafrost peatlands would likely turn into major carbon sources, particularly methane, due to the formation of large water pools and peat subsidence. In this study, the process-based methane biogeochemistry module is integrated into the LPJ-GUESS peatland model. Our earlier studies have demonstrated that the mechanistic multi-layer peat accumulation scheme included in the LPJ-GUESS peatland is sufficiently robust and simulates reasonable vegetation dynamics, permafrost distribution, peat accumulation and dominant plant types across the pan-Arctic region (Chaudhary et al. 2020, 2022). We performed simulations across cold-climate peatland complexes in the pan-Arctic and Tibetan plateau to account for their contribution to total atmospheric CO_2 and methane emissions. The main objectives of the present study are to reproduce regional carbon budgets of potential natural permafrost peatlands and to assess the effects of historical and projected future climate change on their carbon balance.

Understanding cryoturbation processes – using karst caves to improve projections of soil carbon fate upon thawing permafrost

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Abstract

Large amounts of organic matter stored in permafrost soils are largely a consequence of low decomposition rates due to cold temperatures and limited water drainage. Cryoturbation is the crucial process that transports organic matter from the ground surface through the seasonally thawed active layer down to the permafrost table, where it can freeze. The cryoturbation process remains very poorly understood until today despite its crucial role in the permafrost carbon-climate feedback and thus for projections of climate change. Quantification and modelling of greenhouse gas release upon permafrost thaw requires better understanding of the transport process connecting permafrost and atmosphere through the active layer. The existing studies are largely based on observations of organic matter involutions from soil pits thus exact processes driving cryoturbation remain unknown.

The CryoKarst project will try to reveal the cryoturbation mechanisms by investigating ground properties and ground movement in karst caves and Arctic environments using advanced space-time imaging and soil analyses. The project will overcome current cryoturbation observational limitations in the cold environments by automatized space-time imaging of patterned ground in karst caves, where cave walls provide unique stable reference points and where the absence of snow cover allows to draw direct relationships between ground movements, soil properties and ground temperatures. Various photogrammetric methods will be used to derive particle movements in 3D space for hourly intervals. Cryoturbation laboratory experiments will in addition provide a unique insight into internal soil movements. Both field and laboratory observations will be used to generate an empirical cryoturbation model that could be utilized to estimate pan-Arctic cryoturbation rates.

Methane fluxes from the Arctic – an expert survey of chamber measurement techniques

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Abstract

Permafrost regions and boreal wetlands are a known source of atmospheric methane but the magnitude of emissions is unclear. One common way to measure methane emissions in remote polar regions is the static chamber method because of the portability and easy deployment. New multigas analyzers with high frequency concentration measurements reveal patterns and disturbances in chamber methane concentrations over time that call for adjustments in the measurement assumptions, derived from the earlier manual gas sampling methods. In this study, we test whether methodological differences in chamber measurements conceal natural spatial and temporal variations in methane fluxes using an expert survey. A qualitative questionnaire provides information on the variety of approaches for chamber flux measurements, calculation and quality control used by research groups all over the world. By asking experts on greenhouse gas fluxes to process a shared raw data set, we furthermore quantify the difference in methane fluxes resulting from the use of different flux calculation and quality control techniques. Our study shows the potential uncertainties of studies that combine existing flux data sets produced by different research groups as well as the need for a standardized procedure and guidelines for future chamber measurements. This is highly important to reliably quantify methane fluxes all over the world and, especially in Arctic regions where we expect the greatest changes in the near future.

Much more than carbon: Element stocks in ice-rich permafrost of the Yedoma domain

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Abstract

Soils of the permafrost zone store globally relevant reservoirs of frozen matter, such as organic matter, mineral elements as well as other biogeochemical relevant compounds like contaminants. Besides the well-studied organic carbon (OC), other compounds can become available in active biological and hydrological element cycling as global climate change is warming northern permafrost regions nearly four times faster than the global average. Current heating in Siberia is unprecedented during the past seven millennia, triggering widespread permafrost degradation and collapse. This is especially relevant for our study region, the Yedoma domain. In this region, a large amount of belowground ice is present and the ground can become unstable with warming, allowing the mobilisation of previously frozen sediments with their geochemical element contents. With this presentation, we synthesise recent studies, which have improved the understanding of various frozen stocks. Here, we estimated that the Yedoma domain contains 41.2 Gt of nitrogen (N), which increases the previous estimate for the circumpolar permafrost zone by ~46 %. The highest element stock within the Yedoma domain is estimated for Si (2739 Gt), followed by Al, Fe, K, Ca, Ti, Mn, Zr, Sr, and Zn. The stocks of Al and Fe (598 and 288 Gt, respectively) are in the same order of magnitude as OC (327-466 Gt). Concerning contaminants, we focused on mercury. Using the ratio of mercury to OC (R(HgC), value based on own measurements: 2.57 μg Hg g C−1) and the OC levels from various studies for a first rough estimation of the Hg reservoir, we estimate the Yedoma mercury pool to be ~542,000 tons. In conclusion, we find that deep thaw of the Yedoma permafrost domain and its degradation will bear the potential to change the availability of various elements in active biogeochemical and hydrological cycles in northern regions, which will have the potential to change crucial ecosystem variables and services.

Vegetation succession and carbon accumulation following permafrost thaw in Nunavik, (Northern Québec, Canada)

Édith Auclair-Fournier (Université Laval), Michelle Garneau (Université du Québec à Montréal) and Pascale Roy-Léveillée (Université Laval).

Abstract

The carbon balance of permafrost peatlands is vulnerable to warming. However, the net effect of thaw-induced carbon release vs carbon accumulation due to increased primary productivity of vegetation is still unclear. This is largely due to a scarcity of data on recent vegetation succession and productivity in the thaw features of permafrost peatlands. Using a palaeoecological approach, my project aims to document the vegetation succession dynamics following permafrost thaw in a degrading palsa field near Kangiqsualujjuaq, Nunavik. The main objectives are to i) reconstruct vegetation succession following palsa collapse, ii) quantify peat and carbon accumulation since permafrost thaw supported by ^{14}C and 210Pb chronologies, and iii) define a chronosequence of successional changes by comparing data from thermokarst depressions of different ages. It is hypothesized that vegetation composition and plant biomass increased following permafrost degradation and that carbon accumulation rates varied according to time elapsed since degradation. In the field, short peat cores will be collected from the edges of four thermokarst ponds following perpendicular transects extending from two sides of the open aquatic surface. In the laboratory, loss on ignition at 1-cm interval on each core will help quantify organic matter and related carbon content. Plant macrofossils and testate amoebae analyses will support historical plant succession and hydrological variations in the peat. Results will be compared with other studies realized within the circum-arctic domain and help evaluate the response of high-latitude peatland ecosystems to climate warming. This study contributes to documenting the role of thawing permafrost peatlands in the global carbon cycle.

The potential of high resolution landcover classification as proxy for soil properties

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Abstract

Climate-change scenarios indicate that global warming will be amplified in the Arctic regions, which could lead to a large reduction in the geographic extent of permafrost. The resilience and vulnerability of permafrost to climate change depends on complex interactions between topography, water, soil and vegetation what is also reflected in landcover. Landcover does not only provide information on above ground conditions but can be also used as proxy for sub-ground conditions. High spatial resolution datasets are required in this context. An accurate and detailed land surface description reveals spatial heterogeneity of soils and can be for example used for the characterization of permafrost state through modelling. In this study, landcover has been derived based on a two-step un-supervised/supervised classification approach covering the entire Arctic. Five Sentinel-2 bands and Sentinel-1 at 10m spatial resolution are used. The initial classes have been defined based on existing schemes for description of tundra vegetation communities as well as for flux-upscaling studies. A comprehensive soil database is used to evaluate these classes for their potential as proxy for sub-ground conditions. Results show that landscape gradients are well captured allowing quantification of heterogeneity.

Permafrost ground ice geochemistry with implications to its origin and potential post-thaw effects

Nikita Tananaev (Melnikov Permafrost Institute, SB RAS), Evgeniya Soldatova (Tyumen State University), Nataliya Belova (Moscow State University), Aleksey Lupachev (Institute of Physicochemical and Biological Problems of Soil Science RAS) and Alisa Baranskaya (Moscow State University).

Abstract

Permafrost ground ice is an important stock of organic carbon, nitrogen, and mineral elements. Besides, geochemical tracers are instructive in deducing ground ice origin which is frequently disputed. Our study is based on a collection of ground ice samples from across the Russian Arctic, from the Yamal Peninsula to Chukotka (n = 12). Most ground ice samples yield a similar REE distribution, typical for rainfall or soil pore water, depleted in light REEs (La/Lu below 0.5, La/Er below 0.6) and slightly enriched in middle REEs, notably Gd, with no particular anomalies. This pattern holds for both massive ground ice and texture ice in ice-rich permafrost, while the latter is also enriched in Fe and Mn. Two ice samples – Syrdakh (central Yakutia) and a secondary 'horn' side wedge at Stanchikovsky Yar (lower Kolyma) yield a significant negative cerium anomaly ranging from 0.18 to 0.26, which suggests oxic conditions of the open water bodies, or a shallow highly-permeable suprapermafrost aquifer. Negative Ce anomaly is associated with low metals content, but also U/Th ratio above 50, high Ba and low DOC content, which altogether implies co-precipitation of (Fe, Al, Mn)-colloids with dissolved OC compounds and their removal from the dissolved phase before ice accumulation. For these two samples, ice geochemistry is close to a signature of seasonal icings or pingo core ice accumulating in an open system. Massive ground ice with high Fe content, between 2 and 5 mg/L, we expect to be epycryogenic, and most likely from hydraulic (Parisento) or hydrostatic (Uelen) ice buildup under anoxic conditions. Potential post-thaw effects include the release into streams of organic constituents, which is most important for interstitial (texture) ice accumulating up to 270 mg/L of DOC, 34 mg/L of nitrogen (total).

Legacy effects of Siberian 2020 heatwave in 2021

Min Jung Kwon (Universität Hamburg), Philippe Ciais (Le Laboratoire des Sciences du Climat et de l'Environnement), Ana Bastos (Max Planck Institute for Biogeochemistry) and Christian Beer (Universität Hamburg).

Abstract

Intense and persistent heatwave hit Siberia in the first half of 2020. It resulted in earlier and larger CO_2 uptake in the early growing season in all biome types compared to previous years, then reduced CO_2 uptake in the late growing season in grasslands partially due to soil drying. We carried out a model experiment using a land surface model, ORCHIDEE-MICT, to investigate whether effects of heatwave in 2020 remained in 2021. We estimated the legacy effects in 2021 as the differences between the simulation results of 2021 (1) with the actual climate forcing including a heatwave event in 2020, and those (2) with the 2020 climate forcing replaced by the previous five years (2015–2019), thus, without a heatwave event in 2020. Heatwave in 2020 widely reduced soil ice content in continuous permafrost zone in Siberia in 2021 by warming soils, and accordingly it increased soil water content. Warmer and wetter soils increased CO_2 respiration, especially in central Siberia (the center of the heatwave in 2020). Warmer and wetter soils, however, resulted in contrasting responses in CO_2 uptake in 2021: forests, where CO_2 uptake was enhanced in the whole growing season of 2020, showed increased CO_2 uptake, while grasslands, where CO_2 uptake was reduced in the late growing season of 2020 due to soil water deficiency, showed reduced CO_2 uptake in 2021. Colder and drier soil environment in 2021 was coincided with reduced CO_2 respiration and uptake, and the reduction in CO_2 uptake was large in grasslands, which experienced soil water deficiency in 2020. Our results highlight that effects of strong heatwave can remain aboveground (vegetation) and belowground (soil temperature and water content) and affects CO_2 fluxes in the following year.

Soil organic carbon stocks in mountain periglacial settings of Patagonia, SW Argentina and Vindelfjällen, NW Sweden

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Abstract

We have performed detailed landscape-level inventories of soil organic carbon (SOC) storage in high mountain areas of Northern Patagonia and Vindelfjällen. The two mountain areas show similarities regarding altitudinal vegetation zones and periglacial features. Above the treeline, at c. 1400 m in Patagonia and c. 700 m in Vindelfjällen, there are patches of alpine dwarf shrubs, grasses and herbs extending up to high altitudes where the plant cover is sparser and the ground becomes gradually mostly bare. Permafrost terrain types (degrading rock glaciers in Patagonia and collapsing palsas in Vindelfjällen) are a very small landscape component, but periglacial features such as solifluction landforms with buried organic layers are prominent in both areas. Solifluction landforms are hotspots of SOC storage in the Patagonian area (mean SOC 0-100 cm of c. 18 Kg C m-2). The climate is wetter in Vindelfjällen, which favours the development of small wetland areas in the alpine vegetation belt with high SOC storage (mean SOC 0-100 cm of c. 65 Kg C m-2). Mean landscape-level SOC 0-100 cm storage is, therefore, slightly higher in the alpine vegetation belt of Vindelfjällen (8,12 Kg C m-2) compared to the Patagonia area (6,96 Kg C m-2). Both the inventories in Patagonia and Vindelfjällen show very little SOC storage in the high alpine zones. A future upward shift of plant life zones in these mountain settings will most likely result in a net total ecosystem carbon sink and a negative feedback on global warming, in contrast to the positive feedback expected from the extensive lowland permafrost regions in the high latitudes of the northern Hemisphere.

Greenhouse gas exchange beyond initial thermokarst formation in permafrost peatlands

Hanna Lee (Norwegian University of Science and Technology - NTNU), Casper Tai Christiansen (University of Copenhagen), Inge Althuizen (NORCE Norwegian Research Centre), Anders Michelsen (University of Copenhagen), Peter Dörsch (NMBU Norwegian University of Life Sciences), David Risk (St. Francis Xavier University) and Sebastian Westermann (University of Oslo).

Abstract

Initial thermokarst formation is expected to release large amounts of greenhouse gasses to the atmosphere, creating positive feedback to climate warming. The current understanding supports that thermokarst formation will lead to surface inundation, which leads to dominantly producing methane during the decomposition. Over time, natural succession may occur leading to decreased methane release and increased carbon uptake. We investigated how thermokarst formation and subsequent natural succession over time affect CO_2, CH_4, and N_2O release and uptake in northern Norway (69°N), where recent degradation of permafrost created thaw ponds in palsa peat plateau-mire ecosystems. We observed changes in vegetation, soil and water microclimate, biogeochemistry, and soil CO_2, CH_4, and N_2O fluxes. We show that abrupt permafrost thaw and land surface subsidence increase net annual carbon loss. Permafrost thaw accelerated CO_2 release greatly in thaw slumps (177.5 gCO_2 m-2) compared to intact permafrost peat plateau (59.0 gCO_2 m-2). During the growing season, peat plateau was a small sink of atmospheric CH_4 (-2.5 gCH_4 m-2), whereas permafrost thaw slumping and pond formation increased CH_4 release dramatically (ranging from 9.7 to 36.1 gCH_4 m-2). Furthermore, CH_4 release continues to increase even in natural succession likely due to aerenchyma transport of CH_4 from deeper soil. Beyond thermokarst formation, carbon uptake from the natural succession of vegetation, but we show that greenhouse gas emissions continue to increase beyond abrupt permafrost thaw event towards natural succession.

Greenhouse gas emissions from permafrost landscapes of Central and Northern Yakutia, Russia

Liudmila Krivenok (Institute of Atmospheric Physics RAS), Vladimir Kazantsev (Institute of Atmospheric Physics RAS), Nikita Ustinov (Institute of Atmospheric Physics RAS) and Nikita Tananaev (North-Eastern Federal University).

Abstract

Permafrost disturbances result in vertical differentiation of local topography, changing thermal state of soils, pathways of water transfer through ecosystems and its overall distribution in the landscape. Changing topography, insolation and soil humidity directly affects the GHG emissions from degrading permafrost soils. Our research aimed at quantifying the effects of byllars and hillslope water tracks, two widespread permafrost-related landforms, on GHG fluxes in changing climate. The 2021–2022 field studies were performed at three key sites: (1) Lena-Aldan interfluve, Central Yakutia, where byllars were mostly studied; (2) lower Indigirka near Chokurdakh, High Arctic Yakutia, where hillslope water tracks were studied; (3) lower Kolyma near Chersky, where data on recent khasyreys and fire scars were collected. Gas concentrations were observed using static and floating closed chambers, CO_2 measurements were done in situ with in-chamber mini loggers, CH_4 samples were conserved in glass vials, transferred to the lab, and analyzed with gas chromatograph. Time-averaged fluxes were calculated by approximating the time-concentration curve using linear or exponential regression. Byllar development leads to terrain differentiation into drier byllar mounds and wetter inter-byllar hollows; low CH_4 consumption is noted (median flux −0.1 mgC□m-2□h-1) but CO_2 fluxes from byllar tops are the highest observed (233.4 mgC□m-2□h-1). We can conclude that the transition from intact sparce forest surface to better drained and dissected byllar slope leads to overall increase in CO_2 fluxes. In High Arctic, both hillslope water track nourishment area and higher order streams produce high methane emissions (1.7–10.2 mgC□m-2□h-1), while inter-water track spaces, as dry tundra areas, show sub-zero CH_4 fluxes. In Chersky, recent forest fire scars produce negligible methane fluxes (0.03 mgC□m-2□h-1) given topsoil organic carbon loss to fire, though soils were significantly overwetted. Moist khasyrey sections (inter-mound ponds) produced methane but not CO_2. This study was funded by RFBR, Project 21-55-75004 PRISMARCTYC.

Impact of micro habitat properties and seasonal weather conditions on N_2O, CH_4, and CO_2 fluxes in the Arctic

Nathalie Ylenia Triches (Max Planck Institute for Biogeochemistry), Maija Marushchak (University of Eastern Finland), Christina Biasi (University of Eastern Finland), Richard Lamprecht (University of Eastern Finland), Martin Heimann (Max Planck Institute for Biogeochemistry), Timo Vesala (University of Helsinki) and Mathias Goeckede (Max Planck Institute for Biogeochemistry).

Abstract

Carbon dioxide (CO_2) and methane (CH_4) emissions in the (sub-) Arctic regions have been documented for many years, but only recent studies suggest that also substantial amounts of nitrous oxide (N_2O) may be emitted from permafrost soils. Nitrogen (N) losses occur in different forms, including N_2O, and are likely to affect the local biogeochemistry and global climate change. Up to date, only very few datasets are available that investigate the magnitude and drivers of N_2O fluxes across different micro habitats in (sub-) Arctic regions. As a result, the spatial heterogeneity of N_2O fluxes and interactions between C and N cycles in cold regions are not well understood. At the sub-Arctic Stordalen palsa mire in Sweden, field measurements were conducted using dark and transparent chambers with portable greenhouse gas analysers in September 2022 on a palsa-bog-fen thawing gradient. In May, July, and September 2023, these measurements will be repeated, providing the first extensive database of N_2O flux measurements in the (sub-) Arctic. In 2024, comparative field measurements along a disturbance gradient in Kilpisjärvi in a sub-Arctic location of Northern Finland will be added to our database. Based on these data, we analyse the effect of micro habitat properties (e.g., soil moisture, soil temperature, soil C and N content, vegetation composition) and environmental variables (e.g., PAR, air temperature) on N_2O, CH_4, and CO_2 fluxes. Our analyses differentiate between ecosystem components at very small scales, with a focus on seasonal variability between spring, summer, and autumn. Our study aims at process-based insights on the spatio-temporal variability of factors controlling N_2O emissions in the (sub-) Arctic zone, and therefore contribute to understand the potential role of N_2O fluxes for present and future Arctic greenhouse gas budgets.

This abstract participates in the Outstanding PYRN Oral Communication / Poster Award.

Ratio of in situ CO_2 to CH_4 production and its environmental controls in polygonal tundra soils of Samoylov Island, Northeastern Siberia

Leonardo A. Galera (Universität Hamburg), Tim Eckhardt (Universität Hamburg), Christian Beer (Universität Hamburg), Eva-Maria Pfeiffer (Universität Hamburg) and Christian Knoblauch (Universität Hamburg).

Abstract

The Arctic is warming and causing permafrost to thaw, which is accelerating the decomposition of soil organic matter and release of carbon dioxide (CO_2) and methane (CH_4). However, the ratio of CO_2 to CH_4 production is not well understood. Our study aimed to address this gap by measuring CO_2 and CH_4 fluxes from a polygon in Samoylov Island, Lena River Delta, Siberia. We found that at the water-saturated site, the CO_2 to CH_4 ratio decreased sharply over the vegetation period, with a median of 12.2 (7.70 - 17.1). When considering the impact of CH_4 oxidation, the ratios were even lower. The main factors affecting these ratios were soil temperature and active layer depth. Heterotrophic respiration was related to topsoil temperatures, while CH_4 production was associated with subsoil temperature. On the other hand, the ratios were substantially higher at the dry site, with a median of 373 (292 - 500). Both sites lost carbon primarily in the form of CO_2, and CH_4 only represented a small fraction of the total carbon loss. Our study provides important insights into the dynamic of CO_2 to CH_4 ratios from soil organic matter decomposition in the Arctic. These findings will help to improve predictions of future CO_2 and CH_4 fluxes from thawing tundra soils and provide a clearer understanding of the impact of permafrost thaw on the Arctic environment.

Research on landscape-permafrost diversity of the carbon polygon

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Abstract

Global warming has the greatest impact on the permafrost conditions of circumpolar latitudes, including the Yamal Peninsula. Rising air temperatures inevitably lead to the permafrost ground warming, which changes the overall landscape pattern of the Arctic North. In 2019, a representative carbon polygon was established within the II Karginsky terrace in the vicinity of Labytnangi (66°43'34 "N, 66°16'22 "E). The purpose of the polygon was to organize observations of methane emission within the frozen tundra areas, to provide heterogeneous tundra space monitoring: the seasonal thaw condition evaluation, soil temperature regime, their physical and chemical characteristics, description of the main prevailing geophytocenoses and the species composition of their composing plants. To reveal patterns of permafrost conditions distribution in different physical conditions, the landscape-indication method was used on «key sites»: natural-territorial complexes were identified according to geomorphological and biogeographical features. Geo-referencing was carried out using a GNSS receiver; seasonal thaw depth was estimated using a permafrost dipstick; soil horizons were assessed using pits; and surface, ground and air temperatures were measured using TAYLOR 9842 and CEM DT-130 thermometers. At the first stage of the research, the north-eastern section of the landfill was studied, selected according to the wetting, microrelief and vegetation conditions affecting greenhouse gas activity. The work results of the collected data identified 10 NTC within the site, showing different types of tundra space. A map of the distribution of NTC within the north-eastern section of the carbon polygon has been drawn up based on the results of the permafrost-landscape research.

Greenlandic Glacial and Periglacial Catchments Mobilize Particulate and Dissolved Organic Carbon of Contrasted Ages and Fates

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Abstract

Climate-change driven thaw of the Greenland ice sheet and permafrost amplifies organic carbon mobilization from soils to aquatic ecosystems. Leaching of dissolved organic carbon (DOC) and erosion of particulate organic carbon (POC) from Arctic landscapes impact aquatic ecosystems and greenhouse gas emissions in contrasted ways. While DOC fuels riverine microbial activity, POC is translocated and buried in the marine environment. The fate of old glacial and permafrost-derived DOC and POC remains unclear but is crucial for predicting feedback on aquatic ecosystems and climate change. As radiocarbon measurements are suitable tools for investigating sources and processing of carbon, we investigate variations in ^{14}C ages of POC and DOC along the land-to-ocean compartments (soils, groundwater, lakes, rivers and benthos) in the Zackenberg valley (Northeastern Greenland, 74°N). Samples were collected in August 2019 and 2021 and analyzed for carbon concentrations and radiocarbon ages. We found that POC was substantially older (650 to 32,000 years, equivalent to Δ^{14}C -86 to -982‰) than DOC (modern to 3,000 years, equivalent to Δ^{14}C 156 to -327‰) across the sampled compartments. Small streams fed by glaciers and perennial snowpacks exported older DOC (Δ^{14}C ~-200‰) than the big glacial Zackenberg (Δ^{14}C ~-200‰). Permafrost ice (1 m depth) had the oldest DOC in the watershed (Δ^{14}C -495‰, ~5,000 years). In the periglacial catchment, the contribution of the old DOC pool was greater in suprapermafrost groundwater (Δ^{14}C -110 to -290‰) than the stream (Δ^{14}C 156 to -123 ‰) and the young DOC pool contribution increased downstream. Those streams, affected by thermokarst, exported the "radiocarbon-dead" POC (Δ^{14}C −980‰). The different rivers exported carbon of contrasted ages and DOC and POC evolved differently in the land-to-ocean continuum. Perspectives would be to test POC bio-photo-degradability, trace DOC incorporation into microbial biomass, and elucidate the shared dynamics between solid and dissolved phases.

Carbon degradation and potential greenhouse gas production in a changing Arctic thermokarst landscape

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Abstract

Permafrost carbon pools are vulnerable to a warming climate and bear the potential to alter the terrestrial carbon cycle. In the extensive drained lake basins that span across Arctic lowlands, enhanced degradation of organic-rich deposits upon permafrost thaw could lead to greenhouse gas emissions to the atmosphere. Yet, little is known on the geochemical properties of the sediments in these basins and on the rate of release of greenhouse gases. This study investigates processes and intensity of organic matter decomposition and associated potential greenhouse gas production in thawed sediment from drained lake basins on the Yukon Coastal Plain in the western Canadian Arctic. We conducted a three-month low temperature (4 °C) incubation experiment, during which we measured carbon dioxide (CO_2) and methane (CH_4) production in thawed sediment from two permafrost cores from adjacent drained lake basins. To simulate current and near future greenhouse gas production potential we incubated material from the active layer as well as from the transition layer and permafrost to account for projected active layer deepening. Four replicates of each sample were incubated under aerobic and anaerobic conditions, respectively. CO_2 and CH_4 concentrations were measured by gas chromatography. The experiment was supplemented by a comprehensive lipid biomarker analysis of the same sample material before and after the incubation covering n-alkanes, n-fatty acids, triterpenoids and hopanes. Biomarker concentrations and indices (average chain length, carbon preference index, higher-plant fatty acid index) gave insights on the origin and degradation state of organic matter as well as changes to carbon accompanying the incubation experiment. In a multi-proxy approach, findings are further aligned with biogeochemical and sedimentological parameters. Results will reveal organic matter vulnerability to decomposition and potential greenhouse gas production in sediments after thawing, both of which are key elements in assessing future trajectories of carbon dynamics in drained lake basins.

Soil organic carbon burial and preservation in solifluction landforms

Peter Kuhry (Department of Physical Geography, Stockholm University).

Abstract

Detailed inventories of soil organic carbon (SOC) stocks in solifluction landforms are currently being compiled for an area with continuous permafrost on Disko Island (W Greenland), and for the Berlevåg area on Varanger Peninsula (N Norway) and areas in N Patagonia (SW Argentina) experiencing extensive seasonal frost. First results from Patagonia show highly variable SOC 0-100 cm stocks depending on solifluction feature and the location of profiles within. Very high SOC storage is observed in the riser of a solifluction terrace (51 Kg C m-2), but is moderate in a stony surface on the tread of a terrace (6 Kg C m-2). SOC stocks in slopes with extensive solifluction on Disko Island range between 1-26 Kg C m-2. Analyses for profiles in the Berlevåg area is currently underway, but field inventories indicate multiple buried organic layers in the riser of some solifluction lobes, but fragmentation or absence of such layers under treads. Available geochemical data point to significantly higher bulk density and similar or lower %C and C/N values in buried organic compared to topsoil organic layers, pointing to a compaction and variable degradation of buried organic matter in the profiles. The majority of radiocarbon dates from these buried organic layers in all three areas under investigation are of Late Holocene age. Multiple buried layers in some single profiles indicate a reactivation of solifluction processes during this time period. Solifluction landforms can represent SOC hotspots, even under conditions of extensive seasonal frost in the absence of permafrost. In order to understand their contribution to SOC storage at a landscape level it is key to assess their proportional landscape cover, the distribution and fragmentation of buried layers in the solifluction landform itself, and secondary decay processes affecting buried stocks.

Thermal Stability and Molecular Composition of Organic Matter Across a Permafrost (Yedoma sediment) Chronosequence in Alaska

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Abstract

Arctic and boreal permafrost soils store approximately 50 % of the total terrestrial carbon amount, which is two times the amount of carbon found in the atmosphere. Yedoma deposits are a special type of permafrost that have accumulated syngenetic sediment, peat, and ice in unglaciated regions, making up 10 % of the total global permafrost area and 25 % of the total C stored in permafrost-ecosystems. We collected Yedoma-permafrost samples from the CRREL Permafrost Tunnel (PT) located 12 km north of Fairbanks (Alaska, US) , at depths of approximately 10 m, 52 m, and 94 m from the tunnel portal. The organic matter in these samples was dated to be 19,000 (PT19), 27,000 (PT27), and 36,000 (PT36) years old. Additionally, near-surface (~6 m depth) permafrost located directly above the tunnel (AT) (C ~8000 years old), and Yedoma permafrost that had thawed in the past 10 years nearby CRREL Farmer's Loop site (FL) (~7 m depth). X-ray diffraction analysis confirmed the presence of quartz as the major mineral phase (>55 %), plagioclase (>20 %), and muscovite (>10%), with absence of typical soil clay minerals. Thermal analysis revealed that the C stability (i.e., temperature peak for C oxidation) of AT, PT27, PT36, and FL was approximately 290ºC and PT19 was around 310ºC, both of which were close to the purified standards of chitin (~319ºC) and cellulose (~345ºC), but far from humic acids (~510ºC). The Pyrolysis-GC/MS provided molecular information about the organic C preserved in each sample, highlighting the presence of organic compounds with low or no humification degree (e.g., squalene). The lack of organic C protection by clay material and a significant proportion of fresh organic C suggest that the C stored in this permafrost region is highly susceptible to microbial degradation upon thawing, releasing CO_2 and/or CH_4, which could further exacerbate climate warming.

Large Animal-Induced Effects on Arctic Soil Carbon Storage

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Abstract

Permafrost degradation and organic matter decomposition in the terrestrial Arctic are strongly depending on soil temperature throughout the year. These temperatures are affected in numerous ways by activity of large herbivorous animals. We identified snow compaction and animal-induced vegetation changes as key elements. Therefore, we analysed soil parameters along transects following grazing intensity in both a permafrost environment (northeastern Siberia) and seasonally frozen ground (norther Finland). Parameters included TOC, C/N ratio, d13C, bulk density and radiocarbon age. While we observed a strong increase in soil carbon storage with high grazing intensity under permafrost conditions, this effect does not show in seasonally frozen ground. However, an obvious animal-induced change in both areas was a shift in vegetation composition and structure, following the grazing gradient. We conclude that material and water fluxes in seasonally frozen ground outweigh the animals' effects, contrary to permafrost environments, but state that on permafrost, animals could help maintaining low soil temperatures and hence reduce organic material decomposition.

More than one third of the organic carbon exposed by the world's largest thaw slump (Batagay, Siberia) is not directly available for mineralization but geochemically stabilized

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Abstract

Mineral-organic carbon (OC) interactions account for 30 – 80 % of the total permafrost OC pool. Quantifying the nature and controls of mineral-OC interactions is necessary to better assess permafrost-carbon-climate feedbacks. This is particularly true for ice-rich environments that are impacted by rapid thaw and the development of thermokarst landforms. Retrogressive thaw slumps are amongst the most dynamic forms of slope thermokarst and they expand through the years due to the ablation of an ice-rich headwall. These phenomena are important to consider in the permafrost carbon budget since they expose deep OC sometimes tens of thousands of years old that would not have re-entered the modern carbon cycle if these disturbances had not occurred. Here, we analyzed sediment samples collected from the headwall of the Batagay megaslump, East Siberia, locally reaching 55 m high. The series of discontinuous deposits comprises also older sediment up to ~650 ka old. We present total element concentrations, mineralogy, and mineral-OC interactions in the different stratigraphic units. The mineralogy in the deposits is very similar across the sedimentary series. Our data show that up to 34 ± 8 % of the total OC pool is stabilized by mineral-OC interactions. For most of the analyzed samples, associations to poorly crystalline iron oxides do not have a significant role in OC stabilization. Hypothesizing a retreat rate of 26000 m^2/yr and constant thickness of stratigraphic units within the headwall, we provide a first order estimate of ~ 2 × 10^7 kg of OC is exported annually downslope of the headwall, with ~ 38 % being geochemically stabilized by complexation with metals or associations to poorly crystalline iron oxides. These data support that more than one third of the organic carbon exposed by this massive thaw slump is not directly available for mineralization, but rather stabilized geochemically.

This abstract participates in the Outstanding PYRN Oral Communication / Poster Award.

How do post-thaw hydrologic changes affect carbon cycle during the degradation process of a palsa in northern Finland?

Mélissa Laurent (Alfred-Wegener-Institut), Jens Strauss (Alfred-Wegener-Institut), Mathias Hoffmann (Leibniz-Centre for Agricultural Landscape Research), Joerg Schaller (Leibniz-Centre for Agricultural Landscape Research), Timo Kumpula (University of Eastern Finland), Mariana Verdonen (University of Eastern Finland) and Claire Treat (Alfred-Wegener-Institut).

Abstract

With climate change, discontinuous permafrost is thawing rapidly and is predicted to reach a “tipping point” in the next decade. Permafrost affected peatlands store about 185±66 Pg C. Due to permafrost thaw, the landscape topographies and hydrologic conditions could change quickly and thus, release carbon (C) stored in soils. However, there is a current lack of understanding regarding the C lability post- thaw and how the microbial community will affect methane (CH_4) and carbon dioxide (CO_2) fluxes. Here, we quantified and qualified the effect of hydrologic changes on CH_4 and CO_2 emissions and production during the thawing process of a palsa (peaty permafrost mounts, mainly in discontinuous permafrost areas). We used a chronosequence approach along a thawing transect from an intact palsa to a thawed wetland site during fall and measured CH4 and CO_2 emissions. Additionally, we experimentally simulated palsa degradation by incubating 1 m soil cores from the palsa and the wetland sites. The CO_2 and CH_4 emissions were continuously measured for 60 days. The field measurements showed that the intact palsa and the intermediate site were net CH_4 sinks while the thawed wetland site had the highest CH_4 emissions. Furthermore, we showed that a top-down sequential thawing incubation setup is an efficient and robust way to study C cycle dynamics and upscale laboratory results to the field. With permafrost thaw and former permafrost areas turning into wetlands, bridging scales to understand processes underlying greenhouse gas production is necessary to better estimate the future C emissions.

Byllars : typical periglacial landforms in central Yakutia, their origin and ecosystem functions

Nikita Tananaev (Melnikov Permafrost Institute, SB RAS), Aleksey Lupachev (Institute of Physicochemical and Biological Problems of Soil Science, RAS), Andrey Shepelev (P.I. Melnikov Permafrost Institute SB RAS), Lyudmila Krivenok (Institute of Atmospheric Physics RAS), Evgeniya Soldatova (Tyumen State University) and Vladimir Efremov (P.I. Melnikov Permafrost Institute SB RAS).

Abstract

Byllars were first described by G. Ognev (1927) as slope outwash landforms abundant at the Lena-Amga interfluve in central Yakutia, Siberia. We now consider them to be among the sentinels of permafrost degradation, created by terrain settlement due to loss of volume long the ice wedge tops, thus being thermokarst landforms. Byllars would typically not have an ice core, in which they differ from baydzherakhs. Byllars are encountered in three distinct environmental settings, (1) along the northern (south-facing) slopes of alas depressions, (2) over the abandoned clearcut areas, tills and pastures, and (3) in khasyreys. Thermokarst over alas depression slopes is driven by intense insolation, and over disturbed terrain, by the alteration of the natural land cover. Their diameter varies normally between 5 and 15 m, with an average height from 0.5 to 1.5m on plain terrain and between 2 and 3 m along the steep slopes. 'Plain' byllars have symmetrical planform while 'slope' byllars would normally have a smooth upslope side and steep downslope wall. A network of hollows was observed to experience fluvial reworking. Byllars differentiate the terrain vertically, into mounds and depressions, transforming the water transfer alond the slope and significant gradients in soil humidity; byllar tops are xeric and may expose open soil while inter-byllar hollows are relatively moist, with grasses and, locally, sedge communities between 'plain' byllars. This differentiation leads to redistribution of soil organic and inorganic carbon within the landscape, can be traced in distribution of metals and rare earth elements (REEs) within the soil profiles, and promotes carbon dioxide emissions from byllar tops exceeding those of intact forest-covered slopes. The data collected in several key sites in central Yakutia will be presented and supported by GIS analysis and discussion on future climate and its potential effect on byllars.

Soil microbiome, organic carbon stocks and stability of organic matter in permafrost soils under changing environments of North-Western Siberia

Ivan Alekseev (Arctic and Antarctic Reserch Institute), Aleksandr Shein (Yamal-Nenets Center of Arctic Research) and Antonina Chetverova (Arctic and Antarctic Research Institute).

Abstract

Qualitative and quantitative analyses of soil organic matter and soil microbial communities are crucial research directions for better understanding of changing Arctic environments, since the massive amount of organic carbon stored in permafrost soils might be vulnerable to priming, caused by the increasing availability of plant-derived organic compounds with rising temperatures. Chemical composition of soil organic matter determines its decomposability and may affect soil microbial activity. This is very important for understanding variability in soil organic carbon stocks in the context of changes in plant cover or climate. This work is aimed at characterizing existing carbon stocks and molecular organization of the humic acids as well as the assessment of microbial communities structure and identifying potential vulnerability of soils organic matter in context of possible mineralization risks. We analyzed more than 400 samples from across a vast region of North-Western Siberia. Mean soil organic carbon stocks for the study area were 7.9 ± 2.2 kg m^{-2} (for 0–10 cm layer), 15.0 ± 5.5 kg m^{-2} (for 0–30 cm), 24.0 ± 8.0 kg m^{-2} (for 0–100 cm). ^{13}C-NMR spectroscopy showed low amounts of aromatic fragments in majority studied soils and predominance of aliphatic structures as well as carbohydrates, polysaccharides, ethers and amino acids. Low level of aromaticity reflects the accumulation in soil of poorly decomposed organic matter due to cold temperatures. We found only small variability of humic acids across the latitudinal gradient of studied sites. The soil microbiome was investigated at different locations using 16S rRNA gene pyrosequencing. The taxonomic analysis of soil microbiomes revealed 48 bacterial and archaeal phyla, among which proteobacteria (27 %) and actinobacteria (20 %) were predominant. The pH range and nitrogen content were found as the main environmental determinants of microbial community diversity and composition in studied soils.

This abstract participates in the Outstanding PYRN Oral Communication / Poster Award.

SESSION 20

Characteristic Upland Periglacial Landscapes: Reality or "Geomorphic Chimera"?

Conveners:

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- **Frederick E. Nelson.** *Northern Michigan University;* fnelson@udel.edu

Summary:

Recent literature contains controversy about whether distinctive upland periglacial landscapes and erosional topography exist. This session provides a forum for differing viewpoints about the existence of 'characteristically periglacial' erosional upland landscapes and terrain We invite contributions from a broad spectrum of methodological approaches, including empirical process-oriented work, geomorphological mapping, spatial analysis, literature review, geomorphic modeling, geomorphometry and systems analysis. Similarly, the topical focusis broad, and includes such themes as cryoplanation, nivation, blockfields, weathering, mass-wasting, periglacial facies, topoclimate, structural influence, and paleoenvironmental reconstruction. The session is dedicated to the late Hugh French, who was intensely concerned with the question posed in the session title. Papers contributed to this session will be considered for a scheduled special issue of the peer-reviewed journal Permafrost and Periglacial Processes.

Cryoplanation Terraces of Interior and Western Alaska

Richard Reger (P.O. Box 3326, Soldotna, Alaska, USA, 99669) and Frederick Nelson (Michigan State University, Department of Geography, Environment, and Spatial Sciences).

Abstract

Cryoplanation terraces (CTs) are widespread in interior and western Alaska in uplands above and generally outside areas covered by Wisconsinan glaciers. The most sharply angular terraces are sited on massive volcanic rocks, greenstones, and hornfels. Relatively few planar treads exist on finely crystalline schists, phyllites, and slates, and on fine- to medium-grained sedimentary rocks. Among 686 samples studied in 1967-1970, scarps range in height from 3 to 76 m and slope 9o to 32o where covered with rubble. Where bedrock is exposed or thinly covered, scarps are nearly vertical. Simple nivation hollows indent lower surfaces of sharply angular ascending scarps, the typical sites of large, transverse seasonal snow patches. Terrace treads slope 1o to 10o and typically cut across bedrock structures, like bedding, rock contacts, foliation, joints, faults, and shear zones. Debris on terrace treads is generally 0.8 to 2.5 m thick. Side slopes are shallowly buried bedrock littered with a variety of mass-movement deposits. CTs have close relations with climatic indicators, like permafrost, active solifluction lobes, treeline, and snowline. However, these alpine terraces are not currently active in interior and western Alaska. Close associations with Wisconsinan glacial deposits imply that sharply angular terraces are Wisconsinan in age. Field evidence indicates that CTs form by the action of the nivation process suite, including mechanical and chemical weathering, mass movement, piping, and wind. The retreat of ascending scarps into ridges and hills is a response to nivation attacking initial topographic irregularities. Weathering products are removed across treads and down descending scarps and side slopes. Terrace form is a function of the dynamic interaction of formative and destructive (rounding) processes.

The Enigmatic History of Cryoplanation Processes and Research

Kelsey Nyland (George Washington University).

Abstract

Cryoplanation terraces are large landforms with a striking resemblance in profile to fluvial terraces, if not for their summit and upland topographic positions in periglacial (cold, but unglaciated) environments and starkly contrasting sedimentological characteristics. Periglacial processes producing landscape-scale features such as cryoplanation terrraces can be traced over more than a century of published literature. Following published maps, articles, and discussions on cryoplanation is complicated by the many names applied to these landforms and the many and vastly differing hypotheses proposed. English-language terminology used in this context besides cryoplanation includes altiplanation, equiplanation, nivation, and goletz. Hypotheses about the formation of these upland periglacial terraces have ranged from those based on Davisian erosion, modified solifluction, mass-movements combined with complex sorting, a precursor to the concept of isostatic thaw subsidence, and coarse-scale polygonal cracking. The last several decades of literature have centered on two hypotheses: structural controls and nivation (late-lying snowbank-induced erosion processes). This presentation will review and discuss (1) the diverse lexicon used on the topic; (2) the global distribution of terraces documented and studied; and (3) the timeline of hypotheses, with emphasis on the collection of publications within the last five years lending support to terrace development driven by nivation.

Development of North American and Russian investigations on cryoplananation terraces

Vasily Tolmanov (Michigan State University, Department of Geography, Environment and Spatial Sciences), Frederick Nelson (Northern Michigan University, Earth, Environmental and Geographical Sciences) and Kelsey Nyland (George Washington University, Department of Geography).

Abstract

Cryoplanation terraces (CTs) are large staircase-like series of landforms widespread in unglaciated uplands of the world’s cold regions. They are especially prominent in unglaciated Beringia and are distributed zonally in uplands between the Lena and Mackenzie Rivers. Early North American investigators charged with general geological and geographical surveys of eastern Beringia (Alaska and Yukon) in the early 20th century found the characteristics of these landforms to be inconsistent with the Davisian “normal cycle of erosion”, then the prevalent geomorphological theory in North America. After introduction and diffusion of Matthes’ nivation hypothesis and Lozinsky’s periglacial concept, a unified theory of CT formation was published in 1912 by Cairnes in Yukon and, apparently independently, by Prindle in Alaska in 1913. These papers outlined hypotheses of CT development consistent with contemporary geomorphic theory expressed by Reger and Péwé in the 1970s, although the landforms have remained controversial. In Russia, the heyday of cryoplanation research emerged in the 1930s and is associated with the names Obruchev, Boch, Krasnov, Bashenina, and Sukhodrovskiy. The primary source of early Russian information about CTs are the papers of S.V. Obruchev, who described them in detail from Chukotka and integrated his own field observations with the accumulated experience of earlier scientists. Much of the Russian work involved detailed field studies in the Ural Mountains and in western Beringia (Chukotka). These studies involved ideas that contributed to the development of an influential 1969 monograph by the Czech geographer J. Demek, who worked closely with Soviet scientists. The last major Russian-language study of cryoplanation landforms was a 1985 review monograph by M. Chaiko. Terminological concerns have been the subject of controversy throughout the history of cryoplanation research. Current views hold that CTs can be formed under contemporary climatic and geomorphic conditions, and should simply be divided into active and non-active groupings.

Permafrost and periglacial landscapes: Reality or “Geomorphic Chimera”

Wojciech Dobiński (Uniwersytet Śląski w Katowicach).

Abstract

The key to distinguishing and understanding the permafrost, periglacial and landscape interactions is to clearly define them. At the very beginning, in Łoziński’s periglacial concept, it was a geological term denoting the weathering process and the near-surface layer of clastic rocks formed in situ in the conditions of a cold near-glacial climate. Then, this term was assigned to a number of characteristic relief forms accompanying this geological layer and emerging in cold climate. They shape and differentiate the Earth’s surface, creating a periglacial landscape. Permafrost, on the other hand, is a phenomenon that does not cover the surface of the Earth. It is an geological layer defined thermally. The only processes that can be attributed to it are aggradation and degradation. So there’s no way it could affect the Earth surface to shape it in any material way. This can take place when accompanied by the presence of water. If the immaterial permafrost is “transferred” by means of water and its phase change to the material environment, then it can initiate periglacial processes and create of relief of the periglacial environment, i.e. landscape. But there cannot be a permafrost landscape, just as there cannot be a thermal landscape as such. Term landscape also needs to be clarified. There are currently more than 50 definitions of landscape, which means that it is not clearly defined. The only thing these definitions have in common is that they apply only to the Earth surface and what is on it. Therefore, the term cannot be applied to any medium of a geological nature lying under the surface of the Earth, such as permafrost. It can therefore be seen that all three terms: permafrost, periglacial and landscape are somehow a kind of “geomorphological chimeras” that require clarification.

Upland Periglacial Landscapes in the Salamanca Re-entrant, Southwestern New York, USA

Susan Millar (Syracuse University; Uppsala University).

Abstract

What constitutes an upland periglacial landscape has been long-debated and continues to elude precise definition. The Salamanca Reentrant in southwestern New York and adjacent northwestern Pennsylvania is considered a relict upland periglacial landscape owing to its proximity to late-Pleistocene ice margins, and therefore provides an ideal region to examine Late Glacial Maxima (LGM) non-glaciated terrain. Early work in Potter County, Pennsylvania, by Charles Denny, subsequent studies conducted in southwestern New York, and a smattering of other bore-hole studies and paleoenvironmental reconstructions, highlight the presence of a suite of forms and processes that can be interpreted as evidence of periglacial activity. These include bedrock outcrops affected by frost, large concentrations of angular locally derived bedrock fragments, buried sorted features, including stone circles and stone stripes, and an overall landscape morphology that exhibits elevated pediments with emergent tors, stepped ridgelines and concavo-convex debris mantled slope profiles. This presentation reviews evidence that, taken as a whole, supports the notion that there is such a thing as a characteristic periglacial signature on the landscape that remains identifiable in a relict context. The polygenetic nature of the landscape, with evidence of both Neogene and Holocene processes, however, makes any declaration that the relict LGM upland landscape of southwestern New York is a purely periglacial landscape somewhat less tenable.

Characteristic Periglacial Landscapes: What's in a Name?

Clayton Queen (Michigan State University, Department of Geography, Environment, and Spatial Sciences) and Frederick Nelson (Michigan State University, Department of Geography, Environment, and Spatial Sciences).

Abstract

The existence of a "characteristic periglacial landscape" has been questioned in recent literature. Dismissal of one of periglacial geomorphology's most basic assumptions is provocative, and could serve to undermine the foundation of the discipline. Conversely, such questioning provides virtue in its potential for sharpening thought processes, constraining definitions, and honing analyses. Here, we focus on the concept of "landscape," a much used but often inadequately defined term. Review of literature demonstrates that the term carries highly divergent connotations from different disciplinary perspectives. Skepticism about the existence of a distinctively upland periglacial landscape is based primarily on the idea that periglacial processes are not sufficiently powerful to effect landscape-scale erosional modification, and that periglacial microforms are "superimposed" on pre-existing terrain. However, both opponents and proponents of the "characteristic" periglacial landscape have failed to define the term "landscape" and thus the arguments remain unclear. Recent studies have demonstrated that the upland periglacial landscape can be viewed as an assemblage of smaller periglacial features operating in integrated fashion as "tools" that shape and bevel the macroforms, cryoplanation terraces and cryopediments, constituting "cryoplanated terrain." We conclude that periglacial landscapes are organized assemblages of interconnected periglacial landforms operating over a range of geographic scale. The upland periglacial landscape is best expressed in areas where periglacial processes operate over extended periods of geological time. These landscapes are typified in unglaciated Beringia.

Geographical Periglacial Geomorphology of the Appalachian Highlands, Eastern USA

Raven J. Mitchell (Michigan State University), Frederick E. Nelson (Northern Michigan University, Michigan State University) and Michael T. Walegur (Moorpark College).

Abstract

Geographical periglacial geomorphology, the study of the distribution, zonation, and altitudinal trends of periglacial features, is a research approach used to examine assemblages of periglacial landforms (e.g., patterned ground, cryoplanation terraces, blockfields, etc.) and to relate these distributions to trends of climate, latitudinal position, and form communities. This line of research became popular in the German-language literature beginning in the mid-twentieth century, leading to the development of inventories of periglacial features and their relation to macro- and topoclimate, snowline, and Quaternary history over extensive regions, including Europe, North Africa, South America, the Middle East, and the cordillera of western North America. Although the diffusion of this research vein was central in advancing past and current understanding of periglacial conditions and landform development history, large areas remain “uncovered” with respect to geographical periglacial geomorphological analysis. One such region, the Appalachian Highlands of the eastern USA, contains an abundance of periglacial features, but a systematic and integrated regional inventory and determination of altitudinal trends is largely absent, creating a substantial gap in understanding of the origins and climatic affinities of hypothesized periglacial features in this region. In this study we present a review of the literature of periglacial features in the Appalachian Highlands and synthesize the major findings. We also present the case for a revitalization of periglacial research in the Appalachian Highlands with emphasis on geographical distribution and altitudinal zonation. The results of this work will help to clarify the Quaternary history and extent of periglaciation in the eastern USA. This line of research will also contribute to the ongoing worldwide inventory of periglacial features and can be used to better understand how currently active periglacial landforms may be impacted by global climate change.

Constraining the frost weathering potential in blockfields in Scandinavia through near-surface temperature measurements and modeling

Maria Peter (Department of Geography, Norwegian University of Science and Technology), Jane Lund Andersen (Department of Geoscience, Aarhus University), Francis Chantel Nixon (Department of Geography, Norwegian University of Science and Technology), Bernd Etzelmüller (Department of Geosciences, University of Oslo), Sebastian Westermann (Department of Geosciences, University of Oslo), Henriette Linge (Department of Earth Science, University of Bergen) and Ola Fredin (Department of Geoscience and Petroleum, Norwegian University of Science and Technology).

Abstract

Blockfields remain enigmatic regarding their origin, internal structure, surface processes, and glaciological implications. In Scandinavia, blockfields are found on high-elevation, low-relief mountains (plateaus) across the Arctic and Subarctic. We employed a 1D numerical model that uses near-surface temperatures measured between summer 2018 and summer 2020 to calculate frost-cracking intensities (FCI) within the ground column in three different blockfields in Norway and Svalbard. Eighty-nine miniature temperature loggers were distributed on Tron Mountain (1650 m a.s.l.) in Alvdal, Gamlemsveten (780 m a.s.l.) near Ålesund in southwestern Norway, and on Platåberget (460 m a.s.l.) near Longyearbyen, Svalbard. We modelled FCI by scaling the time spent in the frost cracking window (between -3 and -8 °C), with the temperature gradient and water availability with a penalty function for distance to available water. The highest FCI are obtained where the subsurface consists of boulders and stones in a matrix of relatively fine sediment (sand, silt, gravel). In contrast, significantly lower FCI were modelled for blocky layers with large air-filled pores because of the low water availability. On Platåberget, FCI are extremely low (factor 10 to 100 lower than at the two Norway mainland sites) as water availability is limited due to i) permafrost and ii) near-surface temperatures remaining below the frost-cracking window for 3/4 of the year. This indicates that boulder-rich blockfields with air-filled hollows are preserved in very cold climates, whereas warmer, maritime settings with higher availability of fine interstitial material place blockfields in the fast lane for frost weathering. We discuss our findings with cosmogenic nuclide (CN) data taken from Gamlemsveten, as well as published CN-dates from other blockfields in Norway. Finally, we discuss how climate change in the next 100 years may affect frost cracking intensity.

SESSION 21
Periglacial geomorphology

Conveners:

- **Marc Oliva**, *Universitat de Barcelona;* marcoliva@ub.edu
- **Gonçalo Vieira**, *Universidade de Lisboa;* vieira@edu.ulisboa.pt
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- **Line Rouyet**, *Norwegian Research Centre;* liro@norceresearch.no

Summary:

Periglacial and permafrost processes and landforms are widespread in high-latitude and high-altitude environments, where frost action generated a variety of periglacial phenomena, including weathering, mass movement, fluvial, aeolian, coastal and paraglacial features. Such periglacial processes and the associated geomorphological changes are being affected by the global warming trend. Despite their scientific value and societal relevance, our comprehension of periglacial dynamics in many mountain and polar regions is still insufficiently addressed. Periglacial geomorphology should maintain a bridging position between geomorphology, geocryology, Quaternary and engineering studies. This session welcomes research studies focusing on conceptual, empirical, experimental, and modeling approaches covering all spatial and temporal scales in periglacial and permafrost regions, including those related with the thermal state of permafrost and active layer dynamics.

DISTRIBUTION AND CHARACTERISTICS OF PERIGLACIAL LANDFORMS IN CENTRAL-WEST ICE-FREE GREENLAND

Enrique Serrano (University of Valladolid), Marc Oliva (Universitat de Barcelona), Xosé L. Otero (Universidade de Santiago de Compostela), Sergi Pla-Rabes (CREAF-UAB), Santiago Giralt (CSIC), Dermot Antoniades (University of Laval) and Juan Ignacio López-Moreno (Instituto Pirenaico de Ecología (IPA-CSIC).

Abstract

This study focuses on the Quingaussarsuaq Peninsula, located west of the Greenland ice sheet in central-west Greenland (69º37´N/50º19´W). The research area encompasses a surface of ca. 75 km^2, and is mostly formed of metamorphic rocks of Palaeozoic age. This peninsula was entirely shaped by glaciers during the Late Pleistocene, which receded and exposed the current ice-free environment during the Late Glacial and the Holocene. Today, the area is underlain by continuous permafrost and is organized in four main units: high plateaus, mountain slopes, glacial valley floors and the recent moraine complexes. Periglacial processes are very intense and reshape moraine and disperse till, as well as the exposed bedrock. Up to 15 different periglacial features were identified and their distributions were accurately mapped. In the high plateaus of the peninsula, the most abundant periglacial landforms correspond to patterned ground features in flat areas and block streams on gentle slopes. Solifluction features, including stone-banked lobes and turf-banked lobes are widespread across the slopes, where other phenomena such as nivation niches and hollows, earth hummocks, small-sized stone stripes and debris slopes were also observed. The valley floors show a variety of solifluction landforms, earth hummocks and patterned ground phenomena. The glacier forelands include several moraine complexes and proglacial environments that are being reworked by periglacial dynamics. Here, small frost mounds, solifluction lobes and sorted circles were also detected, as well as ice-wedge polygons developed in recently exposed lacustrine deposits. Indeed, aeolian activity is reshaping these areas, with frequent sand dunes and thick loess accumulations.

Chronology of relict rock glaciers in European mountains since the last deglaciation

Marcelo Fernandes (Centre of Geographical Studies, Institute of Geography and Spatial Planning, Universidade de Lisboa), Marc Oliva (Department of Geography, Universitat de Barcelona), José María Fernández-Fernández (Department of Geography, Universidad Complutense de Madrid), David Palacios (Department of Geography, Universidad Complutense de Madrid), Gonçalo Vieira (Centre of Geographical Studies, Institute of Geography and Spatial Planning, Universidade de Lisboa), Julia Garcia-Oteyza (Department of Geography, Universitat de Barcelona) and Josep Ventura (Department of Geography, Universitat de Barcelona).

Abstract

Ridges and furrows characteristic of rock glaciers can be preserved for thousands of years, which allows the identification of these permafrost-related features and the reconstruction of past permafrost conditions in areas that today are absent. However, only a few studies have been dedicated to the timing of development and stabilization of these landforms in European mountain environments. In this communication, we present an accurate revision of the rock glaciers dated by means of cosmic-ray exposure (CRE) dating. Although this review can be biased according to the reduced number of studies, it already shows the major role of the deglaciation history in the timing of rock glaciers and the importance of the geomorphological setting in their development. Most studied rock glaciers occurred in the Southern European mountains, i.e. Iberia, European Alps, Carpathians, and Caucasus. They are distributed at a wide altitudinal range between ca. 500 m a.s.l. in the northernmost European ranges and above 3000 m in the southernmost ones. Exposure ages from rock glaciers show the continuous process of stabilization from 19.0 ± 1.5 to 0.2 ± 0.04 ka, near the ones that are still active or transitional. According to the paleoclimatic evolution inferred from the Greenland ice cores, the highest concentration of ages occurs during the transition between the Bølling–Allerød interstadial to the Younger Dryas stadial (YD; 39/ka), when conditions reveal a period favorable for stabilization. However, 60 % of all ages are constrained in the long period of the Holocene. In fact, Holocene stabilization of rock glaciers occurs mainly in the European Alps as revealed by palaeokinematic studies but also in Iceland and Scandinavian Alps. This preliminary approach shows a wide chronological gap in some European mountains and the need for multi-dating techniques to better constrain the rock glacier formation.

Potential for development of the process of thermokarst in the zone of discontinuous permafrost in Alaska.

Alexander Kholodov (University of Alaska Fairbanks).

Abstract

As a climatically driven phenomena, permafrost recently is undergoing the process of degradation following the global trends of air warming. This process can be subdivided into two stages – (1) warming of frozen deposits to the range of phase transition of soil water (sensible heat) and (2) intensive melting of ground ice (latent heat). In Alaska within the zone of discontinuous permafrost nowadays mean annual ground temperature had reached critical values and the process of degradation passes in the second phase. Depending on ground ice content it might be realized in two ways: first - formation of talks, i.e. perennial unfrozen horizon between seasonally frozen layer and permafrost, when ice content does not exceed soil porosity, and second - the thermokarst, i.e. subsidence and collapsing of the ground surface due to melting of excessive ground ice. Within the boreal forest ecotype which spans most of the area of Interior Alaska presence of ice-rich deposits depends on the history of wildfires, while within the tundra biome which occurs in this region at the hilltops (alpine tundra) and at the Seward Peninsula excessive ground ice is a more common feature. In this presentation, we will discuss the case studies of the potential of thermokarst development in the alpine tundra north of the Alaska Range (Healy) and tundra at Seward Peninsula (Council). Deep (5 to 7 meters) frozen cores were collected and analyzed for cryostratigraphy and the basic soil properties. The values of volumetric ice content exceed the soil porosity in both analyzed cores. Three boreholes (2 at Healy and one at Council) were instrumented for long-term geothermal measurement. Results of temperature measurements indicate extreme deepening of the active layer and active thawing of upper horizons of permafrost. Visible evidences of the thermokarst development were also noticed at both research sites.

How large and how fast can needle ice transport stones downslope? Lessons from two-decade observations in the Japanese Alps

Norikazu Matsuoka (Ibaraki University).

Abstract

Whereas field studies have highlighted the effect of seasonal frost heave on lifting meter-scale stones, field evidence is lacking on the size and velocity of stones moved by superficial needle ice (diurnal frost heave). This presentation reports 21 years (2000–2021) of frost heave and downslope stone movements caused by needle ice on an alpine debris slope (inclination 12°), with particular attentions to the stone size transported by needle ice and the effect of climate change on stone movements. Displacements of 12 stones, 10–27 cm in diameter, were determined from time-series images manually taken 2–5 times per year. Frost heave and soil temperature were recorded at 1- or 3-hour intervals.

Needle ice prevailed on the slope with a frequency of 24–85 times/a, an annual maximum heave of 1.8–5.6 cm and accumulated heave of 18–59 cm/a. Stones moved downslope at rates of 4–16 cm/a (mean 8.9 cm) and mostly disappeared from time-series images within a few years, but the largest stone was traced over 21 years with a total displacement of 80 cm. A significant positive correlation was found between the stone size and velocity. On an assumption of a linear relationship between the two variables, needle ice can transport stones with a diameter of about 30 cm.

During the monitoring period the annual mean air and soil surface temperatures rose at rates of 0.024°C/a and 0.078 °C/a, respectively. Correspondingly, the frequency and accumulated amount of frost heave increased at rates of 0.13 times/a and 0.53 cm/a, respectively, although interannual variation was significant. Climatic warming may have raised the frequency of needle ice activity by shortening the snow-covered period.

Estimating permafrost ground ice contents in Central Asia using a multi-method approach (in-situ geophysical measurements, remote sensing, and thermal modeling)

Tamara Mathys (University of Fribourg), Rainer Gardeweg (University of Fribourg), Christin Hilbich (University of Fribourg), Line Rouyet (University of Fribourg; NORCE Norwegian Research Centre AS, Technology Division), Sergey Marchenko (University of Alaska Fairbanks), Tomas Saks (University of Fribourg), Joel Fiddes (WSL Institute for Snow and Avalance Research SLF), Leo C.P. Martin (Utrecht University), Azamat Sharshebaev (Central Asian Institute for Applied Geosciences (CAIAG), Sultanbek Belekov (KyrgyzHydromet), Erlan Azisov (Central Asian Institute for Applied Geosciences (CAIAG), Ruslan Kenzhebaev (Central Asian Institute for Applied Geosciences (CAIAG), Mukhammed Esenaman Uulu (Central Asian Institute for Applied Geosciences (CAIAG), Mikhail Borisov (Central Asian Institute for Applied Geosciences (CAIAG), Ryskul Usubaliev (Central Asian Institute for Applied Geosciences (CAIAG), Bolot Moldobekov (Central Asian Institute for Applied Geosciences (CAIAG), Jovid Davlatov (Center for Research of Glaciers of the Academy of Sciences of the Republic of Tajikistan), Abdulhamid Kayumov (Center for Research of Glaciers of the Academy of Sciences of the Republic of Tajikistan) and Martin Hoelzle (University of Fribourg).

Abstract

In the context of ongoing climate change, mountain permafrost has been discussed in terms of its role as a potential water reservoir, as well as its geohazard impacts due to permafrost thawing and associated slope destabilization, which can lead to rock falls and landslides. In the Central Asian mountain ranges (Tien Shan and Pamir), permafrost ground temperatures have been measured since the mid-1980s. However, geophysical studies are rare or non-existent in some high-mountain areas of the region. This is due to the remoteness and often difficult logistical access to perform in-situ studies. Nonetheless, the region is severely affected by climate change and its impacts have severe implications for the livelihood of the local communities, sustainable development of the mining industry, and engineering structures. Therefore, in Central Asia, it is critical to identify and continuously monitor permafrost distribution, ground ice content, and potentially hazardous moving landforms. Over the past two years, we have conducted intensive geophysical (Electrical Resistivity Tomography (ERT, 30 profiles in total) and Refraction Seismic Tomography (RST, 12 profiles in total) investigations in different watersheds of Kyrgyzstan and Tajikistan. In this contribution, we present the ground ice content quantified for different landforms at the profile scale by combining both geophysical methods within the petrophysical joint inversion model (PJI). Furthermore, we are testing an upscaling technique for estimating ground ice contents at the catchment scale by comparing and linking the geophysical-based ground ice content estimations with Interferometric Synthetic Aperture Radar (InSAR) based subsidence rate distribution maps, which can be indicative of ice-rich or ice-poor permafrost. A thermal modeling approach will also be integrated into the upscaling scheme in the future. We demonstrate our multi-method approach for selected catchments in Kyrgyzstan.

Three-dimensional subsurface architecture and its influence on the spatiotemporal development of a retrogressive thaw slump in the Richardson Mountains, Northwest Territories, Canada

Julius Kunz (Institute of Geography and Geology, University of Wuerzburg), Tobias Ullmann (Dep. of Remote Sensing, Institute of Geography and Geology, University of Wurzburg), Christof Kneisel (Institute of Geography and Geology, University of Wuerzburg) and Roland Baumhauer (Institute of Geography and Geology, University of Wuerzburg).

Abstract

The Peel Plateau Region, adjunct to the range of the Richardson Mountains (Western Canadian Arctic), is known for widespread and ice-rich permafrost. Due to high ground ice contents the presence of retrogressive thaw slumps is common in this region, some of which are classified as mega slumps and belong to the largest thaw slumps on earth. The development of retrogressive thaw slumps is affected by relief-related parameters, subsurface properties as well as climatic triggers. The study at hand investigates the subsurface characteristics in the vicinity of an active slump in the Richardson Mountains to enhance the knowledge about slump development. Relationships and interdependencies between subsurface structures and the spatiotemporal slump development were investigated using a combined approach of geophysical methods and optical earth observation data. Information on subsurface architecture was obtained using electrical resistivity tomography (ERT) and ground-penetrating radar (GPR). The spatiotemporal development was revealed by high-resolution satellite imagery (Planet Scope, 2014 – 2021), and drone-based digital elevation models (2018, 2019 and 2022). The analyses indicated an acceleration of slump expansion for year-to-year and allowed for a detailed balancing of erosion and accumulation based on the drone-derived digital elevation models. The three-dimensional geophysical measurements conducted in 2019 revealed a partly unfrozen layer underlying a heterogeneous permafrost body and a close relation between active layer thickness, morphology and hydrology in the area close to the retreating headwall. Additional measurements conducted in 2022 highlighted the thermal impact below the slump floor of the active thaw slump, but also below a nearby, older and already stable slump scar. The results highlight the complex relationships between slump development, subsurface structure and hydrology, and indicate a distinct research need at other retrogressive thaw slumps in this region.

Quantifying controlling factors of frost weathering in alpine rocks

Till Mayer (University of Bayreuth), Daniel Draebing (Utrecht University) and Martha Eppes (UNC Charlotte).

Abstract

In periglacial environments, frost weathering by ice segregation is a key process in sediment production and landscape evolution. Our current process understanding is based on studies focusing on high-porosity low-strength rocks. However, rock types forming alpine rockwalls are characterized by crack-dominated porosity and high rock strength, therefore, findings from low-strength rocks cannot be transferred to rockwalls. Here, we will perform ice segregation tests on rocks with different saturation levels and fracture density to quantify their influence on frost cracking efficacy. We used Wetterstein limestone samples in laboratory experiments and exposed rocks to real-rockwall freezing conditions while monitoring acoustic emission as a proxy for cracking. To differentiate triggers of cracking, we modelled ice pressure and thermal stresses. We tested the influence of (i) initial saturation (low versus full saturation), (ii) crack density (0.4 versus 0.6 % rock porosity), and (iii) temperature range (-10 to 0°C) on the efficacy of ice segregation. (i) Our data showed that the efficacy of cracking is not controlled by initial water content in alpine rocks. We suggest that water is available at depth within alpine rock masses and can rapidly travel along fractures to form ice lenses near the rock surface. (ii) Crack density has a direct impact on the elastic properties of rocks, which shifts the threshold for crack propagation. All other things being equal, a fractured rock with high crack density can be less prone to ice segregation as its higher elasticity better accommodates stresses without brittle failure. (iii) Our data revealed temperature patterns promoting ice segregation with an increase at temperatures between -10 and -7 °C in high strength Wetterstein limestone. We conclude that frost cracking efficacy in high alpine environments is increased by colder rock temperatures rather than rock moisture, which potentially results in more rockfall at colder north- than warmer south-facing rockwalls.

Evolution of debris cover on Pyrenean glaciers from 2000 to 2020: an increasing trend?

Ander Palacios (Graduate in Geography and Territorial Planning, University of the Basque Country UPV/EHU), Enaut Izagirre (Department of Geography, Prehistory and Archaeology, University of the Basque Country UPV/EHU), Jesús Revuelto (Instituto Pirenaico de Ecología, Consejo Superior de Investigaciones Científicas (IPE-CSIC), Juan Ignacio López-Moreno (Instituto Pirenaico de Ecología, Consejo Superior de Investigaciones Científicas (IPE-CSIC) and Orbange Ormaetxea (Department of Geography, Prehistory and Archaeology, University of the Basque Country UPV/EHU).

Abstract

Very small glaciers (<0.5 km^2), such as the last remaining glaciers of the Pyrenees, are important components of the high-mountain cryosphere that respond sensitively and rapidly to climate variability. Most of them are also influenced by local topographic factors and geomorphological processes that control the energy and mass balance. One important factor is the input of debris into the glacier system, which is simultaneously regulated by periglacial rockwall processes, cirque topography, and bedrock lithology. The main objective of this work is to present the first regional and temporal study of debris cover changes on Pyrenean glaciers from 2000 to 2020. This will allow to identify potential factors triggering debris input into glacier characterising the topographic conditions of each glaciated area. Using high-resolution aerial imagery and based on existing glacier inventories from 2000, 2011 and 2020, we manually mapped the extent of supraglacial debris with their corresponding glacier outlines. The results show that debris cover on Pyrenean glaciers has increased significantly in number and extent over the study period, while glaciers continue to decline and shrink. In 2020, 9 out of the 21 remaining glaciers have debris cover greater than 10 % of their area, and 4 of them have debris cover of more than 30 %. The observed increase in debris cover is mainly originated by geomorphological and topoclimatic factors and for glaciers located on metamorphic and sedimentary massifs, which underlines the important role of paraglacial processes in their development. At the same time, the four largest glaciers (>10 ha) and the smaller glaciers lying on granitic massifs have lower debris cover. Future work should focus on understanding the debris sources and their characteristics to determine the role of debris cover in the response of Pyrenean glaciers to climate change.

Retrogressive thaw slumps in NE Greenland - a hazard for arctic infrastructure

Saskia Eppinger (Technical University of Munich, Landslide Research Group), Thomas Højland Lorentzen (Technical University of Denmark, Department of Environmental and Resource Engineering Geotechnics & Geology), Thomas Ingeman-Nielsen (Technical University of Denmark, Department of Environmental and Resource Engineering Geotechnics & Geology) and Michael Krautblatter (Technical University of Munich).

Abstract

Retrogressive thaw slumps (RTS) are a common thermokarst landslide feature in Arctic permafrost conditions which increasingly become a threat to infrastructure. RTS have been observed in Greenland, however, up till now no detailed studies explicitly focus on Greenlandic conditions. Following a glacial lake outburst flood (GLOF) in 2017, two RTS are evolving near the Zackenberg Research Station in northeast Greenland. The Research Station, which is operating since 1995, one of the northernmost sites for monitoring and research activities in the Northeast Greenland National Park. The station consists of several buildings about 70 m west of the Zackenberg River. The scarp of the RTS is currently 30 meters from the nearest building and poses a potential risk for the station. In August 2022, we conducted a field campaign to investigate the geomorphology, evolution, and stability of the two RTS at Zackenberg. We collected geophysical data alongside with near surface core drilling, supplying samples for laboratory analysis. Two geophysical methods were deployed, namely electrical resistivity tomography (ERT) and seismic data for multichannel analyses of surface waves (MASW). Furthermore, sediment samples from available lithological formations were taken and aerial footage from several drone flights during the last 4 years are available. This combination, along with geophysical and geotechnical laboratory tests, presents a unique dataset for investigating RTS. During this investigation, we particularly focused on the ice content of the slumps as well as the salinity and the thixotropy of a marine clay and silt layers, as these factors are expected to generally control the behaviour of RTS. The investigation aims to better predicting the future behaviour of the two retrogressive thaw slumps and thereby the risk potential they pose to the Zackenberg Research Station.

Growth of a pingo ab initio at Illisarvik, western Arctic coast, Canada

Christopher Burn (Carleton University) and Antoni Lewkowicz (University of Ottawa).

Abstract

Lake Illisarvik was experimentally drained by Professor J.R. Mackay on 13 August 1978. Permafrost aggradation began in the lake-bottom sediments the following winter. Two residual ponds were left after drainage. One was sufficiently shallow for permafrost, including an ice wedge, to form beneath it. The other pond, approximately 4 m deep, remained unfrozen at the bottom year-round. The ice on this pond has formed a conical dome in most winters, about 1 m high and with 11-cm wide dilation cracks at the summit. The dome has formed as a result of pore-water expulsion by aggrading permafrost in the lake-bottom talik. In winter 1994-95, a small circular mound formed adjacent to the frozen pond in ground that was previously flat. The mound top was 60 cm above the surrounding ground, and the mound was approximately 30 m in diameter. The mound was drilled in 1998. A 55 cm thick water lens was delineated 5.3 m below the top of the mound. Brackish water under artesian pressure rose to 15 cm above the surface of the drill hole. The water lens temperature was -0.2 C. Between 1994 and 2022 the surface of the mound rose 73 cm. In 1995-96 the growth of the mound was 9 cm. The growth rate has declined with time, so that in 2019-22 the growth was only 3 cm. The principal dilation crack at the surface of the pingo has increased in width by 16.5 cm in 1998–2022. Shock loggers embedded in the pingo have recorded micro-earthquakes intermittently, suggesting deformation occurs in small but sudden increments. EM31 and ERT surveys indicate an increase in conductivity beneath the mound. Ground temperatures in the mound were higher than in surrounding permafrost while the water lens was freezing but have declined subsequently.

Assessing the simulation of ground surface temperature with the physical model GEOtop

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Abstract

Ground surface temperature (GST), measured at about 5 cm into the ground is essential for understanding the climate change impacts in periglacial and permafrost regions. This work assesses the 1D simulation of GST with the physical model GEOtop at 1500 m elevation in Mazia Valley, North-eastern Italian Alps. This site is part of the International Long Term Ecological Research (ILTER) network. GST was simulated from 1.11.2013 to 31.10.2017 using as inputs the hourly observations of air temperature and humidity, solar short-wave incoming radiation, precipitations, and wind speed. The simulated GST was validated against in-situ observations through time series comparisons, linear regression, Pearson correlation, and the root mean square error (RMSE). The best simulation reveals an R2 of 0.76, a correlation of 0.88, and an RMSE of 2.97 °C. The RMSE is relatively high as the model overestimates the GST almost for the entire year. The largest overestimations are from January to July each year, while in September and October are the lowest. Model performance could be affected by several data gaps in the input of the wind speed, while the solar radiation reveals overestimations for the period March-October. The model encountered the largest mismatches in simulating the GST during the frozen and the soil phase change periods. Accurate modelling of the GST will have significant importance for understanding the thermal evolution of the active layer and the seasonally frozen ground. Ongoing work is aiming to improve the simulations of the GST through an automated model calibration of the soil thermal conductivity and heat capacity.

The thermal regime of a periglaciar area in the Southern Carpathians, Romania.

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Abstract

Ground surface temperature (GST) is defined as the temperature measured in the uppermost centimeters of either the bedrock or the superficial deposits. The GST value and its seasonal and multiannual evolution (thermal regime) are some of the key variables in alpine permafrost research. Here, we analyze the impact that air temperature, snow cover, land cover and incoming solar radiation, including its local variability due to topographic shading, has on GST. We do this by analyzing time series data for the mentioned parameters, from 2011 to present, using descriptive statistics (i.e. multivariate analysis). The study area is located in the central part of Retezat Mountains, in the upper part of 2 main glacial valleys with a number of secondary glacial cirques, which allow the study of GST on different expositions. Ground surface temperature was measured using iButton data loggers, with an accuracy of 0.1º C and a resolution of 0.065º C, at a 6 hours' time interval (4 measurements/day). We have found that ground cover and topographic shading are the main two factors that influence the GST. The areas covered by course blocky terrain and located in glacial cirques with steep walls have the lowest values of GST, both daily and annually, and are also the areas that favor the occurrence of permafrost. The snow cover, especially the onset of snow, has an influence on the multiannual trend of GST. As the period in which snow accumulates, to become an isolating layer for the ground, tends to be later in the winter, the ground is expose to a longer period of colder air temperature.

Past and present-day periglacial environments in the Sierra Nevada, south Spain

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Abstract

The Sierra Nevada constitutes one of the massifs in Europe where periglacial processes have been more extensively and thoroughly examined. Periglacial phenomena in the massif are distributed from the mountaintops at 3,300-3,400 m a.s.l. down to elevations of 1,100-1,200 m. Active periglacial dynamics prevails today above 2,500 m with a variety of landforms mostly related to frost shattering, cryoturbation and solifluction processes, among others. Besides, inherited periglacial landforms formed during Quaternary glacial phases are also found in the summit plateaus (i.e. patterned ground features) and valley heads (i.e. inactive rock glaciers). Since the early 2000s, a multi-approach research program has been carried out in the Sierra Nevada to monitor present-day periglacial dynamics and frozen ground conditions in the high lands of this massif. Results show evidence of the key role of seasonal frost driving environmental dynamics above 2,500 m. Permafrost is spatially limited, and only confined to the areas that were glaciated during the Little Ice Age (LIA), namely in the Veleta and Mulhacén cirques above 3,000-3,100 m. Buried ice derived from LIA glaciers and isolated permafrost patches developed subsequently are still preserved under the thick debris mantle distributed across the cirque floors as revealed by the monitoring of soil temperature at different depths in the Veleta cirque. Here, geomatic and geophysical surveys of an incipient rock glacier indicate that permafrost conditions are undergoing a process of degradation. Seasonally frozen ground prevails in the rest of the Sierra Nevada, even at the summit surfaces at 3,300-3,400 m where mean annual soil temperatures are in the order of ~2.5 ºC. In other periglacial landforms, positive temperatures were also recorded, ranging between 2 ºC (inactive sorted-circles) and 3-4 ºC (inactive and weakly active solifluction lobes).

Characteristics and recent dynamics of thermo-erosional features in small catchments of Arctic Siberia

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Abstract

Thermal erosion is a prominent type of permafrost degradation that can lead to rapid changes in ice-rich permafrost landscapes. The process and its resulting landforms such as thermo-erosional gullies are reported to become increasingly active and widespread. (Re-)Activation of thermal erosion impacts the hydrological regime of affected landscapes and alters the biogeochemical composition of associated surface waters. Our study aims at assessing current rates and mechanisms of thermal erosion in small ice-rich permafrost catchments of Arctic Siberia. We investigated thermo-erosional features in three different areas in and around the Lena River Delta that represent differing geomorphological, lithological and geocryological settings. We used a combination of field measurements, remote sensing methods including tacheometry, DGPS, and UAV surveys and subsequent GIS analyses to 1) quantify the morphometry of thermo-erosional landforms, 2) quantify the spatial extent of current thermo-erosional activity, and 3) quantify areal changes in activation and stabilization of thermal erosion over recent years to decades. Further data on snow depth and distribution in the gullies and valleys as well as hydrological and hydrochemical data of the associated streams aided the interpretation of observed spatial differences in thermal erosion rates and the development of active versus stabilized zones as well as their impacts on headwaters.

Towards improving permafrost monitoring in the Pyrenees

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Abstract

The Pyrenees include more than one hundred peaks exceeding 3000 m at latitude 41-42ºN. Permafrost is known to occur across extensive areas at elevations above 2650 m on northern slopes and above 2900 m on southern sides, with seasonal frost prevailing at elevations below 2500 m. Sporadic permafrost also exists at lower altitudes, where several active rock glaciers have been also identified. In this mountain range, the presence of permafrost has been mostly detected through the mapping of geomorphological indicators (rock glaciers, protalus lobes, frost mounds, etc), bottom temperature snow measurements, geophysical surveys, etc. Temperature loggers have been also installed since the early 1990s in some of the highest massifs (Posets, Maladeta, Infierno, Monte Perdido-Tucarroya and Vignemale) to monitor the ground thermal regime in bedrock, walls and sediment features. The objective of this communication is to list and present the new study sites for monitoring permafrost in rockwalls and rock glaciers in different massifs of the Pyrenees, including those recently installed (massifs from East to West): Pessons (42º 31' 17" N / 1º 43' 05" E; rock glacier with its front at 2535 m), Pica d'Estats 42º 40' 08" N / 1º 22' 58" E; active rock glacier with its front at 2820 m), Besiberri (42º 36' 03" N / 0º 49' 10" E; rockwall+active rock glacier with its front at 2600 m), Aneto-Maladeta (42º 37' 52" N / 0º 39' 25" E; rockwall), Monte Perdido (42º 40' 33" N / 0º 02' 04" E; rockwall) and Vignemale (42º 46' 27" N / 0º 08' 52"' W; rockwall). In addition to these sites, our intention for the next years is to drill the first deep permafrost boreholes in the Pyrenees in order to fill the latitudinal gap existing between Sierra Nevada and the Alps and improve our understanding of permafrost dynamics in Europe's southern mountains.

Periglacial activity in the Central and Southern Andes

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Abstract

The Andes Mountain range runs along the western margin of South America for ~7500 km, from the Sierra Nevada de Santa Marta, next to the Caribbean Sea, to Cape Horn, at the southern tip of the continent. Based on structural differences, the Northern Andes (11ºN-1ºS), Central Andes (1º-47ºS) and Southern Andes (47º-68ºS) have been differentiated. In the Central Andes the mountain range is divided into Western and Eastern Andes, between which the Altiplano, a plateau of 300x500 km and 3800- 4900 m surrounded by peaks that reach 6000 m in altitude. Only the Himalayas and Tibet are higher and larger than Andes-Altiplano. Glaciers are preserved on many peaks of the Andes, and on their slopes, there are moraines revealing a much larger glacial extent in the past. Today, in the deglaciated areas there are extensive periglacial landscapes. However, the extent to which altitude and latitude modify periglacial forms and processes has not yet been investigated. Our team aims to make a first approach to the problem by analyzing three representative Study areas of a north- south transect of the Central and Southern Andes: Nevado Coropuna volcanic complex (16ºS, 73ºW, 6377 m), in the Arequipa region (Peru); Cerro Aconcagua (33ºS, 70ºW, 6960 m), in Mendoza (Argentina) and Cerro Alvear (54ºS, 68ºW, 1490 m), in the Argentinean side of Tierra del Fuego. In the last 20 years we have identified different periglacial processes linked to permafrost, such as: rock glaciers, protalus ramparts, debris lobes, patterned grounds including tundra polygons associated with active ice wedges, cryo-ejected clast, tors, nivation hollows or boulder (clast) pavements. This periglacial activity probably records aspects of current interests, as climate change, interhemispheric teleconnections, or ENSO phenomenon, which modify snow cover. Understanding this record is an interesting geomorphological challenge that we begin to address by presenting this work.

Fine-scale environmental controls of solifluction and nivation activity in a sub-Arctic mountain region

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Abstract

The movement of soil materials and moisture in Arctic-alpine environments is strongly influenced by periglacial processes related to frost activity and snow distribution. The controlling factors of solifluction (the creep or flow of soil materials due to frost activity) and nivation activity rates (snow accumulation-related erosional and depositional processes) have been studied from landscape to regional scales, but assessments of their fine-scale variability across extensive Arctic-alpine areas are lacking. Moreover, the potential interoperability of periglacial processes has not been addressed in a spatially comprehensive setting. We incorporate high-resolution field and remote sensing data into structural equation modelling (SEM) to illustrate the complex spatial linkages between soil, topography, snow and climate conditions affecting observed solifluction and nivation activity at 634 study sites (10 x 10 metres) across a ~140-km^2 sub-Arctic mountain region in northern Norway. Freezing air temperatures exert an expectedly strong effect on solifluction activity, yet most of it is manifested through the amount of vegetation, which acts as a dominant limiting factor for solifluction activity. We also find that the control of snow on solifluction activity is manifested through nivation activity while snow cover duration at the site has no direct effect. Nivation activity, in turn, is dominantly controlled by micro- to meso-scale topography, wind action, and to a lesser degree by air temperature variation in the study area. Overall, these findings suggest that topography-controlled snow accumulation and nivation, as well as soil and vegetation properties, exert important effects on the intensity of solifluction processes down to submeter scale, and subsequently on the circulation of organic carbon and nutrients in the soils.

Structural characterization of a coastal open-system pingo (Adventdalen, Svalbard) using electrical resistivity and induced polarization imaging

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Abstract

Rising mean air temperatures in the northern hemisphere result in permafrost degradation and subsequent landscape changes, especially with respect to landforms with a high ice content such as pingos. Studying the internal structure of pingos is important since pingos can facilitate the release of methane and cause damage to infrastructures. Here, we study an open-system pingo in a marine setting (Lagoon Pingo, Adventdalen, Svalbard), which was formed from the Holocene glacio-isostatically uplifting fjord valley. The pingo is located close to a saltwater lagoon and fed by two perennial groundwater springs. For structural characterization of the pingo, combined electrical resistivity tomography (ERT) and induced polarization (IP) imaging was performed in late September 2022, employing a linear electrode array across the pingo centre. The electrode array comprised 48 electrodes with 3 m spacing, thus providing higher spatial resolution than previous ERT surveys at the site. In contrast to the general conceptual model of pingo structure, the imaging results suggest two distinct ice cores inside the pingo characterized by increased electrical resistivity and decreased polarizability. This is in agreement with the expected breakdown of both electrolytic conduction and electrochemical polarization in solid ice bodies at lower measurement frequencies, as applied here, which do not sense the higher-frequency polarization response of ice. Low resistivity values are found in the thawed surface layer as well as down to greater depths towards the lagoon, indicating saltwater intrusion. The expected permafrost regions show relatively low resistivity, likely because of significant clay content and remaining unfrozen saline pore water. Here, also polarizability is decreased, indicating a partially frozen pore space. Our study demonstrates the improved thermal state characterization capabilities of combined ERT and IP imaging, while resistivity and (low-frequency) polarizability provide redundant structural information.

The Alt Pirineu Natural Park (Central Pyrenees) is integrated into the international network INTERACT

Oriol Grau (Parc Natural de l'Alt Pirineu) and Marc Garriga (Parc Natural de l'Alt Pirineu).

Abstract

The Research Observatory of the Alt Pirineu Natural Park in the Central Pyrenees has been admitted to the international research network INTERACT as an Observer Station. This network, coordinated by Lund University (Sweden), fosters research in Arctic and Alpine areas and promotes knowledge exchange amongst universities, research institutes and institutions from all arctic countries and boreal areas. Over the last few years, this network also expanded into more southern, alpine areas such as Switzerland, Poland, Great Britain, Czech Republic and Austria, among other countries. It is mainly focused on the field of terrestrial ecology and also works for the dissemination and social awareness towards the adaptation and mitigation of climate change and its impacts on society.

The Research Observatory of the Alt Pirineu Natural Park was born in 2021 to promote and coordinate scientific activities within the Natural Park and to support the managing team in decision making. The Park has promoted this adhesion to help convert this protected landscape and nearby areas into an international scientific destination, and to promote interdisciplinary and comparative studies with northern areas. It has now become the southernmost European center within this research network.

Many novel topics can be investigated in the Alt Pirineu Natural Park and nearby areas, particularly with regard to periglacial processes and changing landscapes, or regarding ecosystem-scale responses to climate change. The Pyrenees possibly cover the southernmost permafrost distribution in Europe, and show great variability in abiotic conditions and strong bioclimatic gradients within short distances. This new INTERACT location offers a nice opportunity to promote comparative studies and to monitor and anticipate glacial, periglacial and ecosystem-scale processes that may occur in the future in more northern areas.

Detecting Internal Structures of Retrogressive Thaw Slumps

Saskia Eppinger (Technichal University of Munich, Landslide Research Group) and Michael Krautblatter (Technichal University of Munich, Landslide Research Group).

Abstract

Retrogressive thaw slumps (RTS) are a highly dynamic form of back-wasting thermokarst in ice-rich Arctic permafrost. They are short living but rapidly developing features, which mostly become stable within 30-50 years after reactivation. Many RTS tend to develop a polycyclic behaviour with a long-term-stabilisation and a reactivation in the same area years, decades or centuries later. RTS are important, as they are one of the most rapidly developing features in arctic permafrost, disturbing large areas and releasing enormous amounts of sediment and organic carbon into rivers, lakes, and the nearshore zone. Their number is increasing in the last decades all over the Arctic and some of the biggest RTS are located at our study site on Herschel Island, Yukon, Canada. As RTS commonly form when ice-rich material is exposed to thawing, their behaviour strongly depends on the available ice. Previous studies mostly investigate the bio- and geo-chemical influences of RTS, some studies focus their investigations on visible ice content in the headwall. To better understand the internal structures, remaining ice content in (re-)stabilized slump floor and the ground temperature regime, we measured several electrical resistivity transects (ERT) on Herschel Island (Qikiqtaruk, Yukon, Canada) during field campaigns in 2011, 2012, 2019 and 2022. In combination with active layer probing and laboratory calibration on samples, this unique dataset on different activity stages of large RTS provides a first-time insight into internal structures and ground ice distribution in different slump activity stages. The investigation aims to better understand the controlling factors for different stages, the polycyclic behaviour, and a more precise future predictability of RTS activity.

Frost weathering intensity in relict sand wedges from Hungary inferred from scanning electron microscopy

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Abstract

Quartz grains (n=300) in the 250–500 μm size fraction were studied using a high-resolution scanning electron microscope in order to detect the effects of frost weathering. Samples were collected from relict sand wedge infillings from western Transdanubia (Hungary). Grain size distribution, grain type, roundness, and surface microtextures were determined and statistically analysed (frequency, hierarchical cluster analysis, PCA) to detect past environmental and transport conditions, with a distinct emphasis on surface microtextures related to frost action (i.e., fresh small and big conchoidal fractures, fresh small and big breakage blocks). The frost-action index was also determined along the two vertical profiles. The examined grains are generally moderately rounded (subangular and subrounded), with only a few of them falling into the remaining categories (angular, rounded). Grain types vary among the samples; however, the major types are EM/RM (moderately rounded from aeolian environment), EM/EL (moderately rounded from aquatic environment), and OTHER (grains that went through intensive weathering processes). There are microtextures appearing on (almost) every grain, including amorphous precipitation, dissolution surfaces, mineral scaling, lattice shattering, and adhering particles. Euhedral silica is also a frequent microtexture, and it may point to the source material for the sand wedge infillings. Frost-related features mainly appeared on the concave parts of the grains. However, a notable amount can also be seen on micro steps and in depressions, while sometimes big, altered conchoidal fractures also host fresh features. Mostly small fresh conchoidal fractures and small breakage blocks were found, which only mark the initial stages of frost weathering intensity. Based on this research, the respective transport history of the grains and paleoenvironmental settings of the sand wedges can be defined. The source material (probably granitoids) was eroded and transported in fluvial, then aeolian environment for a short time. Frost weathering also influenced the grains as a post-sedimentary process.

A quantitative analysis of cryostructures and cryogenic soil structures in permafrost-affected soils of three contrasting Alaskan landscapes

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Abstract

We investigated cryostructures and cryogenic soil structures (the structure of soil aggregates formed by freeze-thaw processes) in permafrost-affected soils of three contrasting Alaskan landscapes: the Copper River Basin, Yukon-Kuskokwim River Delta, and Arctic Foothills. These landscapes differ in soil and permafrost formation processes, as well as soil properties and ecosystem dynamics. Through the use of a standardized scheme of description for both cryostructures and cryogenic soil structures, we provide quantitative analysis of the relationship between observed morphological properties in permafrost-affected soils across these three landscapes. In analyzing the depth and spatial distribution of cryogenic soil structures and cryostructures between these landscapes, in association with an understanding of ecological conditions, we can improve our understanding of how permafrost-affected soils provide a record of formation and change. In combination with measurements and predictions of excess ice content, these observations provide important implications for near-surface permafrost susceptibility in response to changing climate conditions.

Interactions and interconnections between glacial and periglacial processes in high alpine environments

Julie Wee (University of Fribourg), Christian Hauck (University of Fribourg) and Christophe Lambiel (University of Lausanne).

Abstract

High alpine environments are characterized by glacial and periglacial landforms that are currently undergoing transformations that illustrate a degrading cryosphere. While glacier shrinkage stands among the most evident signs of a transitioning alpine landscape, visible changes in the periglacial belt such as the degradation of permafrost or the melt of ground ice are more subtle, especially in environments where both glacial and periglacial processes have occurred or still occur simultaneously. From a geomorphological perspective, they constitute environments of complex contact zones between sedimentary and interstitial ice, whose interconnected glacial-periglacial processes is little known and deserve in-depth investigation.

This contribution aims to understand the spatial and temporal complexity of relations and interactions between glacial and periglacial processes through the assessment of ground ice properties and its influence on surface dynamics measured at several alpine sites where glacier-permafrost interactions have occurred or still occur. We base our analysis on long-term time series of ground surface temperature, together with in-situ geodetic and geophysical measurements.

In the debris-covered glacier zones and contact zones, long-term geodetic measurement document surface elevation changes often reaching a few decimetres to some meters per year due to ice melt-induced subsidence. Moreover, geophysical surveys systematically reveal electrical resistivities within the range of 1000-2500 kΩm close to the subsurface, indicating the presence of debris-covered cold glacier ice and/or perennially oversaturated frozen material. In contrast, geophysical surveys performed in periglacial areas indicate the presence of degrading permafrost with electrical resistivities ranging between 100-500 kΩm at depth (5-7 meters, i.e. in the permafrost layer), causing vertical surface changes in the range of centimetres per year due to thaw-induced subsidence.

In complex contact zones, where both sedimentary and interstitial ice occur simultaneously and where interconnected processes take place, we can most often discriminate glacial from periglacial processes as their geodetic and geophysical signatures are (mostly) different.

Database of periglacial landforms and deposits in the NW Iberian Peninsula

Alejandro Gómez-Pazo (Universidade de Santiago de Compostela) and Augusto Pérez-Alberti (Universidade de Santiago de Compostela).

Abstract

In mid-latitude territories, such as the NW Iberian Peninsula, the forms and deposits of periglacial origin indicate past geomorphological processes and serve as paleoenvironmental archives. For this reason, protecting and conserving these areas against prejudicial activities, such as land use modifications for anthropic activities, such as mining or wind farms, is necessary. The first level of classification of these elements can distinguish two groups: those formed under permafrost conditions (blockfields, block slope, block stream, rock glacier, or frost heave) and those resulting mainly from snow processes (nivation hollow, stratified slope deposits, stone-banked solifluction lobes, ploughing boulders, talus slope or terracettes). A complete database was elaborated based on fieldwork surveys, aerial photographs analysis, and previous reviews of scientific investigations. GIS tools were essential for generating this database. The information focused on 1) geoform location; 2) their physical characteristics (slope, orientation, and elevation); 3) delimitation of the occupied surface and elevation range; 4) sedimentological characterization at the outcrop level, and 5) dating. The database has been created as a reference element to carry out paleoenvironmental reconstructions that help precisely characterize the forms. This could improve the interpretation of the current landscape and the territorial evolution. For this reason, the files include not only alphanumeric data, but each record was also created with maps and images that clearly understand each site and, where appropriate, the previous works about these areas. Another key aim of this project is to determine the importance of each site at the local, regional, or international level. This fact aims to propose some specific areas as sites of geological interest, thus preventing their disappearance.

Rock glaciers chronology and Holocene evolution in the mid-latitude Southern Carpathians, derived from absolute and relative dating

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Abstract

Rock glaciers are important landforms for climate reconstruction, relating to both magnitude of debris production and past climatic conditions for permafrost creep. In formerly glaciated ranges, formation of rock glaciers is generally associated to deglaciation and post-glacial warming phases, as consequence of increased debris production under debuttressing effect and destabilization of adjacent source areas. Absolute and relative dating techniques proved to be reliable methods applied in deglaciation and more recently on periglacial landforms chronology reconstruction; in this context, relative dating becomes particularly important when extending at mountain-range scale. We here present 30 10Be surface exposure ages and 25 Schmidt hammer relative dating profiles from 12 rock glaciers in Făgăraș and Retezat Massifs (Southern Carpathians, Romania) situated in the range of 1740-2260 m asl, with the aim to identify i) rock glaciers formation time-interval and conditions, ii) Holocene evolution phases, iii) differences imposed by altitude and lithology in the two massifs. The results highlight different evolution patterns, respectively: the largest complex rock glaciers with fronts below 2000 m asl initiated their formation in early Younger Dryas or rarely before (14-12 kyrs) with the upper lobes forming and being active during Early Holocene. Comparatively, the highest rock glaciers (usually above 2100 m asl) were dated to Early Holocene (11.6-9 kyrs). We infer that a significant part of the large rock glaciers in the two massifs, presently relict, derived from Younger Dryas small glaciers that were covered by debris and maintained ice lenses and permafrost, and were highly active during Preboreal (11.7-10.2 kyrs). We assume these landforms inactivated in the first millennia of the Holocene.

Characteristics and vulnerability of peatland permafrost along its southern limit in eastern Canada

Jordan Beer (Queen's University), Robert Way (Queen's University), Yifeng Wang (Queen's University), Anika Forget (Queen's University) and Victoria Colyn (Queen's University).

Abstract

Labrador's southeastern coastline hosts some of the most southerly lowland permafrost landforms in the world. These ecologically rich landscapes are important grazing grounds for endemic caribou herds and are of high cultural importance for local Indigenous people who use these grounds for berry picking, goose hunting, fox trapping, and Kamutik storage. Recent remote sensing and field investigations along the Labrador Sea coastline have revealed a high abundance of palsas and peat plateaus, but these landforms remain understudied and mostly uncharacterized within the permafrost community. In 2021 and 2022, our team visited 20 peatland permafrost complexes spanning from Blanc-Sablon, Quebec (51.5 °N) to Nain, Nunatsiavut, Labrador (56.5 °N) to characterize peatland permafrost at different degradational stages along a space-for-time transect. At each site, uncrewed aerial vehicle (UAV) surveys and structure-from-motion were used together to generate orthomosaics, three-dimensional point clouds, and digital elevation surfaces. Permafrost mounds at each site were manually delineated, guided by 3-D visualization of surface heights and in situ measurements. These tracings were used with a novel sampling method to extract mound heights, vegetation heights, and permafrost area for each peatland complex. A new metric, permafrost mound volume, was also developed as a proxy for total excess ice volume.

Preliminary analysis has revealed spatial trends in mound height, volume, and fragmentation that can be attributed to a variety of factors including latitude, coastal proximity, site disturbance, and surficial deposits. These results provide insights into the regions that are most vulnerable to future thaw and will support regional planning and ecological integrity assessments. This study provides a much needed description of the characteristics of peatland permafrost complexes in Labrador and provides important insights into the vulnerability and resiliency of discontinuous permafrost to climate warming.

Long-term stabilization of thermo-erosion gullies in the Canadian High Arctic demonstrates the resilience of permafrost to short-term disturbances

Samuel Gagnon (Université Laval / Centre d'études nordiques) and Daniel Fortier (Université de Montréal).

Abstract

Thermo-erosion gullies (TEG) are one of the most common forms of abrupt permafrost degradation. They generally form in ice-wedge polygonal networks where the interconnected troughs can channel runoff water. TEG can form within a single thawing season but take decades if not longer to completely stabilize. For this reason, most studies have investigated the short/medium terms (years to decades) effects of TEG on permafrost environments, but the long-term (centuries) effects and stabilization processes remain poorly documented. For this study, we investigated the geomorphological and geocryological differences between a stabilized (>100y/o) and a recent/active (since 1999) TEG on Bylot Island (NU, Canada) to characterize the state of permafrost after long-term stabilization of a TEG. We used permafrost cores taken from multiple boreholes in and along the two TEG to analyze the cryostratigraphy and permafrost properties. Our results showed that some younger sections of the recent TEG were characterized by major geomorphic, hydrological, and thermal disequilibria enhanced by positive feedbacks. In addition, the degradation of this TEG was uneven and changing: some parts were stabilizing while others were still degrading, and sometime they changed from one state to the other. In contrast, the stabilized TEG was not undergoing any degradation process, but was still affecting local hydrological connectivity. We also observed that the cryostratigraphy and active layer thickness of this TEG were comparable to measurements made in undisturbed conditions. We concluded that although the formation of a TEG has profound effects on the short/medium term and leaves near permanent geomorphological and hydrological scars in periglacial landscapes, on the long term, Arctic permafrost is able to recover and return to geocryological conditions similar to those pre-dating the initial disturbance, which increases it ability to resist other future disturbances and thus its resilience.

Former cold – wet ice polythermal glacier inferred from erratics and moraines SH ages (Schmidt hammer ages), the Madriu valley (SE Pyrenees)

Valenti Turu (Marcel Chevalier Earth Sciences Foundation), Josep Ventura (Marcel Chevalier Earth Sciences Foundation) and Xavier Ros (Marcel Chevalier Earth Sciences Foundation).

Abstract

Mountain glacier landsystem provide geomorphological and sedimentological evidence of former glaciations subject to past climate variability. By reconstructing the glacial phases, we approach the causes of the mountain glaciers' length and type of ice within landforms and known chronology. We present the firsts results of the Schmidt hammer (SH) type-L field campaign conducted on 24th and 25th September 2021, hammering on glacial boulders from the Madriu valley (E Andorra, SE Pyrenees) and measuring their rebound energy value (R). The characteristics, operating principles and procedures for using the SH are according to the standard ISRM recommendations methods. The selected boulders were of metric scale, related to moraines (2), supraglacial tills (5) or erratics (4), and were blown over the same surface with several shots on top (vertically) and horizontally. Except for erratics, the age of the landforms containing glacial boulders and their weathered skin correlates proportionally using the appropriate R/age curve from the closer Carlit area (French SE Pyrenees). However, during the glacier retreat, the size of the Madriu glacier reduces progressively, incorporating erratic boulders on the top-most part of the valley (above 2200 m a.s.l) from former paraglacial activity. Data agrees that paraglacial on top and moraine build-up on the lowland valley were contemporary. To explain the latter, we invoke a languid ice flow (cold ice) above the ELA where the frequent occurrence of erratics matches. A tempered glacier tongue below the ELA may exist in the Madriu valley, advancing to the main Andorra glacier. Cold ice type could have coexisted above the ELA and allowed the former presence of polythermal glaciers in Andorra during the MIS 2. Nevertheless, younger erratics and moraine construction identified a surging ice mass during the Older Dryas.

Investigating Environmental Controls on Epigenetic Ice-Wedge Development using Extended Finite Element Methods

Gabriel Karam (Carleton University), Mehdi Pouragha (Carleton University) and Stephan Gruber (Carleton University).

Abstract

Ice wedge polygons are found extensively throughout permafrost areas and represent a significant amount of ground ice in the upper ten metres of soil. Ice wedge formation occurs with sudden infrequent cracking, making field monitoring difficult, and their large scale makes laboratory replication impractical. A 2-D numerical model capturing a slice of the frozen ground is used to test hypotheses about the invisible processes of ice wedge cracking. With long-term parametric analyses, this study aims to capture the effects of different soil types, ground-ice content, snow, and climatic conditions. In addition, existing analytical solutions for ice wedge cracking will be compared to model results.

A two-part thermal and mechanical finite element model is used to simulate cracking. The thermal model is used to determine ground temperatures from surface forcing, which are then applied to the mechanical model to induce thermal contraction cracking. The extended finite element method (XFEM) allows the formation of cracks anywhere in the soil, and an elastoplastic creep constitutive model is used to represent material properties. Each year when the snowpack becomes isothermal, water is inserted into the crack and freezes upon contact with permafrost. This process is automated and can be repeated any number of times. In future works, this model could be extended to the third dimension and more accurate and computationally intensive frozen soil models would improve results.

What do plants do on periglacial landforms?

Jana Eichel (Utrecht University), Marije Harkema (Utrecht University), Isa Meirink (Utrecht University), Wiebe Nijland (Utrecht University), Steven de Jong (Utrecht University), Teja Kattenborn (University of Leipzig), Philipp Gewalt (University of Tuebingen) and Daniel Draebing (Utrecht University).

Abstract

In high‐latitude and high‐altitude environments, periglacial landforms created and shaped by freeze-thaw processes are a key geomorphic feature. Many periglacial landforms, such as solifluction lobes, can be vegetated and provide habitats for many different plant species. We know that plant cover and roots affect freezing, thawing and transport of soil. Thus, plants growing on periglacial landforms will likely influence landform development and dynamics. Yet, those feedbacks between plants, periglacial processes and landforms are not well understood and rarely quantified. Using data from more than 100 turf-banked solifluction lobes and terraces in Turtmann Valley (Switzerland), we evaluated the role plants play for (1) development, (2) morphology and (3) dynamics of solifluction landforms. By investigating patch size and traits of the prostrate shrub Dryas octopetala in relation to solifluction terrace dimensions, we found that (1) "ecosystem engineer" plants and solifluction terraces develop jointly. D. octopetala's strengthening root system initiates terrace risers, while its extending dense, prostrate mat traps sediments that enlarge the terrace tread. Analyzing the morphology of >100 solifluction lobes showed that (2) vegetated solifluction lobes (> 35 % cover) often possess higher risers but tend to be narrower than their less vegetated counterparts. Repeated high-resolution Uncrewed Aerial Vehicle surveys of three solifluction lobes found that (3) lobes move less with more vegetation cover and longer snow cover duration, but also that movement rates affect which plant species grow. While quickly moving lobes (0.2-13.7 cm yr-1) provide habitats mainly for low, shallow-rooting herbs and prostrate shrubs, stabilizing lobes (0.1-2.7 cm yr-1) support trees and shrubs with deeper roots, as well as highest species diversity. Overall, our results suggest strong biogeomorphic feedbacks between plants, periglacial processes and landforms. With climate change affecting both periglacial processes and vegetation distribution, we expect that those feedbacks will play an important role for future periglacial sediment transport and biodiversity.

The distribution and morphometry of wedge ice in the Barrens of northern Manitoba, Canada

Tabatha Rahman (Université Laval, Centre for northern studies, Québec, Canada) and Pascale Roy-Léveillée (Université Laval, Permafrost Geomorphology Research Chair (Sentinel North), Centre for northern studies, Québec, Canada).

Abstract

Although recent paleogeographic modelling predicts negligible wedge ice in northern Manitoba (Central Canada), satellite imagery shows extensive ice-wedge polygons in the "Barrens" of this province. The Barrens represent a 12 500 km^2 continuous permafrost tundra area within the Hudson Bay Lowlands, a glacio-isostatically uplifted coastal plain covered with glaciomarine sediments and thick peat deposits. The Barrens are characterized by extensive polygonal peat plateaus, suggesting the presence of substantial wedge and segregated ice, which increase the regional sensitivity to warming and thaw induced geomorphological and ecological change. This project presents the first assessment of wedge-ice distribution and morphometry in this understudied subarctic landscape. The total length and density of ice wedges were calculated using manual delineation of ice-wedge troughs on satellite imagery (ArcGIS World Imagery) at fifteen randomly distributed 3-km^2 sample sites. Preliminary results reveal an average ice-wedge trough density of 9700 m/km^2 in the Barrens. Ice wedge vertical distribution and morphometry were estimated from eleven cores (155-234 cm depth) extracted from two short transects perpendicular to ice-wedge troughs. Sampled ice wedges were at least 60 cm below the base of the active layer and measured ≤ 155 cm in width and ≥ 100 cm in height, with an estimated cross-section area of 0.78 m^2. These dimensions are small in comparison to other ice wedges in the Arctic, such as in Yukon's Mackenzie Delta (390 cm width, 350-400 cm height), Alaska's Prudhoe Bay (300 cm width, 330 cm height), and Nunavut's Fosheim Peninsula (146 cm width, 323 cm height). These dramatic differences in wedge-ice volume under comparable surface expressions reinforce that wedge-ice volume cannot be reliably estimated using remotely sensed imagery alone, and that subsurface ice morphometry data are essential. These results provide a basis for subsequent geomorphological investigations, and are necessary for paleoenvironmental reconstructions and predictions of landscape evolution.

New Evidence of Relict Cryogenic Processes and Landforms at the East European Plain

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Abstract

Relict cryogenic processes and landforms assist in interpretation of stratigraphy, the genesis of deposits and paleogeography. The relief and deposits formed in the past influence the appearance of modern landscapes, which is important for understanding the trends in their development. Field work data and luminescence dating were used to better understand the changes in the extent and conditions of the periglacial regions in the Eastern European Plain (EEP). Soil samples were collected at the Lower Volga (south), Orenburg (southeast), and the Oyat River (north) of the EEP. Detailed studies of the loess–paleosoil strata show that the sediments in the region were subjected to cryogenic processes from MIS 5b to MIS2 during which five main stages in the permafrost affected regions can be determined. In the south, processes of cryogenic transformation of sediments largely predetermined the composition and structure of loess sediments in the Lower Volga region, while in southeast specific landscapes, defined as chalk polygons were formed. These unique and previously unexplored landscapes near Orenburg are characterized by polygonal microrelief, resembling tundra medallions, with an average polygon side of 5 m; soil wedges associated with ravine-shaped depressions between polygons; cryoturbation of soil profiles and paleocryotexture. These polygons were formed during LGM in an arid climate and permafrost presence. The complex of paleocryogenic textures, casts and subaerial deposits exposed in the cliffs of the Oyat River reflects very cold climatic conditions of northern part of EEP. The formation of 300 m thick permafrost here occurred in a very short period of time, approximately in 600–700 years (the Younger Dryas), after the retreat of the Scandinavian glacier, which requires additional studies and explanations.

Monitoring the major low-latitude pingo in Southern Europe using geomatic and thermal information

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Abstract

Open-system pingos are common in valley bottoms of mountainous regions with thin or discontinuous permafrost. They develop in different sediments due to the lateral groundwater flow, which may freeze or flow towards the surface depending on the freeze-thaw cycles. This work explores the largest (59x22.5x3.5 m) known frost mound in southern latitudes in central Spain (Guadarrama National Park, Spanish Central System). Often, visual inspection has been used to explore the evolution of such periglacial landforms. A top-to-bottom study has been performed using geomatic techniques and thermal data to improve the knowledge of their genesis and growth. Light Detection and Ranging (LiDAR) and Unmanned Aerial Vehicles (UAVs)-derived data provided accurate geometrical information to constrain the surface evolution of the landform. Several digital elevation models (DEMs) were evaluated and compared to analyse the topographic variations that occurred during different periods (2022 and 2023). Additionally, the thermal gradient correlated well with this structure's subsurface and surface evolution. A 2D-Fourier analysis of this data suggests the presence of thermal anomalies associated with groundwater flow distribution within the structure. Therefore, the seasonal changes in the thermal regime can be explained by groundwater flow responsible for the observed physical changes and height variations detected during the annual freeze-thaw cycles. Then, based on its genesis, we define this open-system pingo as a hydrolaccolith. Our study suggests combining different surveying techniques can improve the analysis and establishment of management plans that ensure their conservation.

The Periglacial Legacy of Louise Arner Boyd's American Geographical Society Expeditions to East Greenland,1933 and 1937

Frederick Nelson (Michigan State University, Department of Geography, Environment, and Spatial Sciences) and Raven Mitchell (Michigan State University, Department of Geography, Environment, and Spatial Sciences).

Abstract

Louise Arner Boyd's expeditions to Greenland in the 1930s were predictive of the type of collaborative campaign that later in the century would characterize government-sponsored and international scientific efforts. "Planned as a unit," Boyd's expeditions were thoroughly integrated scientific enterprises investigating a variety of natural phenomena within representative areas. The publications resulting from this work, appearing as American Geographical Society (AGS) Special Publications in 1935 and 1948, contain large-scale hydrographic and topographic maps, descriptions of periglacial features, high-resolution glacier maps, extended treatments of East Greenland's geology, glacial history, botany, hydrology, and a wealth of photographic documentation. Boyd's expeditions employed scientists who eventually became highly influential in their respective fields. Among others, Boyd employed the glacial and periglacial geomorphologists J Harlan Bretz, Richard Foster Flint, A. Lincoln Washburn, and Noel Odell, along with AGS staffers O.M. Miller and W.A. Wood, who developed and applied innovative ground-based survey and photogrammetric techniques. Several of these scientists obtained their first experiences in Arctic fieldwork on the Boyd expeditions and subsequently became prominent in periglacial research. Washburn, in particular, was influenced deeply by the experience. He returned to the fjord region of East Greenland in the 1950s to conduct an award-winning program of research about periglacial weathering and mass wasting, published in Meddelelser om Grønland. Washburn also wrote several influential periglacial textbooks and research monographs in the 1970s and 1980s. Although this point is not generally recognized, the involvement and collaboration of the geomorphologists and mapping scientists on the Boyd expeditions greatly enriched and helped to direct the development of periglacial geomorphology.

Geotechnical properties of Tyrrell Sea deposits: data gaps and research needs

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Abstract

Isostatic uplift of the Hudson Bay Lowlands (HBL) during the last 8000 years has exposed over 320 000 km^2 of marine deposits, including Tyrrell Sea clay, to cold subaerial conditions. While the distribution and properties of sensitive clays have been extensively documented in other regions, the marine clays in the rapidly warming permafrost of the HBL are scarcely studied. This research aims to synthesize and improve knowledge on the sensitivity of Tyrrell Sea clays by: 1) synthesizing available geotechnical data within the marine limits of the Tyrrell Sea to identify geographical gaps and sampling priorities; 2) comparing properties of Tyrrell Sea clays from different parts of the HBL to known properties of quick clays in non-permafrost regions, such as the Leda clays of the Champlain Sea. A map of known marine transgression limits incorporating recent corrections on the western and eastern sides of Hudson Bay is under production. Geotechnical data from locations within the marine limits will be selected from past Centre d'études nordiques (CEN) studies and gathered from published reports and scientific papers. Available information on grain size distribution, pore water salinity, mineralogy, Atterberg limits, shear strength, and sensitivity will be extracted and compiled. Fresh and preserved samples from ongoing CEN projects in Manitoba and Nunavik will also be subsampled and analyzed for these parameters. Variability in Tyrrell Sea clay properties between different parts of the HBL, representing different thermal conditions and emergence periods, will be examined and compared to the well-documented properties of Leda clay. This research will assess the current state of knowledge on the geotechnical properties and sensitivity of the Tyrrell Sea clay deposits to help identify data gaps and priorities for future research on this pressing issue.

Glacial-to-periglacial transition in the Lòcampo cirque, Central Pyrenees

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Abstract

In the Upper Garonne basin, Central Pyrenees, the formation of a rock glacier at 2200-2300 m occurred after the deglaciation of the Lòcampo cirque (highest peaks 2600-2700 m; 42º38'06" N and 0º59'10"E). However, the chronology of the stabilization of rock glaciers in the north face of the Central Pyrenees is poorly known. We have conducted a detailed geomorphological map and constrained the glacial-to-periglacial transition by using an 8-sample dataset of 10Be terrestrial cosmic-ray exposure (CRE) ages. A cirque moraine surrounds a set of longitudinal ridges typically observed in debris-covered glaciers that are closing a relict rock glacier with several transversal ridges and furrows. The CRE ages suggest that the cirque moraine was built and stabilized during the second half of the Bølling–Allerød interstadial (at 13.2 ± 1.1 ka). CRE dates from rock glacier boulders reported a chronological range between 13.6 ± 0.9 and 11.9 ± 0.7 ka, which makes it difficult to accurately constrain the age of its formation as these ages are indicative of boulders stabilization. CRE results, together with geomorphological evidence, support a complex and rapid glacial-periglacial transition: after the cirque moraine stabilization, a debris-covered glacier formed inside the moraine limits, which was followed by the subsequent formation of the rock glacier in the cirque bottom. The rock glacier flow rapidly ceased at 13.6 ± 0.9 ka. However, the influence of debris mantle on the buried ice melting likely delayed for ca. 2-3 ka the final stabilization of the rock glacier, at 11.9 ± 0.7 ka – or afterward. The results showed in the Lòcampo cirque provide a transitional model between the glacial to periglacial domains during Termination-1 at the low-altitude cirques of the Central Pyrenees. More robust datasets are needed to accurately constrain his transition and show other geomorphological sequences following the deglaciation of the cirques.

Quantification of hourly particle movements on sorted circles in a karst cave in Slovenia

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Abstract

One of the most distinctive periglacial landscape landforms is patterned ground, which has also been reported from karst caves in temperate climates. Observation of surface movements on patterned ground during the freezing season is very challenging due to presence of snow, lack of stable points and difficult site accessibility. Karst caves, on the other hand, are unique environments for such observations due to absence of snow and vegetation and stable cave walls that allow multitemporal comparison of particle movements.

Our observation site is in Barka Cave that lies close to Snežnik Mountain at an elevation of 1100 m. It is a 20 m deep and 50 long oval collapse doline with locally overhanging walls. Sorted patterned ground developed on vegetation free floor under these walls. Especially characteristic are sorted circles with diameters ranging between 40 to 70 cm. We installed four time-lapse cameras steered by microcomputer that are taking photos of the sorted circles from different angles at hourly resolution. We used Structure from Motion (SfM) to generate 3D models for each time-step. A wide grain size range of sediment (gravel and sand) present on sorted circles enables tracking of ground movements.

Up to 20 freeze-thaw cycles per year that can last several days cause intense frost heaving. First results show that needle ice growth and frost heave up to 10 cm were observed during freezing conditions. Lateral particle movements are in the range of 5 cm during one winter. These particle movements will later be related to temperature characteristics, sediment properties and soil moisture. Sorted patterned ground studies in karst caves can thus help to reveal cryoturbation mechanisms that are responsible for large organic carbon storage in soils underlain by permafrost.

Characteristics of freeze-thaw cycles at patterned ground sites in two karst caves in Slovenia

Matej Blatnik (ZRC SAZU Karst Research Institute, Postojna), Franci Gabrovšek (ZRC SAZU Karst Research Institute, Postojna), Jure Košutnik (University of Nova Gorica, Nova Gorica), Paul Overduin (Alfred Wegener Institute, Helmholtz Center for Polar and Marine Research Potsdam), Julia Boike (Alfred Wegener Institute, Helmholtz Center for Polar and Marine Research Potsdam; Humboldt Universität zu Berlin,) and Jaroslav Obu (ZRC SAZU Karst Research Institute, Postojna).

Abstract

The specific microclimate of karst caves can create sorted patterned ground. Sorted patterned ground is a phenomenon typically found in periglacial environments, where repeated freeze-thaw cycles differentially heave the ground and sort sediment particles into different geometrical patterns. In this study, we focused on two caves in Slovenia with suitable conditions for patterned ground development – Barka and Ledenica pod Hrušico. Both are about 30 m deep and open to the surface, which generates a microclimate with cold winter temperatures. As a result, a mixture of moist fine sediment and coarse debris has been sorted into alternating sorted stripes (on inclined slopes) and sorted circles (on flat surfaces). In both caves, we measured air and sediment temperatures continuously at several locations for more than seven years. The temperature loggers were positioned at different depths in the sediment and on the cave walls. Spatial and temporal temperature distribution allowed us to observe temperature dynamics, heat transfer, the propagation of temperature signals and the frequency and intensity of freeze thaw cycles. Temperature measurements revealed that the ground in both caves regularly freezes up to 25 cm deep, but the number of freeze-thaw cycles differs significantly. In Ledenica pod Hrušico we observed 0–2 freeze-thaw cycles per winter, while in Barka cave 10–20. The difference reflects the role of cave geometry in affecting airflow circulation and, as a result, the microclimate at the patterned ground location. There are also quite large interannual differences in winter temperatures. In some warmer winters sediments in Ledenica pod Hrušico did not freeze at all, potentially reflecting a shift to warmer climate. These findings and the continued rise of local air temperatures suggest that the process of sorted patterned ground development will gradually stop.

Debris cover development and its impact on the recent evolution of Infiernos glacier, Spanish Pyrenees

Jesús Revuelto (Instituto Pirenaico de Ecología (CSIC), Eñaut Izagirre (Universidad del Pais Vasco), Francisco Rojas Heredia (Instituto Pirenaico de Ecología (CSIC), Ibai Rico (Universidad del Pais Vasco), Ixeia Vidaller (Instituto Pirenaico de Ecología (CSIC), Luis Mariano del Rio (Universidad de Extremadura), Enrique Serrano (Universidad de Valladolid) and Juan Ignacio López Moreno (Instituto Pirenaico de Ecología (CSIC).

Abstract

The North face of the Infiernos Peak (3,082 m a.s.l.), composed of Paleozoic metamorphic materials, hosts one of the smallest glaciers that still persists in the Pyrenees. As other glaciers in this mountain range, this one has experienced a strong decline in extent and thickness in the last years. However, this glacier has been covered by a particularly extensive debris cover (about 30 % of the glacier surface) as consequence of a recent rockfall, and the intense periglacial activity in the steep surrounding cirque walls. This work presents results of glacier area and ice thickness losses obtained with satellite, airborne LIDAR and UAV (Unmanned Aerial Vehicles) for the years 2011, 2020, 2021 and 2022, as well as a GPR (Ground Penetrating Radar) survey in 2021 to estimate remaining ice thicknesses. Additionally, thermometers were installed at various locations around the glacier in 2021. These thermometers were buried in the ground or holes drilled directly into the rock of the upper steep slopes of the glacier. The glacier has shown intermediate values of glacier shrinkage and wastage compared to other Pyrenean glaciers, but it is relevant that the areas covered by the thin debris cover have shown a marked attenuation in glacier thickness reduction compared to the debris-free areas. Ground and rock temperatures have allowed to determine the existence of permafrost in some places, as well as a high number of freeze-thaw cycles in the surroundings of the glacier, possibly contributing to the further increase of the debris cover over the glacier in the near future.

Relative frost damage index applied to periglacial rock walls in two-dimensions

Justyna Czekirda (Department of Geosciences, University of Oslo, Oslo, Norway), Alan W. Rempel (Department of Earth Sciences, University of Oregon, Eugene, OR, USA), Bernd Etzelmüller (Department of Geosciences, University of Oslo, Oslo, Norway) and Sebastian Westermann (Department of Geosciences, University of Oslo, Oslo, Norway).

Abstract

Frost weathering was traditionally believed to result from the 9 % volumetric expansion of in situ water when it freezes to ice, so-called "freeze-thaw weathering", since the generated pressure should be sufficient for rock breakdown. More recent studies undermine this theory, because such a process requires a fully-saturated, closed system, which is likely rare. Nowadays, the most accepted explanation is the process of segregated ice growth, in which ice-filled cracks are supplied by additional water that is drawn to the freezing front. Numerical modelling and laboratory experiments suggest that segregated ice growth can generate enough stress to cause rock damage and is typically most intense between approximately -8 and -3ºC (the precise range depends on the characteristic crack size, along with hydraulic- and fracture-mechanical properties of bedrock), in the so-called frost cracking window (FCW). Several frost-cracking indices have been developed to link climate and frost cracking potential due to ice segregation in rocks, based on e.g. the time spent vulnerable to cracking within the FCW, the magnitudes of ground temperature gradients that induce water transport, and other factors that affect water availability. Hitherto, several studies applied frost-weathering indices to rock walls in one dimension. In the present study, we model ground temperature using the ground heat flux model CryoGrid 2D and apply a two-dimensional frost weathering index derived from an existing one-dimensional index, where frost weathering potential is assumed to be correlated with porosity changes that accompany gradients in water flux. We run the frost cracking index both for one characteristic crack size and for the ensemble of crack sizes mapped in a rock wall section. Our results predict spatial and temporal patterns of frost weathering in rock walls in the Jotunheimen Mountains in southern Norway.

SESSION 22

Polar Coastal and subsea environments in Transition: Arctic – Antarctic perspectives

Conveners:

- **Matt C. Strzelecki,** *University of Wroclaw;* mateusz.strzelecki@uwr.edu.pl
- **Frederieke Miesner,** *Alfred Wegener Institute, Helmholtz Center for Polar and Marine Research;* frederieke.miesner@awi.de
- **Mette Bendixen,** *McGill University;* mette.bendixen@mcgill.ca
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Summary:

Polar coastlines make up over one third of the global total and are among the most dynamic in the world. Due to climate change, polar coastlines are increasingly vulnerable to rapid change. Patterns of Arctic coastal change are mostly associated with decreased sea ice cover, which is leaving coasts exposed to waves and storm action for longer each year. Additional influential factors include coastal permafrost degradation, storm-surge flooding, and intensified sediment supply from glacierised catchments. These changes have wide-ranging impacts on circum-polar Arctic coastal communities through the destruction of culturally important sites and modern infrastructure. In the Antarctic region, accelerated deglaciation has exposed new coastlines where permafrost-related processes and fluxes of sediments from paraglacially transformed glacial landforms control coastal dynamics. Along the coast, permafrost transitions from terrestrial to submarine where its thermal state rapidly changes. Despite considerable research over the past decade, a great deal remains unknown about the nature and distribution of subsea permafrost. This session invites submissions that will improve our understanding of polar (Arctic and Antarctic) coastal dynamics on local and regional scales. We encourage submissions focusing on both sub-aerial and sub-aqueous processes driving changes to coastal morphology, as well as abstracts which discuss rates of change and socio-economic impacts. We also welcome contributions with new field measurements, mapping or modelling efforts, or process-understanding field and laboratory experiments relevant to permafrost at the coast and beneath the shelf seas. In addition, contributions may focus on sediment and microbiological processes affecting carbon stocks and greenhouse gas emissions, on the morphology of seabed features related to permafrost thaw or gas emissions, or on hypersaline permafrost environments, since salt transport can change subsea permafrost state and remains an important knowledge gap. The objective of our session is to provide a platform for discussions on various aspects of coastal change and itsimpact on the resilience of polar environments and societies. We particularly encourage contributions from members of ACD (Arctic Coastal Dynamics), CACCON (Circum-Arctic Coastal Communities KnOwledge Network), Permafrost Coastal Systems Network (Per-CS), Nunataryuk, and EO4PAC groups.

Coastal erosion dynamics of high-Arctic rock walls on Brøgger Peninsula, Svalbard

Juditha Aga (Department of Geosciences, University of Oslo, Norway), Livia Piermattei (Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Switzerland), Luc Girod (Department of Geosciences, University of Oslo, Norway), Kristoffer Aalstad (Department of Geosciences, University of Oslo, Norway), Trond Eiken (Department of Geosciences, University of Oslo, Norway), Andreas Kääb (Department of Geosciences, University of Oslo, Norway) and Sebastian Westermann (Department of Geosciences, University of Oslo, Norway).

Abstract

Arctic coastlines tend to show increasing erosion rates under a warming climate. This is especially true for ice-rich permafrost bluffs, which have been studied intensively in the past. In contrast, the rock-wall coasts of the high-Arctic are assumed to be quite stable, so less research has been done on their dynamics. For example, estimates of long-term trends in coastal erosion rates in rock cliffs on Svalbard do not exist.

In this study, we investigate the long-term evolution of the coastline along the Brøgger Peninsula, Svalbard. Based on high-resolution orthoimages from 1970, 1990, 2011 and 2021, and a dGPS survey in 2021, we analyze coastal retreat rates along 7 km of coastline during the last 50 years. To do this, we digitized the top of the coastal cliff and calculated the retreat rates using the Digital Shoreline Analysis System (DSAS). The results show that the retreat rates of 0.22-0.33 m/a are higher along the southwest-facing coastline, which is exposed to the open sea, compared to 0.03-0.07 m/a along the northeast-facing coastline, which is protected by the fjord. We detect accelerating retreat rates in the last decade 2011-2021 compared to 1970-2011 as well as an increase in the length of coastline affected by erosion. Furthermore, measurements of rock surface temperature in 2020-2021 show values close to the thaw threshold, with lower values for the southwest-facing coastline. Our study exemplifies how combining historical aerial images with recent aerial data allows us to determine long-term trends in coastal retreat rates and provides insight into the coastal dynamics of rock cliffs on Svalbard.

Arctic Delta Reduced Complexity Model and its Reproduction of Key Geomorphological Structures

Ngai Ham Chan (Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI), Moritz Langer (Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI), Bennet Juhls (Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI), Tabea Rettelbach (Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI), Paul Overduin (Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI), Kimberly Huppert (Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences) and Jean Braun (Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences).

Abstract

Arctic river deltas connect the terrestrial Arctic to the Arctic Ocean. They are unique globally due to the interactions of permafrost, river and sea ice. One of the ubiquitous features is that they are surrounded by a broad shallow ramp. These ramps may form a buffer and protect the delta from waves. As the climate warms and permafrost thaws, the evolution of Arctic deltas will likely take a different course, with implications both local in scale and on the wider Arctic Ocean. Complementary to measurements, numerical models play an important role in understanding and predicting the evolution of Arctic deltas. We present ArcDelRCM.jl, an improved reduced complexity model (RCM) of arctic delta evolution based on the DeltaRCM-Arctic model. Unlike previous models, ArcDelRCM.jl is able to reproduce the ramp feature around the delta. We have found that the delayed breakup of the so-called “bottom-fast ice” on and around the deltas is ultimately responsible for the development of the ramps in our models. However, a series of modifications made to the modelling of frozen-ground erosion and of the protective effects by bottom-fast ice are also important contributors. We also performed graph analyses on the modelled deltas to elucidate the effects of individual features of our new model. Finally, we tested an RCP7-8.5 scenario on the simulated deltas of ArcDelRCM.jl to explore the time-scale over which the ramps would degrade and disappear.

Coastal processes and landforms in the South Shetland Islands (Maritime Antarctica)

Augusto Pérez-Alberti (Laboratory of Environmental Technology, Institute of Technological Research, University of Santiago de Compostela), Alejandro Gómez-Pazo (Universidade de Santiago de Compostela), Marc Oliva (Universitat de Barcelona) and Jesús Ruíz-Fernández (Universidad de Oviedo).

Abstract

In most coastal systems, waves are crucial to explain their evolution, but this factor loses importance in polar environments. In these sectors, the presence of ice, both continental and marine, plays a decisive role. This research presents the results of the fieldwork carried out in the South Shetland Islands, specifically in the Hurd Peninsula (Livingston Island) and Fildes Peninsula (King George Island).

The first element analyzed has been the evolution of these coasts, closely linked to paraglacial dynamics and strongly conditioned by the geomorphic adjustment of the slopes after deglaciation. Another critical element is the role of the numerous freeze-thaw cycles that enhance mechanical disintegration and rock breakup. The third element observed, in intertidal zones, has been the reinforcement of erosion processes by the action of sea ice. This rearranges the sediments, both continental, and marine. The impact of the ice blocks when the sea ice fragments play an essential role in the topographic changes of the current beach profile and the compaction of the pebbles, without forgetting the generation of small marine abrasion processes.

Spatial and Temporal Variability of Shoreline Change in the Tuktoyaktuk Peninsula from 1950 to 2020 (Beaufort Sea, Canada)

Bernardo Costa (CEG/IGOT-ULISBOA), Gonçalo Vieira (CEG/IGOT-ULISBOA), Michael Lim (Northumbria University) and Dustin Whalen (Geological Survey of Canada).

Abstract

The average rate of coastal change in the Arctic Ocean is -0.5 m/yr, though this masks significant local and regional variations, with large areas retreating above 3 m/yr. Recent data suggest an acceleration of coastal retreat in specific regions due to an increasingly shorter sea ice season, higher storminess, warmer ocean waters and sea-level rise. An improved understanding of the linkage between the inland and nearshore zones is crucial to providing information on permafrost coastal processes and their climatic, biogeochemical, marine ecosystem and socio-economic impacts. The Tuktoyaktuk Peninsula (NWT, Canada) is a hotspot of shoreline retreat and an area with complex and differing coastal dynamics. Tundra Bluffs Without Polygons are the main backshore morphology (42 %), Tundra Flats represent 28 % and Barrier Beaches and Sandspits and Tundra Bluffs with Polygons occupy 15 % each. Concerning the Foreshore Morphology, Beaches represent 51%, whereas Tundra Flats occupy 33 % and Active Bluffs represent 15 %. In this study, we present the shoreline change rates from 1950 to 2020, identifying the evolution trends, and analyzing their temporal and spatial variability. The analysis is based on shoreline delineation using NRCan historical aerial photography of 1950 and 1985, and a very high-resolution 2020 CNES-Pleiades survey, supported by the ArcticDEM. Results show an average shoreline change rate of -1.06 m/yr between 1985 and 2020, which is double the Arctic average rate, showing that the Tuktoyaktuk Peninsula has been losing c.48 ha of land yearly. This largely impacts Inuvialuit coastal settlements, subsistence harvesting, travel, and cultural sites. From 1985 to 2020, coastal retreat was higher in Tundra Flats (-1.74 m/yr). Foreshore assessment may be crucial, as there is great distinction in average rates between the three classes. We identify the distinct roles and impacts of erosion and submersion on coastal dynamics, a distinction lacking in automated shoreline delineation.

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In situ temperature distribution of bottom sediments of the East Siberian Arctic Seas

Boris Bukhanov (Skolkovo Institute of Science and Technology), Evgeny Chuvilin (Skolkovo Institute of Science and Technology), Oleg Dudarev (V.I. Il'ichev Pacific Oceanological Institute), Maksim Zhmaev (Skolkovo Institute of Science and Technology), Natalia Shakhova (Sadovsky Institute of Geosphere Dynamics) and Igor Semiletov (V.I. Il'ichev Pacific Oceanological Institute).

Abstract

The Arctic Shelf is a rapidly-developed rich petroleum province. Meanwhile, the region, and specifically the East Siberian Arctic Seas, still presents large knowledge gaps in many aspects, because the harsh weather conditions, vast sea-ice coverage, and logistic problems make this region extremely hard to explore. Geological surveys, with drilling and sampling, are risky and expensive and thus remain limited. In this regard, actual data of subsea permafrost distribution are very limited. New field data confirm that the East Siberian and Laptev shelves have unfrozen (ice-free) cryotic sediments on the top, with -1.0 to -1.8 °C negative temperatures, i.e. 0.6 oC above the freezing point. The shallow bottom sediments apparently lie over buried ice-rich permafrost, which is however absent or deepened in the shallow shelf waters impacted by the river's plum heating effect and at water depths >100 m, where the sediment temperatures are above 0 °C. Surveys in the northern part of the Laptev Sea shelf have revealed patches of warmer bottom sediments spatially associated with methane seeps. The temperature anomalies in these areas are most likely produced by a relatively high heat flux from deformed crust along basement faults. Local warming of permafrost from below became favorable for methane venting into the water through permeable zones. Unlike the Laptev Sea shelf, the zones of methane seepage in the East Siberian shelf are free from temperature anomalies, though the gas emitted in the two areas is compositionally similar. The absence of warmer sediments in the zones of methane emission in the East Siberian shelf can be explained by a greater thickness of subsea permafrost and younger ages of the seeps. The activity of the younger seeps may have been too short to melt out permeable gas conduits of sufficient sizes and numbers, whereas the older seeps in the Laptev Sea have produced large permeable zones.

Spatial features of coastal dynamics of the Kara Sea

Daria Bogatova (Faculty of Geography, Lomonosov Moscow State University), Natalia Belova (Faculty of Geography, Lomonosov Moscow State University) and Stanislav Ogorodov (Faculty of Geography, Lomonosov Moscow State University).

Abstract

In the Arctic the mean annual air temperature is rising faster than anywhere else in last decades. The permafrost coasts occupy more than fifty percent of the Kara Sea coastline. That is why any human activity in the Kara Sea coastal zone must take into account the permafrost and its reaction to the changing climate. Three key-sites were chosen for investigation of coastal dynamics in the western part of the Kara Sea (the Ural, Yamal and Kharasavey coasts). This area is situated in the continuous permafrost zone with mean annual ground temperatures from -1 to -7°C and permafrost thickness ranges from 50-100 m to 200-300 m. The coastal retreat rates estimation was conducted based on field observations and the analysis of the satellite imagery. Bluff position was derived from the images and fieldwork data from 1980s to 2020s. The virtual transects was drawn every 10 m normally to the general direction of the shoreline. The coastal retreat rates were calculated as the proportion of the retreating area (m2) to the length of line formed by the intersection of transect and coastline.The neighboring points have similar rates of retreat for all sites, which is statistically confirmed. Semivariograms were made to reveal spatial correlations. Three types of semivariograms were obtained during data analysis. The first type is a spatial pattern of one factor that spreads its influence over the entire area. The second one is a uniform alternation of sections (each hundreds of meters long) correlated by the coastal retreat rate. The third type is the absence of spatial correlations. Understanding the spatial features to the coastal dynamics will provide a basis allowing us to predict the evolution of a complex and sensitive Arctic coastal environment in the future. The study was supported by the Russian Science Foundation project No. 22-17-00097

Permafrost coasts of Pechora and Kara seas in Transition: environmental forcing change

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Abstract

Two-thirds length of Pechora and Kara seas coastline consists of ice-rich permafrost deposits. The dynamic of these coasts is forced mainly by the change of natural environment induced by the global warming. For key areas on the coasts of Pechora and Kara seas environmental forcing changes have been calculated and analyzed. Restored long-term series of temperature, wind speed and direction; the dates of the beginning and end of the ice-free period at hydrometeorological stations were obtained. Calculations of the variability of the temperature and wave-energy components were performed. At all the stations considered, the sum of positive air temperatures increased statistically significantly over the period 1979–2021 with trend 8-12°C per year. It has been established that at all the considered stations of the coastal-shelf zone of the Pechora-Kara sector of the Russian Arctic, the duration of the ice-free period increased statistically significantly over the period with trend 10-25 days per 10 years. Wind-wave energy potential for the destruction of thermal-abrasion shores also increased statistically substantially at all high sea stations, about 20-50 % for 40 years. Rising temperatures are altering the arctic coastline and much larger changes are projected to occur during this century as a result of reduced sea ice, thawing permafrost. Less extensive sea ice creates more open water, allowing stronger wave generation by winds, thus increasing wave-induced erosion along Pechora and Kara seas coast. Analysis of multitemporal aerial and space images and field observations have shown considerable increase in erosion rates of coasts with bluffs composed by ice-rich sediments, about 1,3-1,5 times, as well as the start of erosion of many accumulative marsh coasts that have remained stable in the XX century.

The study was supported by the Russian Science Foundation project No. 22-17-00097.

Regional division of the East Siberian and Chukchi Sea shelf for subsea permafrost modeling

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Abstract

The issue of distribution, extent and thickness of permafrost on the bottom of the Arctic seas is crucial for any decision-making during the exploration of the shelf. Information on permafrost and its properties is important for ocean drilling technology development, prediction of the gas hydrate stability zones, and many other applied tasks. At present, one of the best ways to predict the distribution of subsea permafrost within large areas is modeling verified by field geocryological data where available. Here, we collected data on palaeogeography, bathymetry, past sea level evolution, tectonics, geology, ground properties, geophysics, geocryology, ocean dynamics and water mass properties of the East Siberain and Chukchi seas, which are estimated as areas of the most extensive subsea permafrost in the Arctic (Angeopoulus et al., 2020). We elaborated an algorithm, according to which we divided the territory in separate regions. The evolution of subsea permafrost in each of the regions will be modelled separately for the last 125 ka. We have selected three main groups of criteria to select regions: 1) a relatively uniform history of permafrost evolution in each region, i.e, a similar scenario of sea level history and other palaegeographic events; 2) relatively uniform geological and tectonic conditions which determine the heat flow and the properties of the ground, and therefore their reaction on the changing conditions on the surface. As a result, about fifty areas were selected; for each region, a scenario of permafrost evolution will be elaborated based on literature data on temperature conditions and sea level changes in the past. According to these scenarios, subsea permafrost modeling will be performed.

References
Angelopoulos, M., Overduin, P.P., Miesner, F., Grigoriev, M., Vasiliev, A. (2020). Recent advances in the study of Arctic submarine permafrost. Permafrost and Periglacial Processes. 31. 10.1002/ppp.2061.

Aquifer-ocean interactions as catalysts of coastal arctic change

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Abstract

Arctic coastlines are in rapid transition due to the combined effects of thawing permafrost, decreasing sea ice, and rising sea levels. While advancements in remote sensing have enabled robust assessments of surficial coastal change, understanding of coastal Arctic groundwater dynamics and feedbacks with climate change is lacking, limiting capacity to predict coastal Arctic conditions in a changing climate. In mid- and low-latitude environments, groundwater plays a critical role in mediating coastal ecosystem function and nearshore biogeochemistry through two-way interactions between land and the ocean. While many processes mediating groundwater flow transcend coastlines globally, high-latitude coastlines have added complexity associated with the presence of permafrost, seasonal ground ice, and seasonal sea ice that shape Arctic coastal regions. This talk will discuss recent field and numerical modeling studies that provide insights into present and future coastal Arctic groundwater dynamics and the implications of changing hydrology on ecosystems, water quality, and carbon and nutrient budgets. Both saltwater intrusion into terrestrial environments and groundwater discharge to marine environments will be discussed, including how saltwater intrusion impacts coastal permafrost and land-sea connectivity and what drives coastal groundwater discharge now and in the future. Together, these studies will highlight the role of groundwater in accelerating coastal change and shaping future Arctic coastlines.

Svalbard coasts under warming climate - changes, rates and landforms

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Abstract

During the post-LIA period (ca. last 120 years), paraglacial processes have been erasing the effects of glacial legacy from the relief of Svalbard landscapes. The rapid deglaciation activated also sediment cascades through which glaciogenic sediments are transported to the coastal zone where they contribute to the formation of new beaches, barriers, spits, and tidal flats. Lack of sea ice, thawing of coastal permafrost, and more frequent storms impact rocky cliffs and shore platforms, so characteristic elements of rugged shorelines of Svalbard fjords. Finally, in the last few decades, a shift from marine-terminating to land-based glaciers accelerated, resulting in the exposure of not only new shores but also new isles. In this study we report the post-LIA rates of coastal change in Svalbard, highlight the richness of new coastal landforms that evolved particularly along recently deglaciated fjord zones and provide insight into Svalbard heritage and settlement infrastructure sites which are threatened by coastal hazards.

The research is a contribution to the National Science Centre project:'ASPIRE-Arctic storm impacts recorded in beach-ridges and lake archives: scenarios for less icy future' No. UMO-2020/37/B/ST10/03074 and Norwegian Financial Mechanism 2014-2021: SVELTA - Svalbard Delta Systems Under Warming Climate (UMO-2020/37/K/ST10/02852) based at the University of Wroclaw

Earth Observation for Permafrost dominated Arctic Coasts (EO4PAC) – contributions to the next generation of the Arctic Coastal Dynamics database

Annett Bartsch (b.geos), Anna Irrgang (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Ingmar Nitze (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Julia Boike (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Goncalo Vieira (Centro de Estudos Geográficos, IGOT - Universidade de Lisboa), Benjamin Jones (University of Fairbanks Alaska), Guido Grosse (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Hugues Lantuit (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Julia Martin (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Barbara Widhalm (b.geos), Clemens von Baeckmann (b.geos), Rodrigue Tanguy (b.geos) and Pia Petzold (Alfred Wegener Institute for Polar and Marine Research).

Abstract

The multifaceted impacts of coastal environmental change on local communities, ecosystem services, and socio-economic dynamics have not yet been quantified in an integrated framework at the circum-Arctic scale. The development of maps is required that delineate areas at risk of permafrost degradation and coastal erosion, to produce vulnerability maps for determining safe building locations, and to provide information where mitigation efforts should be focused to protect Arctic coastal areas.

We will present progress regarding the following Earth Observation (EO)-guided activities in order to address these issues with the possibilities offered by remote sensing: - Creation of the first circumpolar consistent dataset of coastal erosion trends. - Creation of the first circumpolar consistent dataset of infrastructure at risk along the coasts. - Validation of the circumpolar datasets of (1) and (2) as well as permafrost time series which are already available through permafrost_cci - enhancement of the current Arctic Coastal Dynamics database (ACD) through ingestion of results from (1), (2), (3) and Permafrost_cci for full coastal environment characterization. - Development of a roadmap for future EO based updates of the ACD

Coastal erosion at Lorino community,Eastern Chukotka: new data for the western Bering Sea region

Alexey Maslakov (Lomonosov Moscow State University), Ivan Stekolshchikov (Lomonosov Moscow State University), Mikhail Drugov (Lomonosov Moscow State University) and Alisa Baranskaya (Lomonosov Moscow State University).

Abstract

Arctic coastal erosion is a widespread phenomenon affecting both coastal ecosystems and engineering infrastructure. In the last decades, a lot of new data on coastal erosion rates appeared, as along with new methods and approaches to their studies. The most valuable are long-term series of field observations of coastal dynamics in remote sites. This study presents new detailed data on coastal erosion within a coastal segment at Lorino community, Chukotka Autonomous Okrug, Russia. Previously published studies cover the period of 1967-2017. We updated the existing time series with the data for 2018-2021 summer seasons using an UAV. The obtained raw data was processed in Agisoft Photoscan software and compared with previous coastal positions. Moreover, available Corona satellite imagery allowed to reconstruct erosional bluff position in 1963, considerably expanding the timeseries backwards. The obtained coastal erosion rates were compared with wind energy potential values calculated for every open water period. Both characteristics show good correlation that provides an opportunity to calculate the expected coastal erosion rates and develop mitigation strategies for the coastal community of Lorino.

This study has been been supported by the RSF 22-77-10031 project "Coasts of the Russian Arctic seas: past, present, future".

Little Ice Age iceberg plughmark at the bottom of the Kara Sea

Osip Kokin (Geological Institute (GIN RAS), Nikita Meshcheriakov (Geological Institute (GIN RAS), Irina Usyagina (Murmansk Marine Biological Institute (MMBI RAS), Vasiliy Arkhipov (Geological Institute (GIN RAS) and Stepan Maznev (Geological Institute (GIN RAS).

Abstract

The work presents the results of the study of morphology, morphometry, geological structure and determination of the age of a large ice scour (or gouge) in the southeastern part of the Kara Sea near the entrance of the Baydaratskaya Bay. The study of the ice scour was carried out as part of the 52 cruise of the R/V Akademik Nikolaj Strakhov. Information on morphology and morphometry of the ice gouge was obtained by the sea bottom survey with a multi -beam echo sounder. Information on the geological structure of the deposits in which the ice scour was formed, as well as the deposits accumulated inside the ice scour, was obtained using seismic profiling and studying the bottom sediments cores sampled by the gravity corer from the ship board. The age of the ice scour was dated by measuring the content of the excess natural radionuclide 210-Pb and anthropogenic radionuclide 137-Cs in bottom sediments filling the scour. As a result of the analysis of all the information received and its comparison with the previously published data on the formation of the ice gouges, it was concluded that the studied ice scour was formed by the iceberg at the end of the Little Ice Age, most likely at the end of the 19th century. The work was supported by the Russian Science Foundation (project no. 21-77-20038).

The Future of the Arctic shoreface: A study on the role of permafrost in controlling coastal changes in the subaqueous environment

Deniz Vural (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, University of Potsdam) and Hugues Lantuit (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, University of Potsdam).

Abstract

Arctic permafrost coastlines account for 34 % of the world's coastlines and are greatly impacted by warming air and sea temperatures. Changing climatic conditions lead to the lengthening of the open water season and the increase in the open water area, as well as the warming of permafrost on land and below the sea floor. Storms are therefore more likely to lead to greater coastal erosion, threatening coastal infrastructure and communities. Most efforts to study these processes are limited to the projection of shoreline movement and often neglect the movement of the underlying shoreface. This is problematic because the arctic shoreface potentially reacts to warming temperatures in very different ways than temperate ones, because of the occurrence of subsea permafrost and the presence of sea ice in the nearshore zone. In this study, we devise a framework to comprehensively address this issue in the vicinity of Herschel Island Qikiqtaruk in the Yukon. Specifically, we will 1. lead an effort to harvest existing bathymetric data collected from science boats and local stakeholders to build a baseline dataset for the modeling of shoreface evolution, 2. use the bathymetric dataset together with subaerial topographic information to identify vulnerable areas along the Yukon Coast. Finally, we introduce the concept behind the study and highlight the cooperation framework established with local stakeholders to address the issue in this presentation.

Influence of permafrost on the formation of fluidogenic landforms within the shelf of the Pechora and Kara Seas

Anna Denisova (Geological institute of RAS), Andrey Kokhan (Geological institute of RAS), Eugene Moroz (Geological institute of RAS), Ekaterina Eremenko (Geological institute of RAS), Roman Ananiev (Shirshov Institute of Oceanology of RAS), Elena Sukhikh (Geological institute of RAS) and Sergey Sokolov (Geological institute of RAS).

Abstract

At present, the question of the formation of specific relief forms of the Arctic shelves, pingo-like features, remains debatable. The connection of this phenomenon with the areas of distribution of subaqueous permafrost becomes obvious. In particular, one of the proposed mechanisms for the appearance of ping-like features involves the combined action of permafrost and the degassing process. During the cruises of the R/V "Akademik Nikolai Strakhov" and "Akademik Boris Petrov" in 2018-2022 multibeam bathymetric survey and high-frequency seismic profiling were carried out in the areas of distribution of pingo-like features on the shelves of the Kara and Pechora seas. The main patterns of changes in morphometric parameters and the internal structure of pingo-like features in the study area were established, and the contribution of slope processes and bottom currents to their modern dynamics was assessed. The morphological parameters of pingo-like features and the density of their distribution depend on the time of flooding of the territory during the Holocene transgression, the intensity of degassing, the geological and geomorphological position, as well as and thickness of subaqueous permafrost was revealed. In the deepest areas (with a depth of 70-80 m) within the key polygons pingo-like features probably formed in the early stages of the Holocene transgression and now these landforms are significantly reworked by bottom currents and slope processes. In shallow water areas (up to 20-30 m) pingo-like forms are rare, which is due to the still large thickness of subaqueous permafrost, which prevents the uplift of fluids and has low plasticity. At depths from 20–30 to 70–80 m the density of pingo-like forms is maximum. Their accumulations are confined to areas of insular or discontinuous permafrost, where a high intensity of fluid flow is also noted. This work was supported by RSF grant No. 22-77-10091

Permafrost and lithological features of the Gulf of Kruzenshtern coast, Kara Sea

Daria Bogatova (Faculty of Geography, Lomonosov Moscow State University), Georgii Kazhukalo (Faculty of Geography, Lomonosov Moscow State University) and Alisa Baranskaya (Faculty of Geography, Lomonosov Moscow State University).

Abstract

The Arctic coastal zone is characterized by high dynamics due to presence of permafrost and wide spread of ground ice (massive and wedge's). In some Arctic regions more than tens meters of coastline are lost each year. The combination of hydrometeorological factors determines the conditions for soil thawing and removal of thawed material in the sea. However, the response of frozen shores to climate change depends on the permafrost and lithological features of coast. Our investigation carry out within the northwest part of Yamal peninsula (Russia) at the Kara Sea coasts. This area is situated in the continuous permafrost with annual ground temperature -1.5..-6°C. Saline deposits and cryopegs are widespread in the investigated territory. There are few morphological units observed at the key-site. The high terraces (up 20 m) mainly composed at the top by silty sands underlain by frozen more icy loams and silty loams. Laida (surface up to 3 m) is composed by silts and loams with peat or only peats. In August 2022 the thickness of the seasonally thawed layer ranges from 0.4 to 1.4 m: at the laida the mean value was 0.8-1.2 m, at the terrace was 0.4-0.9 m. The water content vary from 45 to 72 %, density from 1480 to 1600 kg/m^3 in laida's sediments. There are seven thermocirques (thermal denudation landforms) were observed at the slope of high terrace, it diameters was from 8 m up to 172 m. For erosion rate prediction it is necessary to know the parameters of the coast, including permafrost, ground ice and lithology The research was supported by the Russian Science Foundation project No. 22-77-10031

Observing ice-rich permafrost coastal bluff erosion at Drew Point, Beaufort Sea Coast, Alaska using UAV surveys and airborne multispectral imagery

Melissa Ward Jones (University of Alaska Fairbanks), Benjamin Jones (University of Alaska Fairbanks), Ingmar Nitze (Alfred Wegener Institute Helmholtz Centre for Polar and Marine), Matthias Gessner (Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR) and Guido Grosse (Alfred Wegener Institute Helmholtz Centre for Polar and Marine).

Abstract

Ice-rich coastlines, such as those along the Beaufort Sea in Alaska, are eroding rapidly due to high ground ice content. Dominant erosion mechanisms for ice-rich coastlines include thermal abrasion (i.e. block failure) and thermal denudation (i.e. slumping). We present a high spatial and temporal resolution time series using UAV surveys and airborne multispectral imagery, of 15 different image acquisitions spanning the 2018 and 2019 open water season along a 1.5 km stretch of coastline at Drew Point, Beaufort Sea Coast, Alaska. We measured erosion dynamics by measuring erosion every 1 m using the Digital Shoreline Analysis System v.5 (DSAS) ArcGIS Desktop software extension tool and also quantified volumetric change by differencing digital surface models. We explore sub seasonal erosion rates, erosion dynamics based on erosion mechanism type (thermal abrasion and denudation), and erosion dynamics with and without fallen blocks present (creating protected or exposed coastlines).
The 2018 open water season was shorter (93 days) with fewer storms (13) than in 2019 (132 open water days and 26 storms). Average air temperature was less (5.10 °C) in 2018 than 2019 (6.58 °C) as well as total precipitation measured in Utqiagvik, Alaska was 19.78 mm in 2018 and 60.59 mm in 2019. Mean annual erosion rates for the entire 1.5 km coastline was 10.5 m in 2018 and 28.7 m in 2019. The 2018 season had a higher number of blocks present (between 98 and 122) and therefore a higher percentage of protected coastline (36 % to 51 %) compared to 2019 (25 to 70 blocks present and 9 % to 48 % of protected coastline). Accounting for block dynamics along the foot of the bluff and creating protected or exposed coastlines can aid our understanding of erosion rates at rapidly eroding coastlines with ice-rich permafrost.

Impact of marine inundation on permafrost thaw and pan-Arctic distribution of thermokarst lagoons

Maren Jenrich (Alfred Wegener Institute Helmholtz Center for Polar and Marine Research, Permafrost Research Section), Michael Angelopoulos (Alfred Wegener Institute Helmholtz Center for Polar and Marine Research, Permafrost Research Section), Susanne Liebner (German Research Center for Geosciences, Helmholtz Centre Potsdam, Section Geomicrobiology), Paul Overduin (Alfred Wegener Institute Helmholtz Center for Polar and Marine Research, Permafrost Research Section), Christian Knoblauch (Institute of Soil Science, University of Hamburg), Guido Grosse (Alfred Wegener Institute Helmholtz Center for Polar and Marine Research, Permafrost Research Section) and Jens Strauss (jens.strauss@awi.de).

Abstract

Thermokarst lagoons, forming when thermokarst lakes are inundated by the sea, are an important transition stage where terrestrial permafrost is introduced into the subsea realm. Here, temperature and salinity conditions of sediment and porewater change and permafrost and lacustrine carbon pools are transformed. During current and future climate change in the Arctic, sea-level rise, accelerated permafrost thaw, intensified coastal erosion and changing sea ice regimes likely will increase the rate of thermokarst lagoon formation. Given the potentially increasing frequency of thermokarst lagoon formation and their rapid effect on permafrost degradation, it is important to understand the impact of marine inundation on permafrost thaw and its effect on greenhouse gas (GHG) production during this transition. To provide an initial assessment of how widespread these features are, we mapped thermokarst lagoons along Arctic coasts in the Canadian and Alaskan Beaufort seas, as well as the Siberian seas. Further, we analyzed sediment and porewater from two 30-m-long sediment cores from two thermokarst lagoons on the Bykovsky Peninsula, Northeast Siberia. To estimate GHG production from thawing lagoon sediments, we conducted long-term incubation experiments on samples of the two lagoons. Here we present the first map on thermokarst lagoon distribution in the pan-Arctic revealing that 54 % of the mapped 469 lagoons are originated from thermokarst basins. We further found that marine flooding and bedfast ice formation caused the saline enrichment of pore water, which led to cryotic talik development. First results of the incubation experiments suggest that increasing salinity is favoring carbon dioxide production while methane production is low. Climate change in the Arctic may increase the rate of thermokarst lagoon formation and thus increase the importance of lagoons as biogeochemical processors of former permafrost OC.

Paraglacial coasts transformed by extreme waves – Greenlandic perspectives

Mateusz Strzelecki (Alfred Jahn Cold Regions Research Centre, University of Wroclaw), Krzysztof Senderak (Alfred Jahn Cold Regions Research Centre, University of Wroclaw), Malgorzata Szczypinska (Alfred Jahn Cold Regions Research Centre, University of Wroclaw) and Oskar Kostrzewa (Alfred Jahn Cold Regions Research Centre, University of Wroclaw).

Abstract

The rapid retreat of glaciers exposed vast areas of new coasts, particularly along steep slopes of Arctic fjords. Glacial debuttressing, permafrost degradation, heavy rainfall, or mid-winter snowmelts combined with regional seismic activity often lead to destabilization of slopes which in extreme cases may trigger landslides. Reports from Greenlandic and Alaskan fjords provided information on big landslides that triggered massive tsunamis exceeding over 50 m run-up heights! Here we present the results of mapping of the effects of two tsunamis that hit the western coast of Greenland in 2000 and 2017 and destroyed the settlements of Qullissat and Nuugaatsiaq, respectively. In both locations, tsunamis not only led to severe infrastructure damage but also destroyed tundra vegetation, eroded local beaches, and left on shore a diverse range of sediment accumulations.

This study is the contribution to the National Science Centre project 'GLAVE' (Award No. UMO2020/38/E/ST10/00042).

Uncertainties in the detection of subsea permafrost using marine Electrical Resistivity Tomography (Tuktoyaktuk, NWT, Canada)

Ephraim Erkens (University of Potsdam / Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research), Michael Angelopoulos (Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research), Jens Tronicke (University of Potsdam, Institute of Geosciences), Scott R. Dallimore (Geological Survey of Canada), Dustin Whalen (Natural Resources Canada, Geological Survey of Canada), Julia Boike (Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research / Humboldt University, Geography Department) and Pier Paul Overduin (Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research).

Abstract

Subsea permafrost degradation due to inundation of formerly terrestrial landscapes affects much of the Arctic coastline. Electrical resistivity tomography (ERT) is useful to detect ice-bonded permafrost, based on the sharp contrast in bulk sediment electrical resistivity between unfrozen, saline and frozen, freshwater saturated sediment. Marine ERT applications are not as well established as terrestrial. We assess uncertainties from survey design and inversion approach for floating marine ERT and their effects on determinations of the depth below seabed of the ice-bonded permafrost table (IBPT). Ground truth data available for the study area included terrestrial and nearshore core holes and nearshore multibeam surveys.
We surveyed coastal waters around Tuktoyaktuk Island, Canada in September 2021 using a floating cable with 13 electrodes arranged in a quasi-symmetric Wenner-Schlumberger array to create 33 intersecting profiles. Cable curvature during measurement was estimated using GNSS units. Three GNSS units sufficed to detect how cable curvature affected the geometric factors of different electrode configurations; on this basis, inversion was restricted to quality ERT soundings.
To invert our data, we tested multiple approaches of laterally constrained 1D inversions using field and synthetic data. Based on the results of our synthetic studies, we selected an inversion approach relying on a blocky model with tight lateral and medium vertical constraints.
Finally, we estimated IBPT depths using resistivity models obtained from inverting our field data. The IBPT was assigned to the depth with the highest vertical resistivity gradient in the model. Based on these depths and historical coastline data, we estimated that subsea permafrost at Tuktoyaktuk Island has degraded at a mean annual rate of 5.2 +/-4.0 cm/yr over the past 270 years.
We conclude that marine ERT is an effective tool for permafrost detection in recently inundated coastal waters and can be improved by using GNSS positioning and target-oriented inversion approaches.

This abstract participates in the Outstanding PYRN Oral Communication / Poster Award.

Quantifying the effect of subsea permafrost thaw on Arctic shelf dissolved inorganic carbon and alkalinity fluxes

Alexis Geels (Université Libre de Bruxelles), Stiig Wilkenskjeld (Max Planck Institute for Meteorology), Fatemeh Chegini (Max Planck Institute for Meteorology), Pierre Regnier (Université Libre de Bruxelles) and Sandra Arndt (Université Libre de Bruxelles).

Abstract

Permafrost thaw is a major climate issue due to its potential to contribute to global warming. While discussions on permafrost-climate feedback have mostly focused on the potential for terrestrial permafrost to release methane into the atmosphere, the impact of subsea permafrost thaw on the Arctic Ocean's (AO) carbon cycling has received less attention. As subsea permafrost thaws, it releases a vast amount of old organic carbon that is converted to methane (CH_4) and dissolved inorganic carbon (DIC) in deep, anoxic sediment. Anaerobic methanotrophs in shallower sediment layers convert the CH_4 to DIC, alkalinity (ALK), and hydrogen sulfides. Whether the seafloor DIC flux contributes ALK to the AO or acidifies the AO depends on the rates of authigenic carbonate precipitation and the fate of the hydrogen sulphide produced during anaerobic oxidation of methane (AOM). Thus the full impact of permafrost thaw on AO carbon cycling remains poorly quantified. A one-dimensional modeling approach is used to understand the early diagenetic response to high fluxes of subsea permafrost-derived CH_4 and DIC, and their impact on DIC and ALK fluxes through the sediment-water interface. Results reveal that AOM converts all of the upward-migrating dissolved CH_4 flux into DIC. High sedimentation rates and high iron-oxide deposition support high benthic ALK fluxes, while lower rates would acidify the AO. We apply this model to projected subsea permafrost thaw rates for three different scenarios until 2300. The increasing thaw rate sustains large benthic DIC fluxes through heterotrophic DIC production in the thawing permafrost and methane oxidation in the shallower sediment. The subsea permafrost-derived ALK flux is further amplified by diagenetic processes in upper sediment layers. Overall, benthic ALK and DIC fluxes are up to one order of magnitude larger than typical coastal settings, with important implications for AO pH, the carbonate system, and air-sea CO_2 exchange.

Recent coastline evolution along the Yukon Coast, western Canadian Arctic

Anna Irrgang (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Goncalo Vieira (Centre for Geographical Studies, Institute of Geography and Spatial Planning, University of Lisbon), Dustin Whalen (Natural Resources Canada, Geological Survey of Canada–Atlantic), Pedro Freitas (Centre for Geographical Studies, Institute of Geography and Spatial Planning, University of Lisbon), Rodrigue Tanguy (b.geos), Pia Petzold (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, University of Potsdam), Hugues Lantuit (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, University of Potsdam) and Annett Bartsch (Austrian Polar Research Institute (APRI), b.geos).

Abstract

Soft sediment permafrost coasts are well known for their very dynamic nature. In some places their erosion can reach tens of meters, even though the erosion time is restricted to the short open water season of three to four months per year. Due to its high ground ice content, the Yukon coast in the western Canadian Arctic is particularly prone to erosion. Building on results from Irrgang et al., 2018, we continued analyzing shoreline movements along the Yukon Coast using Pleiades satellite imagery covering the whole Yukon Coast from 2018 and 2022, as well as very highly resolved data from UAV overflights covering long term monitoring sites in 2019 and 2022. Using the Digital Shoreline Analysis System (DSAS) Esri ArcMap extension tool, we quantified shoreline movements for the time periods 2011-2018, and 2018-2022 for the entire coastline and for 2015-2019 and 2019-2022 for long term monitoring sites. We used the same transects and shoreline proxies as in Irrgang et al., 2018, to ensure comparability of our results and elongate our observation series. We will show how recent shoreline position changes differ from past ones and will provide possible reasoning for these detected changes. We are using our multi-time-step shoreline change rate dataset of the Yukon Coast for training and validation purposes within the Earth Observation for Permafrost Coasts (EO4PAC) project. The increasing usage of machine learning approaches for automated shoreline delineation and shoreline change rate retrieval opens up new pathways – especially if it comes to exploring large and remote areas. Such datasets which contain on site derived shoreline change rates and manually derived shorelines from (very) high resolution airborne and spaceborne data are crucial for training algorithms, validation of results and thus for the quality improvement of machine learning techniques.

Driving mechanisms of permafrost coastal erosion investigated by laboratory model experiments

Justus Gimsa (Institute of Geosciences, University of Potsdam ; Alfred Wegener Institute, Potsdam), Hugues Lantuit (Institute of Geosciences, University of Potsdam ; Alfred Wegener Institute, Potsdam), Nils Goseberg (Leichtweiß-Institute, TU Braunschweig ; Coastal Research Center, Leibniz Universität Hannover and TU Braunschweig) and David Schürenkamp (Leichtweiß-Institute for Hydraulic Engineering and Water Resources, TU Braunschweig, Germany).

Abstract

Arctic permafrost coasts face rising wave heights, air, and water temperature due to climate warming. This leads to greater coastal erosion and a series of potential impacts on coastal infrastructure and ecosystems. The empirical link between the changing climate and erosion is known, yet the actual mechanisms underpinning erosion are poorly understood. A physics-based quantification of these mechanisms is necessary for sound projections of global and local permafrost coastal erosion rates. Reduced scale laboratory model experiments are widely used in temperate regions for the investigation of coastal process, e.g., coastal dune erosion, where complexity is reduced by focusing attention on specific environmental drivers separately. So far, permafrost coastal erosion was not addressed by this method, yet it bears great potential to identify and quantify the processes underpinning coastal permafrost erosion. Here, we simulated permafrost coastal erosion with a modular 0.3 m-wide wave tank inside an adjustable temperature-controlled climate chamber. The permafrost itself was represented by a standardized frozen sediment block made of uniform fine grain sand saturated with water. Errors associated with potential model unconformities were reduced with the use of triplicated experiments and blank tests. We tested the set-up with four different wave conditions and water temperatures matching the range of observed conditions in the coastal Arctic. The resulting thaw depth was measured at the erosion surface, while crest retreat rates and volumetric erosion were calculated with point clouds from laser scanning. This work presents early results from the experiment and the lessons learnt from setting up a unique experimental framework to study permafrost coastal erosion in controlled laboratory conditions. Quantifying the driving processes will facilitate to incorporate permafrost coastal erosion in future earth system models and build prognostic capacities to aid local solutions to mitigate erosion of critical infrastructure.

Beach sediment distribution in the Kharasavey key site, Kara Sea

Georgii Kazhukalo (Faculty of Geography, Lomonosov Moscow State University), Daria Bogatova (Faculty of Geography, Lomonosov Moscow State University), Stanislav Ogorodov (Faculty of Geography, Lomonosov Moscow State University) and Ekaterina Eremenko (Faculty of Geography, Lomonosov Moscow State University).

Abstract

Coastal dynamics and sediment transport in the Arctic seas are extremely sensitive to climate and ice cover changes. In that case, lithodynamic reconstructions that were made decades ago may not reflect current peculiarities of coastal processes due to the changes of dominate wind directions and wave intensity. Fieldworks were held on 33-kilometer-long coastline in the Kharasavey, Kara Sea. Coasts of the study area have different elevations and heterogeneous structure – from ice-rich silty marine sediments with ground ice layers and peat sediments of laida to accumulative beach sediments of fine-grained sand. Investigation was based on identification of coastal geomorphic features (with aerial photography obtained by UAV's) and grain-size distribution analysis. Beach sediments sampling was held at 25 sites of coastline at 3 different geomorphic positions along profile to evaluate both alongshore and transverse mobilization of sediments. Dry sieving method was made by mechanical shaker into 10 fractions. The statistical analysis was carried out in R environment, main geostatistical parameters are mean, sorting, skewness and kurtosis. Despite heterogeneous structure of coastal bluffs, according to results all sample's mode is 0,125 – 0,2 mm (>80 % of total mass). Beach sediments are characterized as very well sorted, fine skewed and mostly leptokurtic. It indicates stable coastal sedimentation and homogeneity of sediments involved to wave distribution. Study revealed no "normal" transverse distribution of sediments at accumulative coasts. It may indicate the predominance of aeolian transport among wave sedimentation. It also reflects with the geomorphic features like foredunes formation on low erosional bluffs which marks the change of morphodynamical type from erosional to accumulative. In contrast to previous researches, results revealed no sustainable alongshore transport, which may be caused by change of the predominant wind directions and wave distribution due to ice cover fluctuations.

This abstract participates in the Outstanding PYRN Oral Communication / Poster Award.

A new microbially explicit model for the degradation of thawed subsea permafrost organic matter

Constance Lefebvre (Department of Geosciences, Environment & Society-BGEOSYS, Université Libre de Bruxelles, Brussels, CP160/02, Belgium), Maria De La Fuente Ruiz (Department of Geosciences, Environment & Society-BGEOSYS, Université Libre de Bruxelles, Brussels, CP160/02, Belgium) and Sandra Arndt (Department of Geosciences, Environment & Society-BGEOSYS, Université Libre de Bruxelles, Brussels, CP160/02, Belgium).

Abstract

The thawing of subsea permafrost (SSPF) is expected to accelerate in coming centuries as a consequence of sea ice loss and the warming of Arctic bottom waters. SSPF thaw has the potential to progressively unlock a vast reservoir of organic matter (OM) that may subsequently be subjected to microbial degradation. OM may thus be converted into dissolved inorganic carbon (DIC) and/or methane (CH4), while nutrients like phosphorus (P) and nitrogen (N) are recycled back into the porewaters. The resulting, yet unquantified, increase in seafloor carbon and nutrient fluxes may lead to important consequences for Arctic Ocean chemistry, primary production, greenhouse gas emissions and, thus, global climate. Numerical reaction-transport models are ideal tools to study the evolution of SSPF thaw and ensuing seafloor fluxes. However, most existing diagenetic models currently do not explicitly resolve microbial biomass dynamics and bioenergetic limitations, nor are they designed to capture the evolving microbial habitat of SSPF (frozen to thawed sediment). We are therefore building a new microbially explicit, bioenergetics-informed model for the degradation of thawed SSPF OM. The model simulates the syntrophic relationships between several functional groups of micro-organisms in the energy- limited environment of thawing SSPF. It accounts, most notably, for the extracellular hydrolysis of OM, fermentation of the resulting monomers, and methanogenesis. The microbial community is divided into active and dormant pools with distinct maintenance energy requirements. Reactivation of dormant cells is only possible when OM is thawed, and the catabolic energy production of a microbial group exceeds the maintenance energy requirements of its active cells. We present preliminary results for conditions representative of thawing SSPF and identify the main uncertainties. Combined with a transport module, this model will be used to quantify carbon and nutrient seafloor fluxes on the Arctic Shelf in response to SSPF thaw on decadal to centennial timescales.

SESSION 23
Permafrost Engineering: risk assessment and adaptation challenges

Conveners:

- **Guy Dore**, *Université Laval*
- **Kevin Bjella**, *Cold Regions Research and Engineering Laboratory – CRREL, Fairbanks*

Summary:

Warming permafrost is projected to weaken foundation soils and create engineering risks. Geocryological processes such as thermokarst, frost heaving and fracturing, icing, thermal erosion, and Arctic coastal erosion are the source of immediate danger and cause of premature deterioration and failure for the engineering structures. For infrastructure built on thaw sensitive permafrost, sustainability relies heavily on sound assessment of risks and adaptation of design parameters. Recent advancements in the use of surface-based geophysics for geotechnical characterization are demonstrating that the heterogeneity of the permafrost ground-ice condition can often be exploited to reduce the risk of poor infrastructure performance and reduce construction and maintenance costs. Innovative adaptation and mitigation techniques have also been developed and tested, providing alternatives to increase resiliency to changing conditions. Additionally, thermal modeling techniques are becoming standard engineering tools for assessing long-term thermal stability of the permafrost foundation and determining performance of innovative designs, considering future warmed condition.
Presentations are invited that provide insight into the current methods for engineering on warming permafrost, and especially those that illustrate results of altered design parameters. We encourage demonstrations of innovation for maintaining or modifying founding soil conditions, innovation on the methods for characterizing the geotechnical condition both ground based and remotely collected, incorporation of permafrost cryostructure and geocryomorphology into the applied realm, assessments of risk and resiliency, and improved techniques for assessing, designing and constructing on warming permafrost.

Response of permafrost conditions in the territory of the Yuzhno-Tambeyskoye gas field (Yamal, Russia) to climate change in the 21st century

Ivan Iliushin (Lomonosov Moscow State University, faculty of geography) and Alexey Maslakov (Lomonosov Moscow State University, faculty of geography).

Abstract

The response of permafrost to global climate changes is the most sensitive in subpolar latitudes, including the Yamal Peninsula. Air temperature increase inevitably leads to the warming of frozen soils, which are the basis for buildings and structures in residential and industrial sites. It also affects the activation of cryogenic processes that negatively affect the infrastructure of the Arctic. The area covered in the study refers to the Yuzhno-Tambeyskoye gas field on the Yamal Peninsula, Russia. The study focuses on assessment of permafrost conditions dynamics due to global climate change. The research is based on the data obtained from engineering and geological surveys, conducted in 2022. To predict the behavior of permafrost under the influence of warming, the reports of the Intergovernmental Panel on Climate Change (IPCC) were used. We considered three scenarios for changes in air temperature by the middle and the end of the 21st century. Modeling of changes in permafrost conditions was carried out in the Frost 3D software, where the calculation of the thermal regime of permafrost soils and the active layer was performed. Indicators of the reaction of the permafrost to climate variations are the characteristics of seasonal thawing depths and the temperature of rocks at the level of zero annual amplitude. Active layer thickness defines the activity of thermokarst and thermal erosion processes, while permafrost temperature is the main characteristic of bearing capacity of frozen piles and thus, engineering object stability. The study demonstrates the numerical changes in both parameters during the 21st century for concrete subzones of Tambey oil and gas filed. Such detailed information can be used by maintenance services and engineering facilities designers. Based on this knowledge, preventive measures can be taken to strengthen the foundations of buildings and structures for the territory of the Tambey group of deposits.

Freezing point and unfrozen water content determination of permafrost soils by the water potential method

Boris Bukhanov (Skolkovo Institute of Science and Technology), Evgeny Chuvilin (Skolkovo Institute of Science and Technology), Aliya Mukhametdinova (Skolkovo Institute of Science and Technology), Erika Grechishcheva (JSC Reseach Center of Construcruction), Natalia Sokolova (Skolkovo Institute of Science and Technology), Andrey Alekseev (JSC Reseach Center of Construcruction) and Vladimir Istomin (Skolkovo Institute of Science and Technology).

Abstract

The freezing point and unfrozen pore water contents are important parameters of frozen soils monitored for various geotechnical and permafrost engineering purposes. The first parameter provides information on the thermal state of the soil in-situ, and the second allows predicting the thermal and mechanical properties of permafrost soils. Currently, many experimental methods have been developed to determine the freezing point and unfrozen pore water contents. However, most experimental measurements consume much labor, energy, and time. In this respect, it is urgent to develop alternative approaches – water potential method. This method allows to determinate the freezing point and unfrozen water content in frozen soils consisting of single measurements of pore water potential (or activity) with subsequent thermodynamic calculations. The obtained freezing point and unfrozen water content estimates show good agreement with the results of direct measurements. For example, the freezing point data show the difference in results is equal 0.05 °C, approximately. The water potential-derived phase composition data are consistent with NMR and contact methods results at both warm (about -1 °C) and cold (down to -15 °C) negative temperatures. The average data misfit is about 0.3°C in temperature and does not exceed 0.5 wt. % in unfrozen water content, which is comparable with the precision of the standard methods. The results of the study showed that the potential method could be used to determine the freezing point and unfrozen water content for soils of the different particle size distribution (from fine sands to fat clays), mineral composition, as well as saline and organic content. Additionally, the proposed method has a number of advantages over other experimental methods, the main of which is the performance. It is necessary not more than 30 minutes for measuring soil freezing point and ~6 hours for unfrozen water content curve (till -16 °C) determination for frozen soil.

Analysis of deformations of engineering objects during the activation of hazardous cryogenic processes

Valery Grebenets (Lomonosov Moscow State University, Faculty of Geography, Department of Cryolithology and Glaciology), Vasily Tolmanov (Lomonosov Moscow State University, Faculty of Geography, Department of Cryolithology and Glaciology) and Fedor Iurov (Lomonosov Moscow State University, Faculty of Geography, Department of Cryolithology and Glaciology).

Abstract

We conducted the research on state of engineering infrastructure in the Arctic region of Russia. One of the main goals was to assess the degree of deformation of buildings and structures. Technogenic impact and warming trends lead to the activation of several cryogenic processes that are threatening the infrastructure in an urban environment. These processes do not always tend to start the degradation of permafrost; often the technogenic impact provokes the activation of “cold” cryogenic processes. As an example, activation of thermal contraction cracking and frost destruction of structural materials on roads and runways of airfields due to the removal of heat-insulating snow cover in winter. Studies show that the degree of deformation of buildings and structures can vary over a very wide range: from 20 to 80 % in industrial centers, up to 100% in small national settlements. We developed a methodology to assess the negative impact of cryogenic processes on the infrastructure of settlements. This methodology uses such parameters as: degree of damage to the territory, the duration and frequency of six groups of processes (thermal erosion and thermal abrasion, thermokarst, frost heaving, cryogenic slope processes, thermal contraction cracking and ice formation). We calculated a degree of risk for infrastructure of 35 settlements located in the Russian Arctic. Emphasis was put on settlements and infrastructure facilities in Western Siberia. This region is characterized by the strongest industrial influence, observed during the development and operation of oil and gas fields and the construction of such facilities. As an addition, we assessed the impact of storage of industrial and domestic waste on permafrost and the infrastructure and classified the main types of their disposal.

Short-term thermal performance of gentle slope embankments for runway built on ice-rich and warm permafrost, case study of the Tasiujaq airport, Northern Quebec.

Emmanuel L'Hérault (Department of civil engineering, Université Laval, Québec, Canada), Guy Doré (Department of civil engineering, Université Laval, Québec, Canada) and Michel Allard (Department of Geography, Université Laval, Québec, Canada).

Abstract

Built in the early 90s, the Tasiujaq airport is one of the 13 airports that form the Quebec Ministry of Transportation runways network in Nunavik. Located at the southern boundary of the continuous permafrost zone, the Tasiujaq runway is entirely built on ice-rich and warm permafrost where significant thaw-related ground subsidence occurred and has affected the integrity of the infrastructure. According to the characteristics of the infrastructure and the major role of snowdrift accumulation insulation effect in the ongoing permafrost degradation processes, the gentle slope embankment (1V:6H) was chosen as the preferred permafrost protection technique and implemented during summer 2018. To assess the short-term thermal performance of the gentle slopes, the site was equipped with thermistor strings and automated cameras to monitor ground temperatures and snow conditions. The site was also equipped with surface temperature sensors placed along transects covering the embankment toes, side slope and shoulder. For the four years monitoring period available to date, ground temperatures under the gentle slope embankment show a slighter than expected cooling of ground temperature and rise of the permafrost table. Snow surveys confirmed that snow accumulations are still reaching thicknesses sufficient to insulate the ground during winter as confirmed by the surface temperature sensors. Thick and water-saturated active layers prior to the implementation of the gentle slope (up to 6 m thick) along with warmer than average summer and winter air temperatures during the monitoring period certainly contribute to the low performance of the gentle slope to date. However, nearby experimental site using gentle slope in similar conditions has shown that ground temperature adjustment can take up to 6 years before reaching equilibrium. Upcoming long-term monitoring data and analyses for this site will certainly help specify the gentle slope embankment performance and its potential uses in warm permafrost and mild subarctic climate zones.

Seismic Hazards of Degraded Permafrost: A Case Study of Northway Airport, AK

Yue Zhao (University of Alaska Anchorage), Zhaohui Joey Yang (University of Alaska Anchorage), Dave Eibert (University of Alaska Anchorage) and Utpal Dutta (University of Alaska Anchorage).

Abstract

Substantial degradation can occur to warm permafrost due to changes in surface conditions resulting from infrastructure development and climate warming. The associated geohazards include differential settlement, slope instability, and liquefaction of degraded, unconsolidated materials in seismically active warm permafrost regions. These hazards pose substantial threats to the safe operation of infrastructure. Among these hazards, seismic hazards of degraded permafrost have received little attention. This paper aims to provide a case study of an airport built on warm permafrost about 80 years ago, focusing on climate changes, permafrost degradation, and seismic response during a strong earthquake. The airport, i.e., the Northway airport, is located in a discontinuous permafrost area in Interior Alaska. The climate data from 1943 to 2021, including air temperature, precipitation, and historical annual trends, are analyzed. The results reveal a warming rate of 0.25 oC per decade and an increase of 3.3 mm per decade. Geotechnical data from 1973, 1991, and 2005 were compiled and analyzed to demonstrate permafrost degradation in an airport setting, which was compared with the degradation from other surface conditions reported in the literature. Furthermore, the responses of the airport runway during the 2002 Denali earthquake (Mw=7.9), including liquefaction and lateral ground displacement, are described and analyzed. In the end, the seismic hazards of the numerous airports built on permafrost across Alaska are discussed. This study will shed light on the seismic risks of degraded permafrost and its potential impact on the built infrastructure.

Egress of contaminated fluids from drilling waste sumps, Western Arctic Canada

Rae Landriau (Carleton University), Tim Ensom (Government of the Northwest Territories - Department of Lands) and Christopher Burn (Carleton University).

Abstract

Since 1920, the Northwest Territories has been an area of oil and gas exploration and development. Various lubricants are used to facilitate drilling and in permafrost settings these fluids require addition of freezing-point depressants, such as salts and other solutes, to ensure that they do not freeze downhole. In the Canadian western Arctic these fluids were disposed of within sumps, large, man-made pits blasted in permafrost. There are over 270 sumps in the western Arctic including Mackenzie delta and adjacent uplands. In 1960-2000, it was assumed that the permafrost would remain frozen in perpetuity and contain the drilling fluids in situ. The stability of sumps has been of increasing concern recently. Climate change, increased vegetation growth, and the shifting of weather patterns have impacted the condition of permafrost surrounding the sumps. Warmer ground temperatures, increased snow accumulation, increased subsidence, and ponds on sumps have been observed. Electrical conductivity surveys with EM31 from the early 2000's detected egress of drilling fluids tens to hundreds of meters away from sumps. These data have been compared with EM31 data obtained at the sites in the delta and adjacent uplands, 20 years later, to examine migration within this timeframe and to assess the risk of sumps to further degradation. Sumps examined in the adjacent uplands typically contained fluids within the sump cap and conductivity anomalies were found mostly adjacent to ponds on or adjacent to the caps edge. Half of the sumps examined in the Mackenzie Delta showed increased contaminate migration fifty to a hundred and fifty meters from the sump cap, suggesting that sumps within the Delta are more susceptible to contaminate leaching.

Bridging the Pretty Rocks Landslide in Denali National Park

Lukas Arenson (BGC Engineering Inc.), Heather Brooks (BGC Ingeniería Ltda.) and Scott Anderson (BGC Engineering Inc.).

Abstract

In late August 2021, park managers of the Denali National Park in Alaska concluded that they would no longer be able to maintain the park access road along a section known as Pretty Rocks, where the road has been constantly slumping since the 2010s. Most recently, the road dropped by more than 2 cm per day. The geology at the site is complex with rock overlying weaker tuff and clay materials, and frozen colluvium present. This geology and the local permafrost conditions result in the presence of ground ice of varying form and volumetric ice contents. Permafrost degradation is thought to play a role in the increasing rate of deformation of Pretty Rocks Landslide and the parks decided that building a bridge over this active landslide would the best option. To reopen the parks road, a hazard avoidance strategy was chosen; thus, a steel truss bridge is planned to span the landslide. The proposed bridge requires stable foundation conditions and rock cuts for the approaches. Considering that excavating and removing all the ground ice at this location is not feasible it was decided that permafrost conditions being maintained, where present, and used in the bridge foundation and cuts. Therefore, complex three-dimensional numerical modelling was completed to evaluate various foundation design options, including thermosyphons at the east bridge abutment. Three-dimensional modelling was considered essential because the complex geology, permafrost and terrain conditions could not be adequately simplified using two-dimensional models only. We present the results of our thermal models, the final design of the bridge foundation, which includes more then 20 thermosyphons, and the challenges we encountered completing this complex task. In addition, we provide an overview of information from the site investigation that was used for the development of the numerical model, including geotechnical drilling, geophysical investigations, ground temperature measurements, lidar change detection and climate change projections.

Quantification of frost jacking of railway bridges on the Hudson Bay Railway, Canada

Natalie Arpin (Queen's University), W. Andy Take (Queen's University) and Ryley Beddoe (Royal Military College of Canada).

Abstract

The Hudson Bay Railway is a critical transportation link in Canada, serving 30,000 people in northern communities as the sole means of ground transportation. The railway is 1,009 kilometres with the northern half of the railway passing over discontinuous and continuous permafrost. Bridge crossings in this northern section face ongoing risks due to frost jacking. Frost jacking of bridge piers has been observed at multiple locations, which limits train speeds and results in significant maintenance to preserve track geometry. Information on frost jacking movement is constrained to yearly bridge inspections and monthly track geometry measurements. To improve understanding of the impact of frost jacking on bridge infrastructure, a monitoring program has been implemented at a ballasted deck bridge in the Herchmer subdivision which is experiencing frost jacking. In July 2022, the bridge alignment was repaired by shortening the jacking piles, with no additional mitigation strategies implemented. To monitor future frost jacking and develop a greater understanding of the impact of frost jacking along the railway, tiltmeters were placed on each bridge span to monitor the movement of the bridge structure and ShapeArray's were installed on the rail sleepers to measure the track deformation. The monitoring campaign began in April 2022 and was able to record the repair of the bridge and the reduction in height due to the repair of 0.49 metres. Additionally, seasonal movements of the bridge due to jackings have been recorded to be a maximum of 18 millimetres over a 6-month period. Current results of the monitoring will be presented to provide an overview of the impact of frost jacking along with the associated climatic conditions. The results from this study will provide an improved understanding of frost jacking along the Hudson Bay Railway and aid future maintenance scheduling and bridge repair techniques.

Laboratory evaluation of skin friction and end bearing contributions to pile capacity in warming frozen ground

Greg Siemens (Royal Military College of Canada), Geoff Eichhorn (Royal Military College of Canada) and Chris Clarkson (Royal Military College of Canada).

Abstract

Engineering foundations in cold climates considers changing ground conditions over the design lifetime due to climate warming. Design of deep foundations considers shaft friction mobilized from adfreeze strength from ice-soil bonds in contact with the pile. Design of piles placed in completely frozen ground as well as completely thawed are both well defined, while the intermediate condition of either partially thawed or warm frozen ground (between -2 and 0 ºC) has less consideration in the literature. During warming the relative contributions of shaft friction and tip capacity are likely to change. Due to challenges associated with testing in changing ground conditions, there is a dearth of field pile load tests and piles at field stress conditions. In this study, physical modeling using a geotechnical centrifuge is performed to evaluate the contribution of shaft friction of piles in cold and warming frozen ground. Model piles are tested using unique protocols to directly measure shaft friction while testing the pile in both tension and compression. The first model pile load test in the centrifuge consists of pullout in frozen ground, which leaves a gap below the pile tip. The model is then removed from the centrifuge, refrozen, reinstalled, and then the model pile is tested in compression. Repeating this sequence allows for isolating the contribution of shaft friction as the pile tip is not in contact with any material. The results show shaft friction is a function of ground temperature as expected. Between -2 and 0oC there is a non-linear relationship between shaft capacity and temperature. Comparing with previous pile load tests the majority of pile capacity is derived from shaft friction but is also a function of temperature.

Zoning of mountain permafrost landscapes to assess the development and forecast of geological processes on roads and railways

Artem Kulakov (Pavlovich).

Abstract

During the organization and operation of roads and railways, natural cryogenic geological processes in landscapes intensify and change in time and space, negatively affecting almost all of their components. Therefore, studies of the ability of natural landscapes to prevent and regulate the development of geological processes due to the organization and operation of man-made systems are becoming increasingly relevant in permafrost conditions. The scientific work considers an approach to the zoning of mountain permafrost landscapes in order to effectively assess and accurately predict the development of dangerous geological processes on railways and highways. The paper reveals a technique for identifying the spatial differentiation of mountain permafrost landscapes and studying the intensity of geological processes on railways and highways using various field and remote research methods, the basis of which is the author's zoning. The methodology for the compilation of permafrost-landscape maps showing the current state and dynamics of heterogeneous landscapes of mountain permafrost is proposed in order to effectively predict the danger of the development of geological processes and the organization of rational monitoring. The peculiarity of the work consists in the spatial analysis of geological processes based on a set of criteria that determine the development of dangerous geological processes, as well as in identifying the most dynamic landscapes of mountain permafrost to climatic and anthropogenic signals and determining the degree of danger of the development of geological processes on the author's zoning scheme. The results of scientific work tested on various key and representative sites have shown that a wide variety of landscape features of mountain permafrost directly affects the speed of development of geological processes and the risk of deformation of railways and highways.

Development of an automated system for temperature monitoring of permafrost at the base of buildings in Salekhard city of the Yamal-Nenets Autonomous District

Alexandr Shein (Arctic Research Center of the Yamal-Nenets Autonomous District), Nataliia A. Vaganova (Ural Federal University), Mikhail Yu. Filimonov (Ural Federal University), Yaroslav K. Leopold (IPGG SB RAS) and Sergei A. Kurakov (IMCES SB RAS).

Abstract

Most residential buildings and capital structures in the permafrost zone are constructed on the principle of maintaining the frozen state of the foundation soils. The climate changing and the increasing anthropogenic impact on the environment lead to the changes in the properties of permafrost. These changes are especially relevant in the areas of piling foundations of residential buildings and other engineering structures located in the northern regions since they can lead to serious accidents due to the degradation of permafrost, leading to a decrease in the bearing capacity of the soil in such areas. Therefore, the organization of temperature monitoring and forecasting of temperature changes in the soil under such capital structures is an actual problem. To solve this problem, we has been developed since 2018 a system of automatic temperature monitoring of permafrost at the base of capital facilities in Salekhard. Together with Kurakov S.A. (Tomsk), thermometric equipment has been developed that allows remote control of registration and transmits soil temperature from wells to the server. A data collection and visualization portal https://monitoring.arctic.yanao.ru has been created. To process temperature data, a program has been developed for computer modeling of three-dimensional non-stationary thermal fields in the ground in the entire area of the pile foundation, considering the geological structure. Comparison of the results of numerical calculations with experimental data showed good agreement. Using the developed computer program, non-stationary temperature fields under this building are obtained and a forecast of their changes in the future is given. The proposed approach, based on a combination of the soil temperature monitoring and computer modeling methods, can be used to improve geotechnical monitoring methods of buildings in permafrost zone.

A New Methodology for Estimating Earthquake-Induced Liquefaction Potential Developed from Thawing Permafrost

John Thornley (WSP USA).

Abstract

Degradation of permafrost due to climate change, anthropogenic activities, and other causes has the potential to result in the creation of other natural hazards. While topics such as retrogressive thaw slumping and thaw settlement are receiving attention, another natural hazard, earthquake-induced liquefaction may also result from permafrost degradation. Earthquake-induced liquefaction can result in ground failure that may damage infrastructure because of an earthquake. Numerous geotechnical explorations have found sites with earthquake-induced liquefaction susceptibility where permafrost degradation has occurred. These observations are especially important in seismically active regions, such as Fairbanks, Alaska, USA. While there are traditional screening methods to estimate liquefaction potential at a thawed soil site, there are no such formal screening methods for permafrost that may thaw in the future. Geologic setting, soil type, and other information can provide proxies for identifying the potential sites where liquefaction may be an issue if the permafrost is allowed to thaw. However, these proxies have limitations and do not meet the current needs of the engineering practice. A methodology is needed to utilize geotechnical parameters collected during site explorations in permafrost regions to better understand the future potential for creation of a liquefaction hazard. A methodology for estimating future liquefaction potential at a permafrost site has been developed through the use of critical state soil mechanics, numerical modeling of permafrost phase change, and geotechnical data collected during site explorations. Application of this methodology is evaluated using site data from a recent geotechnical study where both thawed soil and permafrost was encountered. Recommendations for future improvements will be presented as well.

Single phase active and passive cooling systems combined with phase change material to stabilize permafrost thaw.

Igor Egorov (National Research Council Canada), Juan Cobo Hiedra (National Research Council Canada), Dennis Krys (National Research Council Canada) and Antal Prigli (National Research Council Canada).

Abstract

Permafrost thaw driven by climate change is linked to rapid landscape transition and is threatening northern infrastructure. One of the strategy to develop permafrost sites is preserving permafrost in the frozen state using active and passive mitigation methods. Ground cooling systems can be used in civil engineering operations, roads construction and rehabilitation and building foundations stabilization, as well as stabilization of thermo-erosion. Interaction of different environments with such cooling systems remains largely unexplored. The increasing rates of climate change and landscape evolution coupled with increasing economic activity in the North cause the growing need for the advancement of such ground cooling technologies in the North. Different ground cooling systems were installed in the fill material overlying thawing permafrost at the Tuktoyaktuk Hamlet site in the Northwest Territories, Canada. The systems include combinations of a single-phase active thermosiphons, single-phase passive thermosiphon, a snow reduction structure together with phase change material, natural material like peat. Performance will be assessed based on ground temperature investigations and estimates of net annual heat transfer. All five systems demonstrated a range of ground cooling efficiencies. The "zero curtain" effect is investigated for one freezing season. Active cooling system was the most efficient, yet reliant on energy sources for active circulation of the coolant. Passive cooling systems was less efficient but also less prone to be dependent on renewable source of energy. The snow reduction structure allowed to understand the value of the snow on ground warming effect. The findings of this study are expected to advance the adaptation of cooling technologies specifically for different environments and support climate change adaptation strategies of local communities.

Investigation of thermosyphon fin designs

Anna Wagner (Cold Regions Research and Engineering Laboratory) and Edward Yarmak (Arctic Foundations Inc.).

Abstract

Thermosyphons are passive heat transfer devices designed to provide subgrade refrigeration to cool the ground to maintain permafrost and protect vertical and linear infrastructure from the effects of foundation deformation. We investigated the performance of three alternate fin configurations for thermosyphon condensers and compared them to a control that is a current standard model. Four thermosyphons were installed with identical interiors (i.e., length, diameter, working fluid) but with varied exteriors in the condenser zone including: 1) a standard 6.5 m2 (70 ft3) condenser (control), 2) an identical condenser fin with the exception that the material for the extended surface was 304 stainless steel, 3) a wrapped helical non-serrated fin, and 4) no extended surface. Each of the four thermosyphons were installed to a depth of 12 m (30 feet) at the Fairbanks Permafrost Experiment Station located on Farmer's Loop Road in Fairbanks, Alaska. The four units were installed in a linear array approximately 4 meters apart. In general, the thermosyphons performed similarly in this limited windy environment. This indicates that the cost of each thermosyphon can be decreased if installed in non-windy environments.

The examples of permafrost thermal stabilization systems powered by renewable energy

Egor Loktionov (Northern (Arctic) Federal University), Elizaveta Sharaborova (Ecole Polytechnique Federale de Lausanne), Alexander Klokov (Bauman Moscow State Technical University) and Alexander Tutunin (Bauman Moscow State Technical University).

Abstract

The most obvious outcomes of the global warming induced permafrost degradation happen at constructions and buildings damaging. There has not been much innovation in soil thermal stabilization systems recently that could help compensate the increased heat load. We have suggested an approach that couples sun shields and refrigerators effect in a sustainable manner when the former are made of solar panels to power the latter. High thermal energy storage capacity of the soil reduces the main shortcoming of renewable energy - its intermittency. According to the protected object the soil thermal stabilization could be provided 1) with vertical ground probes to prevent thawing halos merging; 2) shallow (within the active layer) horizontal probes or 3) artificial snow layer to prevent heat penetration in depth in principle. In this report, we are discussing the possible ways of using this approach for oil and gas wells, winter roads, glaciers, coastal cliffs, ice cellars and other buildings based on numerical simulations and the first results of the prototypes field tests. We also show the possible revenue from using the heat diverted from the soil for horticulture and energy for soil monitoring and other needs that makes this approach payable off unlike those currently used. The experimental findings on heat fluxes are discussed to adjust the approaches to soil monitoring and to provide the most relevant data for numerical modeling.

ASSESSMENT OF NATURAL RISKS CHANGES FOR LINEAR STRUCTURES IN THE CRYOLITHOZONE USING METHODS OF MATHEMATICAL MORPHOLOGY OF LANDSCAPE

Veronika Kapralova (Sergeev Institute of Environmental Geoscience Russian Academy of Sciences (IEG RAS).

Abstract

Risk assessment in the context of the development of dangerous geological processes is one of the urgent tasks, it is especially important in the rapidly changing natural conditions of the northern regions. We tried to develop and justify a way to solve this problem for linear objects using methods of mathematical morphology of the landscape, which allows us to proceed to a quantitative assessment of risk. Usually, a mathematical model is based on a number of assumptions and has the form of a set of expressions describing the behavior of the main quantitative characteristics of a pattern formed by an exogenous process on the earth's surface; the expressions included in the model are independent, cannot be derived from each other and therefore act as mutually complementary, not duplicating. When using the proposed approach, the problem of risk assessment is solved for a homogeneous area, therefore, when applying the methods of mathematical morphology of the landscape, any heterogeneous territory must first be divided into areas that are homogeneous according to the conditions of the processes. The solution of the problem was based on the models developed by the authors of the development of morphological structures of thermokarst plains and thermokarst plains with fluvial erosion. In the case of thermokarst plains with fluvial erosion in conditions of asynchronous start and in conditions of synchronous start of the process for thermokarst plains, implemented according to empirical testing, in the largest number of cases. We performed the model approval for several study areas, which are located in different Arctic regions of Russia, Canada, and of Alaska. We selected the districts based on morphological homogeneity and availability of remote sensing data.

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Snowbanks impact on permafrost in the cities

Valery Grebenets (Lomonosov Moscow State University, Faculty of Geography, Department of Cryolithology and Glaciology) and Vasily Tolmanov (Lomonosov Moscow State University, Faculty of Geography, Department of Cryolithology and Glaciology).

Abstract

We observe a substantial increase in winter temperatures and amount of snow in the Russian Arctic in recent decades. It increases the role of snow in the formation of the thermal, moisture regime of the active layer and upper horizons of permafrost. Thick, artificially moved snowbanks play the “blanket” role and protect permafrost in cities and settlements from the winter freezing. The negative impact of snow on the thermal regime of urban areas is exacerbated by the lack of a system of regular observations of snow accumulation in the territories of these settlements. Snowbanks characteristics were monitored and mapped on the territory of the Norilsk industrial region manually in 1987 and repeated in 2021. Thicknesses were measured using a graduated avalanche probe. The aim is to get an idea of spatial distribution of artificially moved snow and assess the warming effect of snowpack on permafrost soils and foundations. Studies show that the thickness of snowbanks in the city of Norilsk ranges from 2 to 5 m, while the average long-term value of snow cover thickness in natural conditions is 69 cm. Numerical modeling in QFrost using the local field data showed that thicker snow cover increases the warming effect on permafrost; maximum influence is observed with the snowpack reaches 2-2.5 m thickness, then the warming effect remains the same. The multiannual formation of snowpacks at the same spots over several decades leads to the development of degradation trends of permafrost in zones next to buildings. As an aggravating factor, in some areas, snow drifts are observed in the active zones of cold ventilated cellars, which does not allow to cool the system and enhances the warming permafrost underneath. Monitoring showed that an increase in temperature was noted in 30–40 % of buildings compared to the design values, which causes deformations.

Evaluating the efficiency of adaptation measures to protect infrastructure built on permafrost

Thomas Schneider von Deimling (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Dmitry Streletskiy (Department of Geography, The George Washington University), Thomas Ingeman-Nielsen (Department of Civil Engineering, Technical University of Denmark), Erin Trochim (Alaska Center for Energy and Power) and Moritz Langer (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research).

Abstract

As a consequence of rising Arctic temperatures, an increasing number of infrastructure sites built on thaw-sensitive permafrost is already affected by permafrost degradation today and will be even more affected in the future. Infrastructure can have a strong thermal imprint on the permafrost ground it is built on, e.g. by the removal of the protective organic surface layer through construction, or by snow accumulation and pond formation in the direct vicinity of infrastructure. The impact of infrastructure constructed on frozen ground is mostly an acceleration of permafrost degradation, leading to earlier infrastructure failure than what might be inferred when not accounting for these effects. In our study, we use a physically-based, process-driven model (CryoGrid) to simulate permafrost thermal conditions affected by infrastructure and analyse the timing when infrastructure might fail in the future. We especially analyse the efficiency of different measures to protect infrastructure – ranging from simple to more advanced adaptation strategies. We diagnose the efficiency of permafrost protection from snow removal, snow compaction, changes in construction designs (e.g. increasing of embankment or gravel pit thickness), and ground stabilization through cooling by thermosyphons. We run our model under a climate mitigation scenario (RCP2.6) and a scenario of intensive future Arctic warming (RCP8.5). We compare the efficiency of different adaptation measures and investigate how this efficiency will be affected under climate change conditions.

Powerlines in Greenland at risk from permafrost degradation

Tom De Ville (Technical University of Denmark (DTU), Danielle Bridle (Technical University of Denmark (DTU), Anton Berggreen Abrahamsen (Technical University of Denmark) and Thomas Ingeman-Nielsen (Technical University of Denmark (DTU).

Abstract

The electricity of Greenland's second largest town, Sisimiut (West -Greenland), is supplied by a hydropower plant, located some 20 km north from the town. In late 2021, Nukissiorfiit – the Greenland public utilities company – observed severe settlements of some powerline masts, constructed on fine-grained ice rich permafrost. These settlements threaten the integrity of the powerlines and may potentially result in a disruption of power supply to the town. This project investigates the cause of these settlements with an aim to suggest appropriate adaptation measures. Frozen soil samples were retrieved from around one of the masts, and soil temperatures are measured at nine locations. At each location, the soil temperature is measured at depths of approximately 20 cm and 1 m below surface. Furthermore, the air temperature and the temperature of the metal mast foundation is monitored. Finally, four Electric Resistivity Tomography (ERT) profiles were collected. The collected soil samples show a stratigraphy consisting of an organic peat top layer, followed by ice rich silt and clay layers at depth. The soil sample information and temperature data is used to set up and calibrate a thermal model using the software Geostudio Temp/W. This model is used to investigate several possible solutions to stabilise the masts under current and future climate conditions. The solutions studied comprise the construction of an elevated gravel pad around the foundation of the masts, or alternatively the use of thermosyphons to stabilize the soil thermal regime. The effect of constructing the gravel pad with and without EPS insulation in the pad is considered as well.

Monitoring and Long-term Predictions of Thermoprobe Performance for a buried concrete arch foundation

Balaussa Kameledenova (Royal Military College of Canada), Ryley Beddoe (Royal Military College of Canada) and Greg Siemens (Royal Military College of Canada).

Abstract

In 2009, a corrugated steel pipe culvert was installed at Gunghi Creek on the Inuvik to Tuktoyaktuk Highway in Northwest Territories, Canada. Within a decade the culvert had experienced significant heave and icing issues, and in 2021 the culvert was replaced with a buried concrete arch built on an adfreeze pile foundation. Also installed were 22 thermoprobes, for passively cooling the ground and stabilize the permafrost and foundation system. During construction 15 thermistor strings were installed to monitor the short and long-term thermal regime. Eight were installed within piles across the foundation, and an additional eight installed at the crest of the road, the crown and haunch of the buried concrete arch, and within the surrounding embankment. Using a commercially available finite element software, Temp/W, a present day thermal model of Gunghi Creek was developed and calibrated using recorded ground temperatures. The numerical model was then used to predict the long-term performance of a foundation system coupled with thermoprobes under future climate warming scenarios. The modelling results show that the inclusion of thermoprobes in the foundation design had significant impact on the future thermal regime and subsequent stability. It was found that they extended the life of the buried concrete arch foundation by over 23 years. The results showed that when all thermoprobes are operating as intended, the subsurface temperatures around the piles increase at an average rate of 0.06 °C/year, thus ensuring that the arch bridge remains fully serviceable for its intended design life. In contrast, when no thermoprobes are functioning, the subsurface temperatures surrounding the piles increase at twice that rate (0.12 °C/year) until permafrost thaw occurs. The results of this study highlight the impact thermoprobes can have on the stability and resilience of a foundation design, and the importance of ensuring their long-term functionality.

Toward large-scale implementation of near real-time ground temperature monitoring LoRaWAN networks in northern Quebec and Yukon: challenges and opportunities

Emmanuel L'Hérault (Department of civil engineering, Université Laval, Québec, Canada), Mickael Lemay (Centre d'études nordiques, Université Laval, Québec, Canada), Michel Allard (Department of Geography, Université Laval, Québec, Canada), Fabrice Calmels (YukonU Research Centre, Yukon University, Yukon, Canada) and Pascale Roy-Léveillée (Department of Geography, Université Laval, Québec, Canada).

Abstract

Thawing of ice-rich permafrost is responsible for numerous infrastructure failures, and in the most dramatic cases, can damage the infrastructure to such a degree that the on-site traffic is disrupted. To track change on the actual state of the ground and assess the risk of occurrence of permafrost-related hazards, the Centre d'études nordiques, Yukon University, the MTQ and LogR Systems Inc. are now testing near real-time geohazard surveillance systems based on star networks of sensors using the LoRa wireless transmission technology and the LoRaWAN communication protocol. During summer 2021, four LoRa star networks of sensors were implemented in Nunavik and in Yukon at airports and road sites. True field conditions performance assessments revealed that the technology allows reliable wireless data transfer over a distance of up to 27 km with very low power consumption. Using a single D-cell battery, the power autonomy of the end-nodes is estimated to 28 years at an hourly data rate for acquisition and transmission. The low-power technology optimization of the datalogger and the organization of the data flow from the end nodes to the ultimate server were designed with safeguards to prevent data loss due to power outages and internet service interruptions (gateway) that may frequently occur in remote northern communities. With near real-time acquisition, data validation and analyses can now be conducted periodically, and monitoring network component failures can now be remotely diagnosed leading to a "Know before you go" maintenance approach. With four fully functional LoRaWAN networks implemented to date and ground temperature data continuously being transmitted to the CEN's server, future work will focus on improving near real-time data processing and results visualization in order to build permafrost-related hazard warning systems to support fast decision-making processes, thus paving the way to a smarter northern infrastructure risk management.

Numerical solution for the hydro-thermo-mechanical framework of one-dimensional large-strain thaw consolidation for engineering adaptation of transportation infrastructure in permafrost regions to climate change.

Anna Pekinasova (Department of Civil Engineering, University of Calgary) and Jocelyn L. Hayley (Department of Civil Engineering, University of Calgary).

Abstract

Understanding the dynamic nature of frozen ground and thawing permafrost is vital for engineering adaptation of transportation infrastructure in northern regions to climate change. An appropriate consolidation model of thawing frozen ground is an important component in evaluating the stability and reliability of infrastructure. A large-strain thaw consolidation model is more realistic compared to small-strain models for ice-rich permafrost terrain, fine-grained soils, and frozen ground with excess ice. It is also important to account for the complex and dynamic heat energy boundary conditions which may be influenced by short and long-wave solar radiation, humidity, precipitation, and wind speed in addition to air temperature.

The goal of this work is to better understand climate change impact and long-term behaviour of embankments built on thawing permafrost focussed on consolidation settlement of thawing ground. The study investigates the numerical solution for the hydro-thermo-mechanical framework of one-dimensional large-strain thaw consolidation using nonlinear effective stress – void ratio – hydraulic conductivity relationship with heat transfer in frozen soils due to conduction, phase change, and advection proposed by Gibson et al. (1967, 1981), Xie and Leo (2004), Dumais and Konrad (2018) and Yu et al. (2020a, 2020b). The Lagrangian coordinate system is used to capture the moving boundary conditions of the ground surface and thawing front for the coupled thermo-hydro-mechanical framework. This study also enriches the solution space with more flexibility in the assignment of upper boundary conditions capable of handling complex non-monotonic time series of atmospheric conditions. Numerical solutions are implemented within an open-source solution engine to make it more accessible to a variety of users in permafrost engineering and climate science. The tool may be used to identify, characterize, and mitigate hazards associated with thawing permafrost to support sustainable linear infrastructure in cold regions.

SESSION 24

Permafrost temperature changes and active layer dynamics: from local observations to global assessments of the permafrost system

Conveners:

- **Dimitry Streletskiy,** *The George Washington University*
- **Jeannette Noetzl***i, WSL Institute for Snow and Avalanche Research SLF*
- **Philippe Schoeneich***, Institut d'Urbanisme et de Géographie Alpine, Université Grenoble Alpes*
- **Anna Irrgang***, Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research*

Summary:

The Global Terrestrial Network for Permafrost (GTN-P) is the primary international programme concerned with long-term monitoring of permafrost. The core mission of GTN-P is to maintain a comprehensive and standardized long-term monitoring network to provide consistent, representative, and high quality long-term data on permafrost parameters. GTN-P ensures the distribution and availability of these data that can be used to assess the state of permafrost conditions and changes over time across Earth's high latitude and altitude regions. This session provides a forum for discussing, assessing, and planning permafrost observational activities in both hemispheres, progress in data preservation, management and dissemination. We invite presentations addressing: (1) results of active layer and permafrost temperature monitoring at site-specific scales; (2) integration of observational data for comprehensive regional and global assessments of permafrost and active layer changes; (3) use of GTN-P data for validation, modelling assimilation and reanalysis products for Earth System Models; (4) integration of remote sensing applications and observational data; (5) collaboration of GTN-P with other related monitoring programs. We seek contributions from those directly involved in GTN-P, as well as representatives from the broader research community who are using GTN-P data.

New state background permafrost monitoring in Russia

Aleksandr Makarov (Arctic and Antarctic Research Institute), Sergey Verkulich (Arctic and Antarctic Research Institute), Nikita Demidov (Arctic and Antarctic Research Institute), Mikhail Anisimov (Arctic and Antarctic Research Institute), Yury Dvornikov (Peoples Friendship University of Russia, Arctic and Antarctic Research Institute), Maria Gusakova (Arctic and Antarctic Research Institute) and Yury Ugryumov (Arctic and Antarctic Research Institute).

Abstract

The state of permafrost (ground temperature, active layer depth, areal distribution, activity of cryogenic surficial processes) is mainly determined by climate and anthropogenic pressure. Warming in the Arctic during the last decades has triggered the consequent permafrost warming and thaw in a pan-Arctic scale. The accurate data on ground temperature are necessary for making decisions on both fundamental and applied permafrost science. Federal Service for Hydrometeorology and Environmental Monitoring of Russia (Roshydromet) is currently developing a new background permafrost monitoring system. The main executor of this work is Arctic and Antarctic Research Institute (AARI). Currently, open access data on two key permafrost variables (ground temperature and active layer thickness) for the territory of Russia are available through GTN-P network established by IPA (International Permafrost Association). These data are scarce and cannot reflect the overall state of permafrost in the country. The new country-level network will consist of boreholes and ALD-monitoring sites connected to the Roshydromet facilities (meteorological stations) in permafrost-covered area and will serve as a reference point both for permafrost science and for permafrost engineering. The main methods that are currently being developed: remote sensing, legacy, and field-based studies for selecting new potential sites, drilling of boreholes (first stage implies 140 new boreholes up to 25 m depth), database architecture for collecting the ground temperature data.

The thermal regime and thermokarst rates of palsas and lithalsas near Kangiqsualujjuaq, Nunavik, Canada

Catherine Deslauriers (Centre d'études nordiques, Université Laval, Québec), Pascale Roy-Léveillée (Centre d'études nordiques, Université Laval, Québec) and Michel Allard (Centre d'études nordiques, Université Laval, Québec).

Abstract

Continued permafrost degradation is expected in the discontinuous permafrost zone but the thermal regime of permafrost landforms affected by thermokarst is understudied. This project investigates the thermal and geomorphological response of palsas and lithalsas to climatic variations near Kangiqsualujjuaq, which is in the discontinuous permafrost zone of Nunavik. We compared air temperatures to permafrost temperatures in the ice-rich core of a palsa and a lithalsa measured between 1989 and 1994 using seven thermistor cables installed to depths up to 20 m. Changes in ground thermal regime and temperature trends within a palsa and a lithalsa were examined in relation to thermokarst rates in the surrounding palsa and lithalsa field, assessed using aerial photographs from 1964, 1984, 2003, 2010 and 2021. Areal loss was 41% for palsas and 69 % for lithalsas between 1964 and 2021. Ground temperatures at both sites warmed at a decreasing rate over the study period as permafrost temperature approached 0˚C and heat exchanges at the surface became increasingly dominated by latent heat. However, even near 0˚C, seasonal temperature variations of up to 0.02˚C were detected up to depths of 18 m in permafrost. Palsa degradation rate varied with interannual variations in air and permafrost temperatures from 1990 to 2021. Lithalsas, which do not benefit from a thermal offset due to their lack of a peat cover, have degraded 2 to 3 times faster than palsas since 2003. The degradation of lithalsas continued to accelerate despite a brief cooling period between 2010 and 2015. This study is based on a unique dataset of over 30 years of ground temperatures in one location and contributes to understanding the evolution of ground thermal regimes in degrading permafrost features of the discontinuous permafrost zone.

Active layer thickness trends in the 21st century

Dmitry Streletskiy (George Washington University), Kelsey Nyland (George Washington University), Nikolay Shiklomanov (George Washington University), Jeannette Noetzli (WSL Institute for Snow and Avalanche Research SLF), Ketil Isaksen (Norwegian Meteorological Institute), Filip Hrbacek (Masaryk University) and Sharon Smith (Natural Resources Canada).

Abstract

Active Layer Thickness (ALT) is recognized by the WMO's Global Climate Observing System as one of the three products of the essential climate variable permafrost. Therefore, assessing regional and global changes of ALT contributes to the characterization of the Earth's climate. However, large spatial heterogeneity of ALT and the variable response of permafrost landscapes to climatic change makes it challenging to assess ALT change at regional and/or global scales. The Circumpolar Active Layer Monitoring (CALM) program of the Global Terrestrial Network for Permafrost (GTN-P), is the primary global archive of active layer data with more than 200 sites located in Arctic, Antarctic, and High Mountain permafrost regions. ALT is measured by mechanical probing and thaw tubes, or interpolated from ground temperature data. We analyzed regional trends from sites established prior to 2000 and having data after 2020. The majority of Arctic sites on continuous permafrost exhibited increasing ALT trends ranging from 0.1 to 0.8 cm/year. In colder regions, such as Northern Alaska and Eastern Siberia changes are smallest. Sub-Arctic sites in discontinuous permafrost are characterized by higher rates (1 to 5 cm/year). The most pronounced ALT increases in the sub-Arctic are observed in Interior Alaska, Scandinavian North, and West Siberia. Trends observed in the European Alps are larger than 10 cm/year. Although the ALT records for the Antarctic are sparse, the available data suggests little change or a gradual thickening of the active layer, similar to the trends from the High Arctic. Globally, ALT and permafrost temperatures show contrasting trends. While ALT increases are highest in regions where permafrost temperature is close to 0 °C, ALT exhibits slow increases in areas with rapidly warming cold permafrost.

Long-Term Active Layer Thickness and Ground-Surface Temperature Trends from the North Slope Of Alaska.

Nikolay Shiklomanov (The George Washington University), Dmitry Streletskiy (The George Washington University), Anna Klene (University of Montana, Missoula), Kelsey Nyland (The George Washington University) and Frederick Nelson (The Northern Michigan University / Michigan State University).

Abstract

In this presentation, we report long-term (1995-2022) observations of the Active Layer Thickness (ALT) and ground surface temperatures from the network of Circumpolar Active Layer Monitoring (CALM) sites on the North Slope of Alaska. This subset of CALM sites represents major North Slope land-cover classes along the dominant bioclimatic gradient. Data show pronounced landscape-specific differences in long-term active-layer trends. Under similar climatic forcing observational sites dominated by shrubs demonstrate higher rates of increasing ALT than shrub-free tundra sites. Analysis of temperature measurements indicates divergent trends in air and ground-surface temperatures manifested by an overall increase in temperature differences between the air and soil surface. These results may suggest an increase in the thermal insulating properties of natural covers attributable to 'Arctic greening.' Several simple indices that indirectly account for complex energy exchange between the atmosphere and the ground thermal regime were used to assess multi-decadal changes in thermal insulation properties of natural covers (vegetation and snow). Our data suggest that vegetation change in non-shrub tundra produces negative feedback, which can partially explain the relative stability of active-layer thickness under a warming climate. Conversely, in shrub tundra, an increase in vegetation height and density produced a strong positive (deepening) active-layer trend attributable to increased winter thermal isolation due to vegetation-related redistribution of snow. Overall, long-term observations from the North Slope of Alaska demonstrate complex, non-linear responses of the active-layer/near-surface permafrost system to changes in climatic conditions. These data provide an empirical basis for the quantitative evaluation of complex interactions and feedback mechanisms between changing ecosystems and permafrost.

Thermal state of Permafrost in the Central Andes

Cassandra Koenig (University of Fribourg), Christin Hilbich (University of Fribourg), Christian Hauck (University of Fribourg) and Lukas U. Arenson (BGC Engineering Inc.).

Abstract

The importance of monitoring thermal state of permafrost around the world is well recognized due to the multitude of risks posed by climate change-induced permafrost degradation. International efforts are in place to collate standardized permafrost monitoring data in order to establish an early warning system for the potential consequences of large-scale permafrost loss. Most of these data have been compiled from circumpolar regions and mountain environments in the Northern Hemisphere, with a distinct lack of such monitoring data from the Southern Hemisphere. This has limited evaluations of the thermal state and possible degradation of mountain permafrost in Chile and Argentina within the global context.

A compilation of ground temperature datasets from 59 boreholes with depths of up to 100 m established by local industry in high altitude regions of the Central Andes (from 3,500 to 5,500 m in elevation and latitude between 27 °S and 34 °S) is presented. The dataset includes measurements for periods up to 11 years within cold and warm permafrost, where average temperatures at the ground surface are above 0 ºC, as well as measurements from non-permafrost zones. Ground temperatures within permafrost zones range from -8 ºC to 0 ºC below depths of zero annual amplitude. The unique dataset shows a decrease in ground temperature with elevation according to a lapse rate of ~0.4 ºC / 100 m altitude, and boreholes installed on south facing slopes are colder than others at the same elevation. Ground temperatures within rock glaciers are significantly lower than ground at similar elevations and tend to be concentrated on south-southwest facing slopes. This is consistent with the expectation that these landforms would delineate the lower limit of permafrost within mountainous environments, providing supporting evidence on the complexity of the ground temperature conditions in the Andes.

18 years of Active layer thickness monitoring in the Middle Siberia (R-32 Site, Norilsk, Talnakh)

Fedor Iurov (Lomonosov Moscow State University, Faculty of Geography, Department of Cryolithology and Glaciology), Valery Grebenets (Lomonosov Moscow State University, Faculty of Geography, Department of cryolithology and glaciology) and Vasily Tolmanov (Lomonosov Moscow State University, Faculty of Geography, Department of Cryolithology and Glaciology).

Abstract

Active layer thickness (ALT) growth is one of the indicators of changes in permafrost occurring due to climate change in subpolar latitudes. Monitoring of the active layer thickness at the CALM R-32 site in Talnakh (Norilsk region) has been conducted continuously for 17 consecutive years, starting from 2005. The work includes mechanical probing of the ALT, and detection of vertical movements of the surface (winter heaving and subsequent thaw subsidence). The data show that the thickness of the active layer has substantially increased since 2005. Mean ALT value at the site was 81-93 cm in 2005-2010. ALT annually exceeds 110 cm (max - 122.7 cm, 2021) starting from 2019. 14 points on the site (out of 121) exceeded 160 cm in 2022. In 2020, we ran an additional geobotanic study on site to track the changes in the vegetation structure and update the microlandscape map made within the first five years of study. We have observed a noticeable expansion of the area covered by bushes, the area of frost boils spread out, while the area of the typical tundra has been reduced. The height of the vegetation increased in general. Geodetic observations show that the surface topography is quite stable. Noticeable negative annual changes could be found at the local watertracks, the wettest type of the landscape. For the last two years, geodetic measurements at the site have been conducted using a tacheometric method using a reference point, which is a high-voltage power line support that can be considered as stable. All the geodetic measurements done before were relative to point one, which experiences vertical displacements because of seasonal movements. Temperature loggers were installed at the site in 2021 that allow us to obtain two years of data on the temperature regime of the active layer.

Bedrock permafrost degradation rates from different sites at altitudes above 2900 m a.s.l. in the Alps

Sarah Morard (University of Fribourg), Christin Hilbich (University of Fribourg), Coline Mollaret (University of Fribourg), Cécile Pellet (University of Fribourg), Adrian Flores-Orozco (TU Vienna), Theresa Maierhofer (TU Vienna), Christophe Lambiel (University of Lausanne), Florence Magnin (Université Savoie Mont Blanc) and Christian Hauck (University of Fribourg).

Abstract

Most permafrost studies in the European Alps focus on the elevation band between 2,400 m a.s.l. and 2,900 m a.s.l., where also most rock glaciers are located. This is also the elevation band, where most degradation phenomena have been observed so far. However, permafrost monitoring data such as borehole temperature and geophysical properties (electrical resistivity, P-wave velocity) have been collected at higher altitudes, mainly in bedrock permafrost. Examples are Aiguille du Midi (3,742 m a.s.l.), Stockhorn (3,410 m a.s.l.), Mont Fort (3,300 m a.s.l.), Wildstrubel (3,227 m a.s.l.), Sonnblick (3,06 m a.s.l.), Cervinia (3,100 m a.s.l.), Pointe du Tsaté (3,050 m a.s.l.), Rottalgrat (2,980 m a.s.l.), and Schilthorn (2,910 m a.s.l.). The objective is to acquire a better knowledge of the evolution of bedrock permafrost at higher altitudes (> 2,900 m a.sl.) in the European Alps. The analysis has already been completed for the PERMOS reference sites and the extensively-studied monitoring sites Stockhorn and Schilthorn, located in the Swiss Alps. We analyzed the monitoring time series of subsurface and surface temperature evolution, soil moisture behavior and evolution of electrical resistivity and p-wave velocity. We also perform a petrophysical joint inversion to quantify ice and water content. The analysis of all available data shows consistent evidence of significant permafrost degradation since the beginning of the measurements in 2001. Regularly monitored electrical resistivity and seismic P-wave velocity values have decreased. At the same time, the active layer thickness has increased together with permafrost temperatures and thawing degree days of the ground surface temperature. We here present a comparison of the extensive data sets from Stockhorn and Schilthorn with monitoring stations across the Alps. The analysis aims to capture diverse climatic conditions, such as humid and dry regions, and the comparison of degradation rates between the different sites.

Diurnal and seasonal active layer and permafrost dynamics from boreholes of the Latin American permafrost network

Kenji Yoshikawa (University of Alaska Fairbanks), Gino Casassa (General Directorate of Water, Ministry of Public Works, University of Magallanes), Bolívar Ernesto Cáceres Correa (Instituto Nacional de Meterología e Hidrología), Hugo Delgado Granados (Instituto de Geofisica, UNAM), Edson Ramirez (Instituto de Hidráulica e Hidrología, Universidad Mayor de San Andrés), Jorge Luis Ceballos (Cooperación y Asuntos Internacionales), Pablo Masías Álvarez (Observatorio Vulcanológico del INGEMMET), Pool Vasquez Choque (Observatorio Vulcanológico del INGEMMET), Guillermo Azócar (Atacama Ambiente Consultores), Pablo Rodrigo Iribarren Anacona (Instituto de Ciencias de la Tierra, Universidad Austral), Victor Soto (Universidad Veracruzana), Dario Trombotto (IANIGLA-CCT CONICET Mendoza) and Jose Úbeda Palenque (Universidad Complutense de Madrid).

Abstract

Permafrost is present in the high-altitude mountains of the Trans-Mexican Volcanic Belt as well as the Andes, even in the extreme dry Atacama highland. The permafrost and active layer thermal state are characterized at Latin American Permafrost Network study sites. Ice rich or extremely dry permafrost was observed during drilling operations from Mexico (Pico de Orizaba, 5636m a.s.l. Iztaccíhuatl, 5230m a.s.l.), Colombia, Ecuador (Chimborazo, 6263m a.s.l.), Peru (Coropuna 5250 m a.s.l., Ampato 5850 m a.s.l., Chachani 5600 m a.s.l.) including the highest human habitation in the world: La Rinconada 5100 m a.s.l., Bolivia (Chacaltaya 5300 m a.s.l. where glacier disappeared in 2005), and the Chilean/Argentinian border (up to 6750 m a.s.l. including Parinacota, Aucanquilcha, Ojos del Salado, Llullaillaco, Tupungato and Tupungatito). The Lower Limit of Alpine Permafrost (LLAP) is redrawn from this study between latitude 19˚N and 40˚S where it is mainly in the tropical and arid Andes. This is not a rock glacier monitoring program that not mapping sporadic permafrost, but continuous permafrost terrains for long term temperature monitoring and understanding for local hydrological problems such as glacier/snow melt runoff or sublimation rate of higher elevations. The maximum active layer is typically influenced by the diurnal fluctuations which is between 12-30 cm deep however, maximum 2m depth of the seasonal active layer was observed at Ojos del Salado near the LLAP (5200 m a.s.l.). Daily severe frost shattering occurs near the ground surface, producing a dusty, fine-material horizon at an active layer near the LLAP, however a few freeze-thaw actions are higher than 6400 m. The snow-covered periods are important for providing protection from strong tropic solar radiation.

The Arctic Methane and Permafrost Challenge – Network data catalogue and sharing platform

Josh Hashemi (Alfred Wegener Institute), Sebastian Laboor (Alfred Wegener Institute), Claire Treat (Alfred Wegener Institute) and Guido Grosse (Alfred Wegener Institute).

Abstract

While there is high confidence that the thaw of terrestrial permafrost will lead to carbon release, there is low confidence the regarding timing, magnitude and relative role of CO_2 versus CH_4 emission contributions to radiative forcing. The Arctic Methane and Permafrost Challenge (AMPAC) strives to address these uncertainties through synergistic measurements, activities to improve satellite retrievals with a clear focus on high latitudes, promoting new dedicated satellite sensors and improving validations of existing and upcoming satellite missions. The aim of AMPAC-Net (the AMPAC Networking Action) is to involve the entire research community in this effort by building and coordinating a network of relevant research communities and to specifically engage experts and ensure integration of the wider community. At the core of this activity is also the review of existing datasets relevant for understanding Arctic methane dynamics. Building upon existing activities and databases, we are developing a community catalogue and data sharing platform (https://apgc.awi.de/group/about/ampac) for permafrost-region methane datasets serving collaborative research across the community. Our catalogue will ensure easy access to earth observation datasets as a basis for activities within the AMPAC initiative. The purpose of this catalogue is to:

- Identify, mine, and integrate existing highly relevant earth observation and field datasets, and to further integrate existing efforts of Arctic methane related data repositories.
- Ensure visibility and access to available in situ data and sharing of data across the community though the AMPAC catalogue. This follows the FAIR data principles of findability, accessibility, interoperability, and reusability.
- Promote a community effort to gather the relevant EO datasets from different activities including ESA projects (e.g., ESA science activities and CCI projects, NASA activities, EC funded projects, nationally funded activities).
- Foster and facilitate collaborative research activities, such as methane data synthesis efforts and joint analysis, to be undertaken within AMPAC.

Open-source tools to support standardization and cleaning of ground temperature data

Nicholas Brown (Carleton University, NSERC PermafrostNet), Alex Gao (Carleton University, Geomatics and Cartographic Research Centre) and Stephan Gruber (Carleton University).

Abstract

The effort required to manage, clean, and standardize ground temperature data represents a significant bottleneck that impedes the publication and dissemination of data. Unfortunately, there are very few resources available to support this workflow and researchers inevitably implement ad-hoc scripts that are difficult to reuse or share, and that can have limited maturity. Challenges arise from the heterogeneity of data formats and the lack of established standards. We developed two open-source software libraries to assist in the data processing workflow: tsp ('teaspoon') and TempCF. The former is designed to increase the ease with which ground temperature time series data from any source can be read into Python. Tsp reads and writes data in a variety of formats used by databases (e.g., GTN-P), data loggers (e.g., Geoprecision) and numerical models (e.g., GEOtop). It can be used not only to convert raw ground temperature observations into a database-ready format, but more importantly to create reusable workflows or tools that can be more widely adopted regardless of data source. TempCF is one such tool. It supports semi-automated data cleaning and comprises an interactive GUI interface for viewing data as well as a library of filters for detecting anomalous observations. Rather than correcting data automatically, it relies on human expertise to evaluate whether automatically flagged anomalies represent instrument error or unexpected, but real, measurements. The underlying filters can also be accessed directly. These tools are designed to be collaborative and extendable to encourage broad adoption and the development of shared best-practices. They are expected to benefit the permafrost community by lowering barriers to data preservation and management, leading to greater availability of ground temperature data.

Enhanced permafrost warming in European Mountains

Jeannette Noetzli (WSL Institute for Snow and Avalanche Research SLF), Ketil Isaksen (Norwegian Meteorological Institute), Jamie Barnett (Department of Geological Sciences, Stockholm University), Hanne H. Christiansen (Geology Department, University Centre in Svalbard), Reynald Delaloye (Department of Geosciences, University of Fribourg), Bernd Etzelmueller (Department of Geosciences, University of Oslo), Thomas Gallemann (Bavarian Environment Agency), Mauro Gugliemin (Department of Theoretical and Applied Science, Insubria University), Christin Hilbich (Department of Geosciences, University of Fribourg), Martin Hoelzle (Department of Geosciences, University of Fribourg), Christophe Lambiel (University of Lausanne), Florence Magnin (Laboratoire EDYTEM, CNRS/Université Savoie Mont-Blanc), Luca Paro (Environmental Protection Agency of Piedmont), Paolo Pogliotti (Environmental Protection Agency of Valle d'Aosta), Claudia Riedl (GeoSphere Austria), Philippe Schoeneich (PACTE, Institut d'Urbanisme et de Géographie Alpine, Université Grenoble Alpes), Mauro Valt (Environmental Protection Agency of Veneto, Centro Valanghe di Arabba), Andreas Vieli (Department of Geography, University of Zurich) and Marcia Phillips (WSL Institute for Snow and Avalanche Research SLF).

Abstract

Permafrost is observed globally as an Essential Climate Variable (ECV) of the Global Climate Observation System (GCOS). Mountain permafrost accounts for 30 % of the global permafrost area. It exists at low to high latitudes on both hemispheres, and it is characterized by high spatial variability in (sub)surface and atmospheric conditions and large environmental gradients. Here, we compile a quality-controlled permafrost temperature data set from over thirty long-term monitoring sites in European mountain regions. This data set has unique spatial coverage and allows for an extended and consistent assessment of permafrost warming from the Alps to the Nordic countries (including Svalbard) by statistical analyses of decadal trend pattern. Attention is also given to the spatial and temporal variability of these patterns and the driving processes and mechanism behind them.
The selected sites cover a latitudinal range from 45 to 78 °N and elevations between 275 and 3850 m asl. They are located in dry bedrock slopes or plateaus, ice-bearing talus slopes and ice-rich rock glaciers. Mean annual ground temperatures at 10 m depth vary between nearly 0 °C and below –6 °C. Calculated warming rates for the past 1–2 decades range from close to zero to values comparable with or even higher than those observed in the high Arctic lowlands. Strongest warming is observed at cold bedrock sites at high latitudes and high elevations (e.g., mountain sites on Svalbard or above 3500 m asl. in the Alps). Ground temperatures in ice-rich permafrost close to the lower permafrost boundary – for example in many rock glaciers in the Alps – increase at a lower rate due to latent heat uptake during ice melt. Significant increase in active layer thickness (ALT) is also observed. For example, in the Alps, ALT increased by meters in the past 1–2 decades, even doubling at some sites.

Soil moisture monitoring network in Antarctic Peninsula region

Filip Hrbacek (Masaryk University), Miguel Angel de Pablo (Universidad de Alcalá), Mohammad Farzamian (Instituto Nacional de Investigação Agrária e Veterinária), Goncalo Vieira (Universidade de Lisboa) and Michaela Knazkova (Masaryk University).

Abstract

Soil moisture is one of the most important factors driving the variability of ground thermal properties. The seasonal or long-term dynamics of soil moisture can highly affect the annual thawing of the ground because 1) increasing soil moisture can significantly promote ground thermal conductivity 2) increasing soil moisture significantly increase the latent heat consumption preventing active layer thawing. In spite of the well-known importance of soil moisture, only a little attention is given to this parameter so far in the Antarctic regions.
This contribution presents the idea and setting of a newly established network for soil moisture monitoring in the Antarctic Peninsula region. The major areas of interest are the long-term monitoring sites on James Ross Island, Livingston Island (Byers and Hurd Peninsulas), Deception Island, Nelson Island and King George Island (Fildes and Barton Peninsulas). The selected sites for soil moisture monitoring are also involved into CALM-S monitoring network and Autonomous Electrical Resistivity Tomography (A-ERT) monitoring network. All sites are equipped by smart dataloggers Microlog SDI-MP (EMS-Brno) equipped with CS655 TDR (Campbell Sci.) probes allowing measurement of soil moisture, temperature and electrical conductivity. We use the setting of 3 or 4 sensors installed into the surficial (1 pc), middle (1-2 pcs) and bottommost parts of the active layer. We expect the network will bring valuable results, allowing us 1) better understand and interpret year-on-year variability of ground thermal regime and active layer thawing 2) provide data necessary for the parametrisation of models for active layer or ground temperature predictions 3) provide soil electrical conductivity data which will contribute to newly establish A-ERT monitoring systems.

Impact of different permafrost definitions on the interpretation of modeling results on different scales

Norman Julius Steinert (NORCE Norwegian Research Centre AS, Bjerknes Centre for Climate Research, Bergen, Norway), Matvey Debolskiy (NORCE Norwegian Research Centre AS, Bjerknes Centre for Climate Research, Bergen, Norway), Hanna Lee (Department of Biology, Norwegian University of Science and Technology, Trondheim, Norway) and Sebastian Westermann (Department of Geosciences, University of Oslo, Oslo, Norway).

Abstract

Since the establishment of the international permafrost definition by IPA in 1989, permafrost as a phenomenon has been involved in studies within a growing number of different fields of research. However, its definition relies on concrete physical quantities and phenomena (temperature, time, soil, water), there is still a degree of ambiguity, which is especially important for permafrost characteristics that rely on this definition (permafrost extent, permafrost distribution). Consequently, two main ways of characterizing the presence of permafrost exist within the scientific community for defining global permafrost extent: 1) by the depth of the active layer and 2) by the soil temperature at a certain depth. Here, we attempt to quantify the discrepancies in permafrost characteristics caused by different interpretations of the permafrost definition based on modeling datasets such as CMIP6 and ISIMIP. The analysis includes present-day permafrost conditions as well as projections for future scenarios. In addition, we estimate the consequences that the use of different physical quantities for determining permafrost may have in the research where permafrost characteristics are used.

ESA CCI+ Permafrost - Validation using international and national permafrost monitoring networks

Birgit Heim (Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung), Mareike Wieczorek (Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung), Anna Irrgang (Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung), Simeon Lisovski (Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung), Heidrun Matthes (Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung), Guido Grosse (Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung), Antonie Haas (Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung), Kirsten Elger (GFZ German Research Centre for Geosciences), Sebastian Westermann (Department of Geosciences, University of Oslo), Chloe Barboux (University of Fribourg), Cécile Pellet (University of Fribourg), Reynald Delaloye (University of Fribourg), Frank Martin Seifert (European Space Agency (ESA), Tazio Strozzi (GAMMA Remote Sensing) and Annett Bartsch (B.GEOS).

Abstract

Special emphasis in the Climate Change Initiative (CCI) programme of the European Space Agency (ESA) is placed on validation of the CCI Essential Climate Variable (ECV) products using in situ data from international and national monitoring networks in cooperation with the involved communities. In phase 1, the CCI Permafrost project produced time series from 1997 to 2019 of yearly, circum-Arctic permafrost maps on mean annual ground temperature (MAGT), Active Layer Thickness and Permafrost Probability.

We describe here the ongoing data compilation and standardisation effort deriving the validation data set for CCI Permafrost MAGT products. We compiled the new circum-Arctic collection on ground temperature temporal records from the main communities' (permafrost, meteorology) pre-existing in situ ground temperature records. We assembled ground temperature within a wide range of depths from shallow measurements down to 20 m depth mainly from the Global Terrestrial Network for Permafrost (GTN-P) managed by the International Permafrost Association (IPA) and associated communities, and from the Russian meteorological measurement program Roshydromet (RHM). Despite GTN-P and RHM time series provide partly standardised ground temperature data sets, they are no easy-to use time-series depth data suitable for validation. We needed to correct and optimise the ground temperature data collections by error-checking, and depths and metadata standardization.

This newly compiled, harmonised data collection of ground temperature depth-time series from 1997 to 2021 will be published in the PANGAEA data repository and as an ESA CCI+ Climate Research Data Package (CRDP) providing the first consistent circum-Arctic data collection with standardized measurement depths. It covers all permafrost zones of the Northern hemisphere. Especially the shallow ground temperature time series represent a very interesting validation and parametrization dataset for climate and land surface models.

Polygonal peatlands in permafrost of West Siberia: distribution and monitoring

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Abstract

Polygonal peatlands with ice wedges are widely distributed in the southern tundra subzone of West Siberia. Thawing of ice wedges controls dynamics of polygonal peatland topography. Our study comprises two aspects (local and regional, respectively): (1) peatland monitoring in the key area in the northern part of Pur-Taz interfluve, and (2) analysis of remote sensing data covering polygonal peatlands in the North of West Siberia. Processing of current weather records and field monitoring of permafrost properties confirmed a fairly high rate of polygonal ice wedge degradation in the study area. Detailed assessment of key peatland monitoring data, including comparison of the rates of terrain changes in natural conditions and under the impact of the highway, as well as in the “peatland-lake” interaction zone was undertaken. Monitoring data allowed to extrapolate detected patterns to the entire north-eastern part of the Pur-Taz interfluve. Study of geological cross-section included determining peat composition and properties along with active layer depth measurements. This study was used to reveal transition and intermediate layers and their specific characteristic playing a buffer role in protecting permafrost. The results obtained allow us to develop the criteria for assessing the persistence of polygonal peatlands to anthropogenic impact along with considering modern climate changes, and create a respective “persistence of polygonal peatlands” map. Remote sensing of polygonal peatlands preliminarily allowed to define southern boundary of polygonal peatlands distribution in the North of West Siberia and gradual change of their features from the north southward.

State and changes of permafrost in the Swiss Alps

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Abstract

Permafrost is classified as an essential climatic variable (ECV) by the Global Climate Observing System (GCOS) because of its sensitivity to changes in climatic conditions. The Swiss Permafrost Monitoring Network PERMOS was founded in the year 2000 to document the state and changes of permafrost conditions in the Swiss Alps by collecting and assessing long-term baseline data. The distribution and characteristics of mountain permafrost at local and regional scale is heterogeneous due to topography-related differences in snow cover and substrate characteristics. To account for this diversity, PERMOS developed a comprehensive monitoring strategy relying on three complementary observation elements: (1) ground temperatures, (2) permafrost electrical resistivity, and (3) permafrost creep velocities. Currently the PERMOS network includes 16 sites where permafrost temperatures are continuously measured, 5 sites where annual electrical resistivity tomography (ERT) surveys are performed and 15 sites where permafrost creep velocities are observed annually. In this contribution, we present and discuss a comprehensive overview of the state and changes of permafrost in the Swiss Alps based on the 20-year long dataset of mountain permafrost collected within the PERMOS network. Combining observations of permafrost temperature, ground electrical resistivity and rock glacier horizontal velocity, we analyse the short and long-term responses of permafrost to climate evolution. Since the beginning of the network in 2000, all three observation elements consistently indicate a general warming and degradation of permafrost. Borehole temperatures show a clear warming trend at 10 and 20 m depth throughout the Swiss Alps. The decrease in permafrost resistivity (indicative of ground ice warming and/or loss) and overall increase of rock glacier creep velocity further corroborate the warming trend. Nevertheless, marked inter-annual variability is observed like for instance the permafrost temperature decrease following the snow-poor winter 2016/2017.

Two decades (2000-2022) monitoring permafrost and active layer in Livingston and Deception Islands, South Shetland Archipelago, Antarctica: the PERMATHERMAL network.

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Abstract

The first two shallow boreholes (<5 m deep) for permanent monitoring of permafrost and active layer temperatures in Livingston Island, South Shetlands Archipelago, Antarctica, were drilled in 2000. These boreholes were the seed for the present PERMATHERMAL monitoring network established by University of Alcalá (Madrid, Spain) in collaboration with the University of Lisbon (Portugal). The sites included air and ground surface temperature monitoring, as well as a permanent grid to monitor the active layer thickness in Deception Island since 2006. During the International Polar Year 2007-2008, a few years later, we established new monitoring sites in both islands by drilling several shallow and deep boreholes (reaching 25m depth) with complementary instrumentation to monitor air, snow, and ground surface temperature, as well as a new active layer thickness monitoring site. Nowadays, the PERMATHERMAL network consists of 12 sites with 15 boreholes within 2 areas in Livingston Island (Hurd and Byers peninsulas) and 1 area in Deception Island. Data from these stations contributes to the Global Terrestrial Network – Permafrost (GTN-P) and the Circumpolar Active Layer Monitoring (CALM) databases, under the International Permafrost Association (IPA). This data also contributes to other databases like SoilTemp, which is not focused on permafrost monitoring, but on soil temperature at the global scale. After more than 20 years of continuous monitoring, the upgrade and standardization of all boreholes in early 2022, assures that PERMATHERMAL network provides continuous data, with higher resolution and accuracy, for several years to come. Here we present the PERMATHERMAL monitoring network, and an overview of the 2 decades of data, as well as the plans to better understand the permafrost distribution and evolution in Livingston and Deception Islands, located in an area close to the climatic limits of permafrost, and under significant heating due to the climate change.

InSAR application for surface displacement investigations in Arctic permafrost regions: a comparison of mitigation methods for interfering atmospheric effects

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Abstract

Freeze-thaw cycles in Arctic permafrost regions can lead to considerable ground displacements. Surface subsidence caused by thawing in summer can be substantial especially for areas of ice-rich permafrost and may be countered by frost heave in winter. InSAR has proven to be a valuable tool to monitor displacements in these often remote locations. In this study, we detect ground displacements using Sentinel-1 data, which has a ground sampling distance of 2.3 m (range) and 13.9 m (azimuth) and provides 12-days repeat time intervals for most Arctic regions. Due to generally low coherence values during longer time intervals, however, the number of usable interferograms for displacement calculations in the study area is restricted. In order to achieve correct InSAR displacement timeseries with this limited number of interferograms, it is essential to correct for atmospheric effects that can significantly distort results, especially during the thawing periods. We therefore processed interferograms in series and compared these unfiltered timeseries with results of applied spatial filtering (linear least-squares method, filter radius 6 km) as well as results corrected with the Generic Atmospheric Correction Service (GACOS), which utilises the ECMWF weather model data as well as DEM data to provide tropospheric delay maps. Comparisons of methods have been performed for selected regions throughout the Arctic, in order to determine a best practice for an easily applied correction method suitable for a circumpolar implementation. Results have been compared to mechanically measured in situ data of yearly subsidence and to borehole temperature measurements. It could be shown that for most regions the filtering methods showed an improvement in error statistics. Highest agreement with in situ subsidence measurements as well as thaw progression in boreholes was found for GACOS corrected results.

Impacts of Winter Warming Events on permafrost in the Swedish subarctic: Insights from a 15-Year manipulation experiment and 42 years of AL monitoring

Didac Pascual Descarrega (Lund University) and Margareta Johansson (Lund University).

Abstract

Winter warming events (WWEs) are short-lived episodes of warm weather during wintertime, often accompanied by rainfall (rain on snow; ROS). These events affect the below-ground thermal regime and thus control various ecosystem processes, including microbial activity, permafrost and vegetation dynamics. In recent decades, the frequency and intensity of WWEs in the Arctic, including the Swedish subarctic, has increased, and this trend is expected to continue in the 21st century. In 2005, a manipulation experiment was set up to simulate future increases in winter precipitation. In this study, we analysed this 15-year record of ground temperature, active layer thickness, and meteorological data to examine the influence of different types and timings of WWEs on permafrost under varying snowpack conditions. Our results showed that all types of WWEs were strongly linked to permafrost warming during the winter months, but significantly warmer summer ground temperatures and thicker active layer were only associated with rain on snow events in manipulated plots. Long-term data from nearby permafrost sites indicate an increasing influence of WWEs on permafrost since the mid-1990s, outweighing the influence of summer air temperatures.

Evolution of mountain permafrost in north western Alps

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Abstract

Permafrost in the Alps plays a critical role in the evolution of mountain environments affecting various aspects of geomorphology and hydrology, such as soil and slope stability, rockfall dynamics and water flow. In these environments, characterized by an extremely complex topography, the permafrost has highly variable properties and thermal responses, and it is important to monitoring the evolution of subsurface temperatures at least in the end-members of this morphological continuum. The study presents an overview of the current knowledge and advancements in the monitoring activity conducted during the last decade in Valle d'Aosta, a small italian region located in the north western Alps. The monitoring is conducted in various high mountain morphological conditions including high mountain plateau, steep rock walls, bare bedrock glacier forefields and rock glaciers. The recent thermal and morphological evolution of permafrost temperatures and active layer in such a various environments will be exposed and discussed in order to provide a comprehensive picture that helps to advance our understanding of the processes and feedbacks involved in mountain permafrost evolution.

Permafrost Measurements Best Practice: GCW's contribution to standardization of global observations

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Abstract

The Global Cryosphere Watch (GCW), in the context of the framework of the World Meteorological Organization (WMO), published the Measurement of Cryospheric Variables, Volume II of the Guide to Instruments and Methods of Observation in 2018, in which best practice for observations of snow parameters was included. As a follow-up effort, measurement best practices for the other cryosphere components are under development, including permafrost and seasonally frozen ground. The measurement best practice for permafrost aims to define reference methods for the configuration and ongoing operation of stations for in situ observations in high mountains and polar regions. It will: address gaps in the existing permafrost monitoring systems, define methods for improving traceability and comparability, recommend instrumental characteristics and provide measurements uncertainty evaluation. A further objective is to support capacity building of countries in terms of developing a permafrost observation network. A Task Team within the framework of GCW was established, to lead the development and publication of a complete guide to the measurements of permafrost variables. The documents in preparation will be coordinated with the ongoing revision of Products and Requirements of the Global Climate Observing System (GCOS) Permafrost Essential Climate Variable (ECV), including existing variables measured by the GTN-P (Global Terrestrial Network for Permafrost). Further, the needs of developing Essential Arctic Variables (EAV) and Shared Arctic Variables (SAV) identified at the Arctic Observing Summit (AOS) are considered. The work will be based on existing methodologies, promoting and recommending methods to improve data reliability and traceability, also for the implementation of new stations.

Rapid warming and thawing of permafrost and active layer reflect climate trends at Bayelva, Svalbard

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Abstract

Svalbard is a hot spot of climate change with even faster warming rates than the Arctic average. Due to the glacial history and the comparably warm and maritime climate, permafrost temperatures are about -3°C at the Bayelva site near Ny-Ålesund. This warm permafrost has the potential to rapidly thaw which may lead to drastic changes in the landscape and its ecology. We have maintained a long-term measurement station at Bayelva (78.92 °N, 11.83 °E) since 1998. The 24-year data series includes many important climate and soil variables such as snow depth, liquid precipitation, and air temperature, as well as soil temperature and moisture content at 7 depths down to 1.4 m. Since 2009, we also measure permafrost temperatures at down to 9 m depth. Using the soil temperature and moisture data, we have estimated the freeze-thaw state of each layer. We have quantified spatial snow cover fraction using webcam images and snow depth data. We have also estimated trends of mean annual and mean monthly values of all variables using a Bayesian statistical analysis. We found that annual air temperatures rose by 0.89±0.56 °C/decade (1999-2022). We observed a shortening of the spatially continuous snow cover by 18 days/decade. These drastic changes in air temperature and snow cover led to equally fast changes in the hydrothermal state of the ground. The active layer warmed by 0.5-0.8 °C/decade at all measured depths. Soil moisture increased at all but the top depths. Additionally, the thawed period lengthened by 12-21 days/decade at all depths, with faster changes in deeper layers. We found that the rapid soil warming has already led to a doubling of the active layer depth within 20 years. Given the rapid increase of soil temperature and moisture over the last two decades, we expect to observe further thaw and permafrost degradation in the near future.

Identifying linkages between EO-based surface variables and permafrost temperature changes

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Abstract

Permafrost describes the thermal state of the subsurface. However, it is impacted by changes at the surface, as ground thermal conditions are connected to climate, topography, hydrology, and vegetation. Quantifying permafrost change is critical as near-surface permafrost loss at local to regional scales impacts ecosystems, hydrological systems, greenhouse gas emissions, and infrastructure stability. Hence, examining changes in the surface thermal regime will help to identify subsequent changes in permafrost due to positive feedback and potentially allows identification of regions that are vulnerable or already active in permafrost thaw.
EO-based datasets enable the analysis of trends and changes from long-term consistent datasets. Relevant surface variables are land surface temperature (LST), land cover (represented by NDVI), snow cover (SC), fire (FI), albedo (AL) and soil moisture (SM). Together with the GTN-P long-term in situ records on permafrost temperatures and the modelled permafrost product, these datasets provide a rich basis for a data-driven analysis on permafrost trends. Our aim is to link trends of the EO-based surface variables with observed permafrost temperature trends to identify and quantify main surface drivers of changes in the permafrost temperature.
Trend calculations and significance tests show spatiotemporal variability in the EO-based surface variables. A principle component analysis (PCA) of the surface variables showed that FI, SM and SC account for 31.8% of the variance and LST, NDVI and SC for 18.8 %. To test the robustness of this analysis, we extended the analysis to 300-1200 potential additional permafrost boreholes. The PCA results show similar trends, despite the varying abundance and distribution (regular vs random) of potential boreholes.
Our study indicates a link between surface and permafrost and the main drivers of permafrost temperature changes. With globally available EO-based datasets, we can make assumptions on where permafrost is particularly vulnerable to experience changes following surface trends.

Results of Permafrost Monitoring in the Mountains of Northern Transbaikalia

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Abstract

Automated monitoring of the thermal state of permafrost in the mountain of Northern Transbaikalia has been going on for 17 years. It was found that the climate changes are similar at different altitudes between 700 and 2000 m a.s.l. However, the permafrost's response to climate change is different and multidirectional. It depends on local landscape factors. The different mechanism of heat transfer in soils also should be taken into account. This mechanism causes both a positive and a negative temperature shift at the base of the active layer compared to the surface temperature. This data help to formulate a new problem: how we can develop the regional indicators of the permafrost state and permafrost dynamics. Such indicators cannot be formed on the basis of simple averaging of regional data. They should take into account the regional variability of permafrost characteristics using landscape zonation with detail, which takes into account the main elements of the relief, types of water exchange, vegetation and cryolithological structure of Quaternary deposits. The main types of landscapes help form subsamples (or matched selection) of geothermal data. This subsamples help us to understand the physics of the permafrost reaction to climatic and anthropogenic impacts.

New and old long-term permafrost boreholes in the Inner Tien Shan, Kyrgyzstan

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Abstract

The cryosphere is currently undergoing remarkable and striking changes worldwide. However, in comparison to snow, glaciers, ice sheets and sea ice, permafrost is much more difficult to detect with remote sensing methods. In situ measurements in permafrost environments are sparse and heterogeneously distributed, especially in remote mountain ranges. Nevertheless, permafrost is reacting very sensitively to changes in atmospheric temperature, both in polar and high-altitude areas. Degrading permafrost leads to intense mass wasting in high mountain regions with steep slopes. In addition, surface and ground ice conditions change rapidly and will lead to a corresponding shift in geomorphic processes, such as debris flow activity in freshly exposed or thaw-destabilized moraines and talus slopes. Systematic long-term monitoring of permafrost in mountain ranges started in 1970/80 in Central Asia and in the European Alps and is still far away from a continuous observation program on a global scale.

Central Asia with its Pamir and Tien Shan Mountain ranges, has vast areas underlain by permafrost, but the observational network is very limited. In this region, only a few monitoring programs in Western China and Northern Tien Shan near Almaty exist. Also in the Inner Tien Shan, where the Kumtor gold mine is located today, more than forty boreholes were drilled in permafrost in the 1980/90s. Permafrost temperature was measured in some of them during 1984–1992.

In 2022, a new borehole was drilled in the Akshiirak area down to a depth of 31 metres. We present the instrumentation together with first results of the measurements. We compare the newly obtained data with the old data from the period in the 1980/90s, which reveals a considerable increase in ground temperatures. Furthermore, we also compare the structural information from the extracted permafrost core to the results from our geophysical surveys taken in the year 2022. The results from this new site are furthermore compared to those obtained in boreholes in other mountain regions.

Permafrost Changes in Alaska: Past, Present and Future

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Abstract

Climate warming promotes an increase in the permafrost temperature and active layer thickness, which in turn affect the stability of northern ecosystems, threaten infrastructure, and cause the release of additional greenhouse gases into the atmosphere. The timing and rate of permafrost degradation are two of the major factors in determining the anticipated negative impacts of climate warming on the Arctic ecosystems and infrastructure. Long-term permafrost temperature data are available from the Geophysical Institute UAF permafrost monitoring network which was established by Prof. Emeritus T.E. Osterkamp in the 1970s – 1980s. The results of almost 40 years of permafrost and active layer temperature observations along the Alaskan Permafrost-Ecological Transect will be presented in this paper. Most of the sites in Alaska show substantial warming of permafrost since the 1980s. The magnitude of warming has varied with location, but was typically from 0.5 to 4 °C. However, this warming was not linear in time and not spatially uniform. While permafrost warming was more or less continuous on the North Slope of Alaska with a rate between 0.2 to 1°C per decade, permafrost temperatures in the Alaskan Interior started to experience a slight cooling in the 2000s that has continued during the first half of the 2010s. The warming resumed in the mid-2010s. By 2020, new record highs for the entire period of temperature measurements at 15 and 20 m depth were recorded at all locations. This warming has triggered near-surface permafrost degradation and talik development in many locations in the Alaskan Interior and in the north-west of Alaska with adverse consequences for ground surface stability. The talik starts to form when the depth of potential seasonal ground thawing exceeds the depth of potential freezing. The timing of talik formation in northern Alaska will depend on the future climate trajectory.

Temporal and spatial patterns of permafrost phenomena during the operation of railways in the southern part of the Bolshezemelskaya tundra in a changing climate

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Abstract

Recently, the problem of temporal and spatial patterns of manifestations of geocryological processes during the operation of railways has been of great interest, which is of particular importance for the areas of permafrost distribution. This problem was considered on the example of a railway in the southern part of the Bolshezemelskaya Tundra. In this work, the scientific and methodological foundations for assessing the state and forecasting the development of the natural and technical system of the cryolithozone of Russia were formed, taking into account the features of the structure and properties of frozen rocks in conditions of climatic changes and increasing anthropogenic load. In particular, it was found that the repeatability of subsidence on different sections of the railway embankment in different years is associated with different leading cryogenic processes and requires special geocryological zoning of the territory adjacent to the railway track to develop an engineering protection strategy. Criteria for ranking sections with embankment subsidence according to their degree of danger are proposed. A unique approach of special geocryological zoning has been developed, which is used in conjunction with the organization of geotechnical and geocryological monitoring, as well as with the development of geocryological forecasting. All this makes it possible to assess the significance of extreme climatic and man-made impacts, as well as long-term trends in changing the activity of geocryological processes. In particular, it was revealed that long-term climate changes lead to background changes in geocryological conditions (primarily the temperature regime of rocks), and extreme climatic events and variable anthropogenic loads cause activation or attenuation of cryogenic processes.

A decade of mountain permafrost monitoring in the French Alps from the PermaFrance network

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Abstract

Monitoring systems installed worldwide within the Global Terrestrial Network for Permafrost (GTN-P) have recorded permafrost warming and active layer thickening at the global scale since the 1980s. In this communication, we will present a decade of permafrost monitoring in the French Alps led within the PermaFrance network. Permafrost temperature (PT) and active layer thickness (ALT) are presented for 9 boreholes spread over 4 sites: the Aiguille du Midi (3842 m a.s.l.) and the Aiguille des Grands Montets (3296 m a.s.l.) in the Mont Blanc massif, the Deux Alpes (2700-3100 m a.s.l.) in the Ecrins massif, and the Grande Motte (≈ 3500 m a.s.l) in the Vanoise massif. They monitor ground temperature in different type of ground and topographic settings: near-vertical rock wall, flat bedrock and rock glacier. Six of these boreholes have monitored PT and ALT over more than 10 years. Analysis of the 2011-2020 decade shows that ice-poor and cold permafrost (high-elevated north-facing rock walls) have registered permafrost warming of up to > 1°C at 10 m depth, which is among the highest PT increase reported at the global scale. Ice-rich permafrost (rock glacier) registered stable melting point temperature. Within this reference decade, ALT increased at all boreholes except one in ice-rich permafrost (at the Deux Alpes), especially since summer 2015, by up to 50 % since the first year of measurement for ice poor permafrost, and by 34 % in ice-rich permafrost. Linear trends suggest active layer thickening of + 2 m within this decade for some ice-poor rock walls, independently of their thermal state (cold or warm permafrost). Besides the decadal analysis, specific ALT patterns measured during the particularly hot summer and year of 2022 will be discussed. The data show a large variety of permafrost patterns and evolution with significant intraregional and local differences. Ice poor and ice-rich permafrost show distinct evolution features, with a more straightforward response to climate signals of both the ALT and PT for the first case, compared to stable PT and a threshold-effect in ALT evolution for the second case. Some peculiar responses can be attributed to snow controls with evidence of favourable conditions for active layer thickening under early snow melting in spring.

35-years of coastal permafrost warming in Svalbard – analysis of two, 70-100 m deep, boreholes

Kjersti Gleditsch Gisnås (Norwegian Geotechnical Institute), Graham Lewis Gilbert (Norwegian Geotechnical Institute) and Ketil Isaksen (The Norwegian Meteorological Institute).

Abstract

In western Svalbard, mean annual air temperatures have increased by 4 to 5 °C since the middle 1980s. This has significant implications for permafrost conditions – which in turn impact the stability of local infrastructure and the frequency and magnitude of natural hazard events. In connection with the International Polar Year (2007-2009), many monitoring stations were established to observe the thermal state of permafrost, including in Svalbard. Most of these sites focus on permafrost conditions within the near surface, with few sites monitoring conditions deeper than ca. 20 m to 25 m depth. Monitoring sites with time series longer than 20 years, and sites with information about deep permafrost temperatures, are sparse.

In the late-1980s, the Norwegian Geotechnical Institute (NGI) instrumented boreholes at four sites in Svalbard, to between 70 m and 100 m depth. The purpose was to investigate permafrost conditions in the coastal zone in Longyearbyen and Svea in connection with development of the local coal mining industry. Two boreholes remain operational today, one in Longyearbyen and one in Svea. These boreholes are near to sea level in saline sediments and are ca. 20 m and 200 m from the fjord, respectively. Temperatures in the boreholes were recorded manually and opportunistically until ca. 2003. In 2018, the sites were instrumented with digital dataloggers to record permafrost temperatures each day.

Significant warming of the permafrost is observed down to 25 m depth at the site in Longyearbyen and down to 50 m depth in Svea. Average decadal temperature increases at 10 m depth for the period between 2002 – 2022 are 0.5 and 0.6 °C/decade for Longyearbyen and Svea, respectively. In comparison, the 10 m temperatures increased by 0.3 and 0.5 °C/decade in the period 1988 – 2018. Thus, we record a significant acceleration of the warming during the past 35 years.

Microtopography and soil temperature regime in the northern taiga landscapes of Western Siberia

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Abstract

West Siberian wetlands act as important indicator and regulator of climate change on a global scale. The northern taiga of the sporadic permafrost is one of the most warming-sensitive regions undergoing dramatic changes. Carbon cycling in wetlands is strongly affected by hydrology, in addition to temperature and associated with microtopography. Taking into account these factors in permafrost regions is necessary for global soil-climate modeling. In this work, we quantitatively assessed the soil temperature regimes in the dominant microrelief forms within different landscape types (flat and large mound bogs, drained lake bottoms, and small river floodplains) at the Khanymey Research Station (Interact Network). After topographic mapping, photogrammetry, and thermometric observations, we related the soil thermal regimes to snow cover, water pathways, peat thickness, ground vegetation, and anthropogenic impact. Very strong limnicity of Khanymey's watershed leads to strong warming of soils in fens that receive water from lakes. In the absence of lakes, the frozen soils proportion would be much higher than current 10-15 %. Most contrasting thermal conditions are observed on the flat mound bog, under approximately similar peat thickness on mounds and in fens. Thick peat deposits, concave forms and lichen cover lead to coldest temperatures on peat mounds. In fens, the sphagnum cover decreases the temperatures during summer. The soils developed on drained lakes freeze to low depth (30-40 cm, even during cold winter) due to lack of peat and efficient insolation by thick snow cover retained on high carix grass. Soil temperature regimes and temporal dynamics of thawing for two adjacent forms of microrelief with similar vegetation cover may be so different as if they were in different climate zones. Under continuous climate warming, the active layer's deepening will occur at different rates with a maximum at the border of frozen concave forms and their decrease towards the central parts.

Spatial Autocorrelation Analysis of 28 Years of Active Layer Thickness Data from North-Central Alaska

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Abstract

Active layer thickness (ALT) measurements have been collected at the end of the summer season on Alaska's North Slope for 28 years. Data were gathered at seven 1 km^2 Circumpolar Active Monitoring (CALM) grids using a systematic sampling strategy. Sites are located in two main physiographic provinces (coastal plain and foothills) and represent the climatic, geomorphic, and landscape structure of the region. Two-dimensional autocorrelation analysis, conducted previously in 1995 and 1996, demonstrated that the main determinant of ALT is moisture variation controlled by topographic elements. The variability of ALT contrasts strongly between the two main physiographic provinces. A more detailed study involving an extended (1995-2022) dataset showed the long-term temporal and spatial variations of the ALT data within each grid, using two-dimensional correlograms. Trend analysis was conducted for five-year segments (1995-2000; 2000-2005, etc.), allowing comparison of multi-year periods and evaluation of the persistence of ALT changes. ALT patterns have more pronounced and persistent spatial structure on the coastal plain than in the northern foothills of the Brooks Range. Significant interannual differences in spatial patterns are related primarily to variations in cumulative summer warmth and precipitation. Our results indicate that site-specific factors, particularly topography and vegetation cover, impact the active layer system over multi-decadal time periods. Two-dimensional correlograms are useful tools for detecting and analyzing interannual variations in ALT. In combination with knowledge about terrain and hydrologic characteristics within a study area, these procedures can be used to infer the processes responsible for changes of ALT. If repeated over a series of years, analysis of spatial time series is capable of discerning between high-frequency (interannual) variability and gradual changes related to longer-term climatic change.

Recent developments in near real-time monitoring of warming and degrading permafrost in Norway and on Svalbard

Ketil Isaksen (Norwegian Meteorological Institute), Julia Lutz (Norwegian Meteorological Institute), Julia Boike (Alfred Wegener Institute), Hanne H. Christiansen (The University Centre in Svalbard), Bernd Etzelmüller (University of Oslo), Steinar Eastwood (Norwegian Meteorological Institute), Atle Sørensen (Norwegian Meteorological Institute), Øystein Godøy (Norwegian Meteorological Institute), Signe Aaboe (Norwegian Meteorological Institute) and Lara Ferrighi (Norwegian Meteorological Institute).

Abstract

25 years ago, the first deep instrumented permafrost boreholes were established on Svalbard and in Norway for climate-related monitoring. They provided the first opportunity to examine temporal trends, adding a critical new dimension to current knowledge of permafrost conditions in northern Europe. Since then, additional instrumented boreholes have been established at remote locations on Svalbard and in Norway's high mountain regions. Such monitoring is nowadays widely practised in the World's permafrost regions, but most data retrieval is done manually on-site annually. This causes delays in adding data into databases or in making them available, meaning that the latest available data can quickly be one to two years old. This may be a bottleneck for global monitoring programs and for users that need the latest permafrost data.

Operational permafrost monitoring is a new service for long-term systematic climate monitoring of the cryosphere and marks a transition of research-based observing systems into sustained, operational services. On https://cryo.met.no, we recently developed products for visualising such near real-time permafrost temperature data. The latest permafrost temperatures are compared to summary statistics calculated from the sites ground temperature data record, providing median, confidence intervals, and extremes. There are also operational weather stations with extended measurement programs at the same locations as the permafrost boreholes. This collocated monitoring provides daily updated data to study and monitor the current state, trends and the effects of e.g. extreme climate events on the warming and degrading permafrost. It provides information more rapidly than at any time in the past, and may contribute to early detection of e.g. record-thick active layer, pronounced permafrost temperature increases and talik development due to extreme events. Additionally, it makes permafrost data more visible and available to other research communities, just as it can support early warning systems for natural hazards caused by changes in permafrost

The response of ground temperatures to a rising atmospheric 0 °C isotherm

Robert Kenner (WSL-Institute for Snow and Avalanche Research), Mohsen Bazargan (WSL-Institute for Snow and Avalanche Research), Jeannette Nötzli (WSL-Institute for Snow and Avalanche Research) and Simon Scherrer (Bundesamt für Meteorologie und Klimatologie MeteoSchweiz).

Abstract

Ground temperatures in alpine terrain are variable over short distances, particularly due to differences in elevation and incoming solar radiation. To allow direct comparisons between sites, regions, and disciplines, we use a new parameter called the potential 0 °C isotherm (PZDI) in ground. This parameter is aspect- and elevation-independent and represents a geo-projection of ground temperatures. It was used to aggregate several ground temperature datasets from the European Alps. We analyse the reaction of the PZDI in the European Alps at different depths to changes in atmospheric temperature, represented by the atmospheric 0 °C isotherm (AZDI). The close relation between both datasets was used to design a ground thermal model, which is driven by anomalies of the AZDI. This allowed a reconstruction of the mean ground temperature development in the periglacial zone of the European Alps since 1955, thus adding 30 years to the oldest existing borehole temperature time series measured in permafrost. With one exception, existing ground temperature time series in the Alps start after a major warming event at the end of the 1980s, which was thus not sufficiently captured in the datasets. As a result of this warming event, about 60 % of the permafrost above 14 m depth has already thawed within the last 40 years. About half of the remaining permafrost area cannot persist under the current climate conditions. This permafrost will thaw to depths of at least 14 m in the coming decade, according to our model.

Active layer thickness database for the Lena Delta region, Northeastern Siberia

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Abstract

The active layer thickness (ALT) is one of currently two Essential Climate Variables related directly to permafrost regions as defined by the Global Climate Observing System at the World Meteorological Organization. The ALT dynamics are being monitored across the Arctic to better understand climate change impacts on landscape, permafrost, hydrology, vegetation, and soil biogeochemistry. We aimed at creating a comprehensive ALT database for the Lena Delta region based on published and unpublished data collected during Russian and joint German-Russian expeditions since 1991. The ALT database contains data from different areas of the Lena Delta with clustering in research-intensive areas including Muostakh Island and Bykovsky Peninsula. ALT data were collected by researchers with different tasks (sampling of exposures, drilled boreholes, soil and vegetation surveys, validation of remote sensing data, etc.) and include opportunistic single as well as targeted ALT transects or grid measurements. The data represent various landscapes formed by different types of deposits (Holocene Lena Delta terraces, remnants of Yedoma Ice Complex, etc.) characterized by various relief positions, microtopography, soil and vegetation cover. Collected ALT data show landscape unit-dependent variabilities, intraseasonal fluctuations, and long-term trends. For some sites repeated ALT measurements were conducted at the same location. For Bykovsky Peninsula, Yedoma upland profiles had average ALT of 39±4.1 cm in 2015, 32±5.6 cm in 2016, and 42±9.1 cm in 2021. For comparison, the CALM Yedoma site located 5 km southeast shows an average ALT of 34, 29 and 36 cm in 2015, 2016 and 2021, respectively. Our new ALT database presents a valuable synthesis of soil surface dynamics in an important Arctic region for the last decades in addition to CALM sites and published literature data for other permafrost regions. The data may be useful for parametrization or validation of permafrost modeling results and remote sensing studies.

First decade of PERMACHILE network: high altitude ground surface monitoring along the Andes.

Balázs Nagy (Eötvös Loránd University, Budapest, Hungary & PermaChile network) and Sebastián Ruiz-Pereira (DIHA, Pontificia Universidad Católica de Chile & PermaChile network).

Abstract

The PermaChile monitoring network is a systematic survey on signs and consequences of climate change on permafrost environments. It assembles a database to provide strategic decision-making assistance for water and land management designs. The Chilean Andes offers unique landscape types for both altitudinal and latitudinal analyses, ranging from hyperarid environment of the tropical Dry Andes to the Antarctic polar tundra. The first monitoring site of the PermaChile program started operating in 2012 on the highest mountain massif in Chile, Ojos del Salado, rising in an arid environment without any active glaciers. The choice of location was justified by the fact that we can also consider the mountain giants of the Dry Andes higher than 6000 meters a.s.l. as frozen water towers. The main activity from the high Puna Plateau level (4,200 m a.s.l.) to the top of the mountain (6893 m a.s.l.) is to monitor ground temperatures, active-layer evolution layer, water content and permafrost extent. This implies understanding the length and variation of thawing periods, and subsurface ice. The monitoring site also provided an opportunity to explain the formation of the highest wet habitats on Earth, above 5,800 m a.s.l., to explore their wildlife, but also to analyse Martian analogues in a dry high-altitude environment and even test Mars field analyses. A new location of the PermaChile program (from early 2020) is a monitoring system in the Torres del Paine National Park in the Patagonian Andes, which analyses subsurface heat management and physical changes in the tundra above 800 m a.s.l. Here, the pressure of strong outdoor tourism and a sensitive ecosystem also justify the installation of a series of measuring sites.

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Permafrost thermal regime across periglacial landforms in Nordenskiöld Land, Svalbard, 2008-2022

Sarah Marie Strand (The University Centre in Svalbard (UNIS) and Hanne H. Christiansen (The University Centre in Svalbard (UNIS).

Abstract

Increased understanding of the variability and controls of ground thermal regime in different periglacial landforms is needed to understand present and future permafrost change across the heterogenous terrestrial Arctic. In situ permafrost measurements are generally sparse in the high Arctic, meaning results from individual study sites are applied to areas with varying landforms, topography, geography and climate. The Svalbard Nordenskiöld Land Permafrost Observatory provides decade-plus ground temperature timeseries from boreholes that are uniquely representative of the region, its landscape and periglacial landform variability. This study presents the long-term trends in permafrost temperature observed at the Nordenskiöld Land Permafrost Observatory sites, compares these trends to observed climatic changes, and differentiates the climate sensitivity of the studied periglacial landforms. The boreholes established in the observatory cover (a) the variety of periglacial landforms found on Svalbard, (b) Spitsbergen's climatic gradient, and (c) an elevation gradient from near sea level to mountaintops. The studied landforms with boreholes include: ice wedge polygon, loess terrace, mountaintop blockfield, pingo, rock glacier, solifluction sheet, and strandflat. The majority of the boreholes were established as part of the International Polar Year (IPY) 2007-2009, with additional boreholes being added in subsequent years. Five of the studied boreholes are approximately 10 m in depth, and four are 19 m deep or more. During the 2008-2022 study period, mean annual air temperature at the Svalbard airport, Longyearbyen, averaged 1.2 °C warmer than that of the 1991-2020 normal period. From 2008-2022, almost all of the studied sites exhibit a steady increase in permafrost temperatures, with a magnitude of ca. 1 °C at 20 m depth.

Potential integration of Automated Electrical Resistivity Tomography data into GTN-P and CALM monitoring networks: Case Studies from the Western Peninsula, Antarctica

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Abstract

Permafrost is a widespread phenomenon in the cold regions of the globe and is clearly under-represented in global monitoring networks. GTN-P and CALM monitoring networks observe the response of the active layer and permafrost to climate change over long time scales, with the former mainly focusing on borehole temperature monitoring and the latter involving manual measurements of thaw depth, usually once per year during summer using mechanical probes. Major limitations of these approaches are the one-dimensional nature of ground temperature measurement, the lack of temporal information about ground ice content changes, and the practical difficulties associated with probing coarse and deep soils. Electrical Resistivity Tomography (ERT) has become a standard tool in permafrost research, as the strong contrast in measured electrical resistivity for unfrozen and frozen material allows the detection and monitoring of permafrost and active layer dynamics in two or three dimensions. Automated ERT systems (A-ERT) are a logical extension of manually repeated measurements, enabling the continuous acquisition of ERT measurements. Such stations rarely exist worldwide, as the system must be low-cost, robust, and with low power usage to operate and withstand harsh conditions in polar and mountain areas. In this context, we developed low-cost, low-power, and robust A-ERT systems and installed them in the western Antarctic Peninsula at sites associated with the existing GTN-P and CALM monitoring networks. Based on the analysis of obtained A-ERT datasets we show that it is possible to i) run A-ERT monitoring stations in harsh Antarctic environments and obtain high-resolution ERT data with high quality, ii) monitor subsurface freezing and thawing processes in high temporal detail, iii) map the spatial and temporal variability in thaw depth with high resolution, and iv) detect the impact of short-lived extreme meteorological events on active layer dynamics.

Geotechnical monitoring of geocryological processes during the operation of railways in the southern part of the Bolshezemelskaya tundra

Alina Gorbunova (Lomonosov Moscow State University), Guzel Zaripova (Lomonosov Moscow State University), Vladislav Isaev (Lomonosov Moscow State University), Vladimir Mansky (Lomonosov Moscow State University), Roman Sobin (Lomonosov Moscow State University) and Alla Bezdelova (Lomonosov Moscow State University).

Abstract

Experience in the construction and operation of railways in the cryolithozone shows that the causes of deformations of the roadbed are found not only in the embankment and its base, but also in the zone of influence of the road on the surrounding landscape. The main causes of the destruction of the body of the roadbed are: subsidence and uneven precipitation of thawing, spreading of the embankment of the roadbed, landslide of roadsides and slopes, destruction of slopes under the influence of processes such as thermal erosion, frost heaving, ice formation, solifluction. To minimize the deformations of the roadbed, special examinations should be carried out. The content of the survey consists in assessing the condition of the structure, as well as in conducting a complex of field geocryological, geological, geomorphological and geobotanical studies. However, a one-time examination may not be enough for such a diagnosis. Therefore, the authors consider it important to organize comprehensive monitoring in areas with chronic deformities. The paper presents the results of a survey of the Northern Railway section over three years to determine the causes of deformations of railway track structures, identify areas of development of cryogenic processes and phenomena in the roadbed, as well as to observe man-made changes in the surrounding natural landscapes that may cause the development of road deformation processes in the future.

Thermal status of permafrost peatlands in northern Fennoscandia

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Abstract

Peatlands cover vast areas in the permafrost region and store large amounts of soil organic carbon. Circum-Arctic permafrost warming has occurred in recent decades. In northern Swedish peatlands, permafrost temperatures are now close to 0 °C. To better understand how these ecosystems will respond to ongoing climate change and be able to assess future carbon-climate feedbacks more information on permafrost temperatures and trends are needed from regions with poor data coverage, like northern Fennoscandia. At five permafrost peatland sites located along a topographic and climatic gradient from sea-level maritime conditions at the Norwegian Barents Sea coast to upland continental settings in northern Norway, Finland and Sweden ground temperatures down to 2 m depth have been recorded every 3 hours since 2019. The first results unexpectedly suggested slightly colder permafrost at the more maritime sites, despite approximately 4-5 °C warmer mean annual air temperatures compared to at the continental sites. To explore the reasons for this, snow depth stakes and field cameras, that also monitor air temperature, were installed at four of the sites in 2021. The same year the permafrost monitoring was extended at two of the sites with additional thermistor cables in palsas that have started to degrade through surface cracking, in order to better project how destabilized palsas will be impacted by future climate change and at what rate. In the intact palsas and peat plateaus ground temperatures have increased by ~0.05 °C at 2 m depth between 2019-2022.

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