Impact of large herbivores on permafrost soil carbon storage

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In our study we examined the effects of large herbivorous animals on soil carbon storage in a permafrost landscape in northeastern Siberia. To assess the impact of those animals on the soil carbon storage we examined soil profiles and permafrost cores from areas with different grazing intensities within landscape units, more specific a drained thermokarst basin and the surrounding uplands. To do so, we chose our study sites in the Pleistocene Park near Chersky, as this area provides known animal densities and also fenced areas, which allowed us to compare between intensively grazed, extensively grazed and non-grazed sites on small spatial scale.

We found significantly higher carbon (TOC) values at those sites with intensive animal grazing, compared to non-grazed sites, especially within the active layer. Also, vegetation was shifted on intensively grazed sites, from shrubby tundra vegetation to grasslands. In addition, active layer depth was smaller on grazed sites.

We conclude that the animals improve carbon storage and permafrost stability by changing the vegetation and removing or trampling down snow in winter, which both leads to colder ground conditions and hence reduces organic matter decomposition.

This could hint on possible strategies to locally prevent permafrost thaw by rewilding or an intensification of animal husbandry in tundra areas.

The Great Unknown: Thermokarst Lakes and Its Response to Permafrost Carbon Feedback Cycle

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Permafrost, which is also called perennially frozen ground, is soil, sediment, or rock that remains at or below 0°C for at least two consecutive years and occupies approximately 24 percent of the exposed land surface of the Northern Hemisphere. The Arctic is dramatically warming, especially over the past 50 years that its temperature has risen at a rate more than twice the global average. This also creates a great risk for permafrost zones which have a significant carbon store, estimating about 1.500 gigatonnes of carbon, that is twice the amount currently present in the atmosphere, frozen in the permafrost. Abrupt thawing of permafrost in the Arctic, thus will double the previous predictions of potential carbon emissions, and is rapidly changing the landscape as well as the ecology of the circumpolar North. An obvious consequences of permafrost degradation, thermokarst lakes, which are also known as thaw lakes of ice-rich permafrost, are net greenhouse gas sources as century-old carbon deposits become bioavailable and are mineralized to CO_2 and CH_4. However, its response to feedback loops in the Arctic still remains uncertain. In a thermokarst system, for instance, a ground ice melt causes the land surface to subside which changes the hydrodynamics of the landscape in return. Due to the further climate change, water balance, or topography affects water bodies of all sizes and may cause diverse trends of waterbodies shrinking and growing which means releasing long-term carbon stocks into the atmosphere, thereby initiating a positive climate feedback. Besides, there are also potential risks to affect local communities and their livelihood, including the loss of Arctic wildlife habitat. This study focuses on literature review of thermokarst lakes in the permafrost lowlands, particularly the Seward Peninsula, Alaska to investigate the relationship between these waterbody differentiation and changes in the Arctic ecosystems.

The transition to a permafrost-free Arctic - revelations from deep soil cores

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Field and laboratory studies aimed at forecasting greenhouse gas emissions from thawing permafrost soils commonly contrast emissions from the seasonally thawed active layer to those from underlying permafrost. However, previous work in the continuous permafrost zone has highlighted the existence of an ice-rich transition zone that can exceed 30% of the active layer thickness and thermally isolates the underlying substrate. Substrate in the transition zone undergoes state changes from seasonally thawed to perennially frozen to over multiple years and may be identified by the presence of ataxitic (suspended) ice.

Here, we show that measurements of the isotopic composition of bulk soil organic matter (Δ14C, δ13C, δ15N) in deep soil cores can be used to identify the long-term position of the active layer, transition zone, and permafrost. In graminoid tundra, the depth of the transition zone almost doubles the depth of intermittently frozen or thawed substrate.

Our data also demonstrates that the transition zone is not just enriched in ice, but also carbon and nitrogen (and likely microbes) and that transition zone emission of CO2 and N2O exceed those from both the active layer and permafrost. Thus, rapid thaw and drainage of the transition zone in the next decades may generate a pulse of greenhouse gas emissions that may not be sustained with deeper thaw. However, an analysis of the International Soil Radiocarbon Database shows that the majority of radiocarbon measurements have focused on 0 to 1.2 m depth.

Taken together, our analyses identify an urgent need and opportunity for the permafrost community to reconsider the 2-layer permafrost model and to study of deeper soil and sediment cores to constrain the greenhouse gas feedback to permafrost thaw and the role of permafrost in a warming world.

Slope failure at the base of permafrost increasing frequency and magnitude of thaw-driven mass-wasting across discontinuous permafrost terrain in the central Mackenzie Valley foothills, NWT

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Widespread hillslope mass-wasting in the extensive discontinuous permafrost zone of the (fluvially-incised) central Mackenzie Mountain foothills has significantly increased in frequency and size in the past 15 years. The increase in thaw-driven mass-wasting is largely a function of increasing air and ground temperatures, precipitation, and legacy thermal disturbance from forest fire activity. In contrast to retrogressive thaw slumps, which initiate and develop from the progressive top-down and lateral thaw of permafrost, we identify an increasing frequency and magnitude of deep-seated translational permafrost landslides with failure planes at depths up to 10s of meters below the active layer. We identify a suite of thaw-driven processes that involve basal permafrost sliding, thaw-driven fluidized flow, and continued scarp enlargement by retrogressive failure. Thaw-driven detachment of materials at depth produce the capacity to rapidly transport large amounts of frozen sediment downslope in a blocky manner, often resulting in individual disturbances covering 10s of hectares across varied permafrost terrain. Characteristic of these features is the presence of conical mounds up to 10 m high on their debris tongues, termed molards, that are produced from the thawing of translocated ice-rich permafrost blocks. We employ high-resolution satellite and UAV imagery, along with repeat digital elevation models, geological observations, and electrical resistivity tomography surveys to infer that 'bottom-up' thaw from the base of the permafrost table is driving the initiation of these features. We present these observations and put forward a conceptual framework outlining the setting and basal permafrost failure mechanisms of these features. Further understanding of the setting and variability of permafrost mass-wasting and landscape trajectories has implications at all scales, not least of which involves assessing permafrost carbon release through hillslope thermokarst.

Vertical distribution of excess ice in icy sediments and its statistical estimation from geotechnical data (Tuktoyaktuk Coastlands and Anderson Plain, Northwest Territories)

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Excess ground ice can be found distributed within icy sediments and in the form of massive ice, and is an important variable to quantify as it strongly influences the landscape's response to permafrost thaw and the release of carbon stored in frozen soils. Thawing of excess ice in the western Canadian Arctic has led to thaw subsidence and abrupt thaw events, such as retrogressive thaw slumps and the formation of thermokarst lakes. These processes play an important role in generating carbon emissions to the atmosphere as they expose previously frozen carbon to microbial decomposition and fluvial export, and alter local to regional topography and hydrology. A large amount of geotechnical data is available in the Tuktoyaktuk Coastlands, however field assessments typically only involve the estimation of visible ice. To add more value to these datasets, a cryostratigraphic dataset collected along the Inuvik-Tuktoyaktuk Highway (n = 566 boreholes) is used to develop and parameterize a beta regression model to predict excess ice content of icy sediments based on depth, visible ice content, materials, and Quaternary deposits. The predictions are compared to recorded massive ice intervals and show that excess ice within icy sediments can contribute up to 65% of the excess ice and thaw strain within the first 10 meters from the surface in this area. Abrupt thaw events in ice-rich soils are known to be influential to the carbon cycle but are not well represented in permafrost models. This new modeling approach to estimate the distribution and characteristics of excess ground ice found as massive ice and within icy sediments may help incorporate better representations of abrupt or gradual thaw processes in coupled models and help account for the additional carbon released in the atmosphere.

Soil and plant community characteristics across successional stages of ice-wedge degradation and re-stabilization in the tundra of northern Alaska

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Recent warming has resulted in ice-wedge thaw in polygonal landscapes of northern Alaska, leading to changing topography and hydrology. Soil warming and altered hydrology influence the availability and transport of nitrogen, with consequential impacts on vegetation. Nitrogen cycling can vary substantially across successional stages of ice-wedge degradation and re-stabilization. Resultant changes in plant communities and biomass can lead to feedbacks of further degradation or stabilization. This study aims to understand how soils and vegetation interact across ice-wedge successional stages at two sites in Arctic Alaskan tundra (Jago River and Prudhoe Bay). Jago is an acidic Arctic tundra site with some topographic heterogeneity and distinct vegetation types across the different successional stages of ice-wedge degradation and re-stabilization. Prudhoe Bay is an alkaline, urban site with less topographic heterogeneity and less distinct vegetation types across stages. We measured soil moisture, total soil C and N, net N mineralization, and soil NO3- and NH4+ at the drier ice-wedge successional sites. We harvested plant biomass from all of the successional stages, and Eriophorum angustifolium was used as a benchmark species to compare across stages. Jago soils had greater soil %N by mass compared to Prudhoe Bay, but due to differences in bulk density, Prudhoe Bay soils had greater total C and N. At Jago, inorganic N availability (resin probes) was greater at sites with some degree of degradation, but the opposite was true for Prudhoe Bay. There is a clear shift in plant functional groups toward dominance by hydrophilic sedges and mosses with increasing degradation at both locations, and greater overall vegetation biomass at Jago. At Jago, the N content of E. angustifolium is elevated in degrading sites, but this is less distinct at Prudhoe Bay. These data suggest that ice-wedge degradation may affect soil characteristics by increasing N availability and transport in sites that have experienced degradation, and therefore may play a key role in vegetation response to climate warming in dynamic, heterogeneous Arctic ecosystems. Our data suggest, however, that these trends may be heavily dependent on specific local conditions.

Submarine Permafrost as a Long-term Late Quaternary Carbon Sink

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Organic carbon (OC) stored in Arctic continental shelf sediment is a climate-sensitive but poorly quantified component of the global carbon cycle. The current interglacial period means that most shelf permafrost, along with its OC, is currently warmer than -2 °C, and therefore susceptible to small additional warming in the near future. Estimating how much OC is potentially stored in subsea permafrost is thus key to a quantitative understanding of potential impacts of permafrost thaw on carbon mobilization in a warming Arctic.

We developed a process-based model of permafrost distribution and organic matter (OM) sedimentation and decomposition to estimate the contribution of submarine permafrost to Arctic shelf organic carbon stocks. Driven by Earth System Model forcing, our model calculates 1D heat flow below the earth surface, ice caps and sea bed, and uses a reactivity continuum model of OM decomposition. We restrict our modeling to sediment that was buried within the last four glacial cycles (450 kyr), and therefore neglect OC stocks deeper than about 100 m, including any gas hydrates.

Restricting OM decomposition to the liquid habitat for microbial activity in the sediment, we estimated that permafrost below the Arctic Shelf stores at least as much OC as the terrestrial counterpart at pre-industrial time, and probably in the range of twice to three times as much OC. We compared the effect of varying the OC sedimentation rates and OC reactivity. Higher reactivity in marine sediments combined with lower ice contents to increase the rate of OM decomposition, relative to sediment deposited in terrestrial settings. As a result, permafrost in our model preserved a greater proportion of marine OM from decomposition while having little effect (< 5%) on the amount of recalcitrant terrestrial OC. These differences in sedimentation rate and reactivity influence the distribution of OC preservation on the Arctic shelf.

Our modeling shows that subsea permafrost is a relevant OC stock and that more research is needed to understand microbial OM decomposition in cold but not necessarily frozen sediments. Given that deeper deposits and gas hydrates are not included, we provide conservative estimates of Arctic shelf OC stocks and suggest that the shelves have acted as long-term carbon sinks over multiple glacial--interglacial cycles.

Ice wedges as a winter paleotemperature proxy: limitations and local noise in their δ18O record.

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Recently, ice wedge research has shifted towards their use as paleoclimate proxies, using the D-18O signature recorded in the wedge ice to reconstruct past Arctic winter climates. The purpose of this research is to investigate the validity of the ice wedge stable isotope signature as a valid proxy for winter climate. Ice wedges in Eureka, Nunavut, were analyzed for DOC 14C and D-18O. Radiocarbon ages extracted from eight ice wedges show peripheral cracking in one-quarter of the sampled wedges. Comparison of sampled ice wedges ages to the MacKay (1974) Gaussian distribution suggests that ice wedges of medium widths (1-2 m) are more reliable for paleoclimate dating because of a higher probability of cracking. Cracking irregularity and peripheral cracking suggest that ice wedge D-18O should rely on veinlets' direct dating to establish a proper chronology. Symmetry analysis of the ice wedge D-18O showed a statistically different average δ18O at depth within three of the four sampled ice wedges. Additionally, the δ18O signature within the sampled ice wedges shows an increasing trend from the center to the wedge's edge. This change can be attributed to increased moisture and mixing near the intersection between ice wedge and icy-permafrost. Consequently, against ice cap Agassiz δ18O, the ice wedge isotopes show a high degree of variability throughout the Quaternary and are attributed to the random timing of meltwater fractionation infiltrating the ice wedge crack. Finally, it is proposed that a smoothing spline be used with multiple ice wedge δ18O records to create a robust and reliable chronology.

Quantifying Erosional Dynamics in Ice-Wedge Networks with Computer Vision and Graph Theory

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In the face of a warming Arctic, ice-rich permafrost landscapes are undergoing rapid changes. Ice-wedge polygonal networks in Arctic lowlands are especially vulnerable and melting ice wedges can induce widespread subsidence and trough formation. The transition from low-centered to high-centered polygons can have important implications on surface hydrology, as the connectivity of the newly forming trough networks determines the rate of drainage for these lowland landscapes. However, quantifying such dynamics can be challenging, as even small-scale changes can have far-reaching implications for the larger scale hydrology of a region. In this talk, we introduce an automated workflow that enables quantification of trough network dynamics in thaw-affected landscapes. We use methods from traditional computer vision to extract (a) the spatial pattern of the trough network and (b) the morphological parameters of trough width and depth from high-resolution digital terrain models. Finally, we (c) incorporate this information into graphs - a mathematical concept used to represent complex networks - and use graph analysis methods to determine progressing subsidence and trough formation. Based on a study area in the Anaktuvuk River Fire scar on the North Slope, Alaska, USA, we present the potentials and benefits of such graph algorithms for quantifying the erosional development of this thaw-affected landscape. In our study region, we observed an increase (+127%) in the number of discernible troughs as well as their connectivity (number of disconnected networks decreased by 89%) over the observed period of ten years. The average width of troughs has increased (+14.5%), while the depth has decreased (-12.5%). With this approach, for the first time, a large-scale analysis of such detailed ground-ice and hydrological surface dynamics is made possible.

Initial investigations of degrading peat plateaus in the central Mackenzie Valley, Northwest Territories

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Peat plateaus dissected by dendritic fluvial and fen networks are common landforms in the central Mackenzie Valley, NWT. These networks tend to be associated with sloping site conditions (up to ~ 3m per km), and are largely developed on moraine and glaciolacustrine sediments. These sites are often covered by tussocks, reindeer lichens (Cladonia sp.) and varying cover of open black spruce (Picea mariana). Field investigation of 3 sites in 2021 showed that peat thicknesses were ~ 2m with structureless pore ice, that was overlaying several metres of ice-rich diamict or glaciolacustrine sediments. Electrical resistivity tomography profiles indicate that permafrost is typically thin in these areas (5-12 m), and through-going taliks forming the channel network are common, and increase in frequency downslope. The taliks appear to extend under the margins of the peat plateaus adjacent to the taliks, and are commonly captured to form the dendritic network. There seems to be little evidence for surface disturbances, and local depressions on the surface appear to extend into the underlying ice-rich sediments and are very recent based on flooded black spruce (Picea mariana) and reindeer lichens (Cladonia sp.) within ponds. We hypothesize that these are slowly expanding thaw networks, likely driven by basal permafrost thaw near taliks.

Holocene Carbon Dynamics from a Permafrost Peatland in the Sporadic Permafrost Zone, Kenai Peninsula, Alaska

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Permafrost and landscape history, in addition to ground ice content, are increasingly identified as important components in predicting permafrost thaw trajectories. Together with cryostratigraphy, plant remains can provide useful information about past permafrost aggradation and thaw. We analyzed plant macrofossil assemblages, cryostratigraphy, and radiometric dating to reconstruct vegetation and permafrost history using peat cores from two permafrost peat plateaus and two adjacent collapse-scar bogs from a peatland complex in the sporadic permafrost zone on the Kenai Peninsula, Alaska. Organic matter content and bulk density are used to evaluate corresponding carbon dynamics. Preliminary results from the permafrost plateau suggest that permafrost aggraded syngenetically with peat accumulation during the early Holocene, but a possible unconformity characterized by mineral-rich sediment interrupted peat accumulation between ~9 to ~3.5 thousand years ago (ka). Evidence from cryostratigraphy and exceptional peat preservation below the mineral unconformity suggests that deep permafrost (>3 m) did not degrade during the Holocene. The resumption of peat accumulation is characterized by abundant rich fen macrofossils (e.g., Carex spp., Calliergon, Drepanocladus spp., Paludella squarrosa) above the mineral horizon suggest near-surface conditions were permafrost free and that permafrost re-aggraded in the late Holocene (<2.5 ka), as evidenced by an increase in taxa commonly on peat plateaus. In the collapse-scar bog similar peat preservation below the mineral unconformity, though unfrozen, suggests that permafrost thaw occurred recently with negligible post-thaw decomposition, possibly due to cold anoxic conditions at >3 m depth. The permafrost plateau is losing surface peat due to oxidation, likely as drainage increased to the adjacent collapse-scar bog. This loss suggests that for permafrost peatlands significantly impacted by recent thaw, remaining peat plateaus can rapidly lose carbon from the active layer before permafrost thaw occurs. These results also suggest that post-thaw peat carbon loss may be confined to the upper 1-2 m.

Circumpolar observations of thermokarst pool expansion from high-resolution satellite imagery

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One of the most conspicuous signals of climate change in high-latitude tundra is the expansion of thermokarst pools above melting ice wedges. Beyond expressing permafrost degradation, this process exerts strong feedbacks on subsequent thaw rates through a series of positive and negative feedbacks which play out over timespans of decades. Preliminary regional-scale modeling studies indicate that, when these feedbacks are accounted for, the mass of permafrost-affected carbon susceptible to thaw by 2100 may be as much as twelve times greater than otherwise expected. However, at the global scale, the magnitude of this effect is poorly constrained, due to a lack of historical observations. In this study, we assessed circumpolar thermokarst pool expansion from 2008-present at twenty-seven survey areas dispersed throughout the Arctic. Our workflow, based on convolutional neural networks paired with subsequent image processing operations, segmented thermokarst pools from submeter-resolution panchromatic imagery from the WorldView satellites. The results revealed that recent circumpolar pool expansion has been uneven but widespread, including in very cold settings. Among other findings, the observations indicate that topography plays a significant role in determining ice wedge vulnerability to climate change, as pool expansion was often concentrated in convex regions within upland landscapes. These data comprise a unique glimpse at recent thermokarst pool expansion around the Arctic and provide valuable context for evaluating the impact this process will have on rates of global permafrost thaw.

Shifts in plant-soil interactions following ice-rich permafrost thaw – implications for carbon storage

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Permafrost soils hold globally significant quantities of carbon that are experiencing enhanced decomposition due to surface warming, forming one of the most important biogeochemical feedbacks to future climates; however, the magnitude of this feedback remains poorly constrained. Current model predications indicate enhanced primary productivity within the vegetative community may initially offset microbially mediated carbon losses from permafrost ecosystems, but confidence in these projections is limited by the availability of empirical data. To address this knowledge gap, we evaluated the impacts of ice-rich permafrost thaw on plant-soil interactions in study systems spanning central Alaska, USA and southern Northwest Territories, Canada. To discern the role of thaw on limiting resources we characterized shifts in porewater chemistry (C and N species) and associated C emissions for two years in incubated permafrost soils. This work was complemented by an in situ simulated permafrost thaw resource pulse experiment, which quantified changes in belowground biogeochemistry, carbon emissions, as well as plant community composition and productivity. Our long-term incubation study demonstrated abrupt changes in porewater C and N quantity and quality following experimental thaw, with dissolved organic carbon and dissolved nitrogen concentrations 160% and 70% above mean values, respectively. Despite this, simulated in situ resource pulses did not affect ecosystem respiration and net ecosystem exchange of CO_2, although CH_4 production rates increased by 11-fold. Early signs of such thaw events were indicated by the vegetative community as an increase in graminoid and sphagna abundance and a decrease in ericoids. Taken together this research provides first-order mechanistic knowledge needed to further constrain the permafrost-carbon feedback and parameterize Earth System Models quantifying the warming potential of global permafrost decay.

Impacts of shrubification on ground temperatures and carbon cycling in a sub-arctic fen near Churchill, MB

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One of the fastest progressing environmental changes reported from permafrost areas is the proliferation of shrub species (shrubification), in tundra ecosystems. Changes in vegetation structure affect ground thermal regime and biogeochemical cycling but the nature of these relations are still poorly understood. This paper examines the impact of shrubification on ground temperatures and greenhouse gas production potential in a fen environment of the Hudson Bay Lowlands, near Churchill MB. Churchill is located near the latitudinal forest-tundra transition, in the continuous permafrost zone. The study site was dominated by Carex aquatilis but in some areas Betula Glandulosa has recently proliferated. We assessed shrubification rates in the Churchill area by evaluating NDVI (Mann-Kendall) trends using Landsat 5 to 8 to assess change from 1984 to present. We installed temperature sensors just below the ground surface in sedges and shrubs to assess differences in thermal regime. We collected active layer samples from shrub and sedge sites to perform incubations in anaerobic (4 weeks) and aerobic (4 days) conditions. Gas samples were analysed for CO2 and CH4 through gas chromatography. Preliminary results show differences in shrubification rates between terrain units. At our study site in the fen (intermediate shrubification rates), mean ground surface temperature was more than 3°C warmer under Betula. There, summer temperatures were greater and more variable than under Carex, due to drier ground and limited shading effects. Winter temperatures were also less variable and greater than in sedges, consistent with insulation provided by snow accumulation in shrubs. While the sedge fen could sustain permafrost, with mean ground surface temperatures below 0°C, it seems unlikely that permafrost would be sustainable where shrubs encroached, with mean ground surface temperatures several degrees above 0°C. Incubations indicated a lower methane production potential in areas where shrubs had encroached compared to the sedge fen.

Ground ice survey designed for data holders and data users to improve understanding of ground ice content in permafrost across the Arctic

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Permafrost contains ice in the form of pore ice, ice lenses, and ice wedges, the latter occupying up to 80% of the soil volume. About two-thirds of the total permafrost zone is categorized as low ice content and one-third with medium to high ice content. Permafrost areas containing high ice content are highly susceptible to abrupt thaw with serious disturbances and consequences to ecosystems and human infrastructure. In order to identify the most vulnerable areas for accelerated permafrost degradation and abrupt thaw, improved accuracy and detailed maps of ground ice distribution are necessary.

With feedback from internationally recognized permafrost researchers and the Interagency Arctic Research Policy Committee (IARPC), we developed a ground ice survey https://tinyurl.com/yxqwhejs that polls data holders and data users about the availability of ground ice data and the need for better ground ice maps. The survey will identify who has data, where they are, and at what scale in time and space. In detail, the survey identifies the region of data collection, ecosystem type, soil type, spatial extent, type and purpose of data collection, as well as ancillary data collected. The goal of this initial survey is to improve ground ice maps that will be useful to the various needs of scientists, engineers, and other stakeholders. We invite scientists, engineers, modelers, and other data holders to fill in the survey with data availability and their specific needs for improved ground ice maps.

The Thermokarst Detection Algorithm: A Case Study at Eight Mile Lake, AK

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To date, thermokarst detection from remote sensing techniques has been limited to areas with repeat elevation imagery or by spectral methods which cannot be applied beyond a single image, making it difficult to assess the extent of abrupt thaw across the circumpolar region, despite the important role this process has in our ability to predict future carbon fluxes. To try to overcome this obstacle, we developed the thermokarst detection algorithm, which is capable of detecting thermokarst features from a single elevation image, and applied it in an 81 km2 area surrounding Eight Mile Lake, AK, near Denali National Park. The algorithm identifies areas where the local elevation is lower than the median elevation in a surrounding circular neighborhood of variable size, allowing the detection of variously sized features. The algorithm had an overall accuracy of 71.5% and identified thermokarst features in 7% of the study area with sizes ranging from 1 m2 (the resolution of our imagery) to over 100,000 m2 and an average of 25 m2. The majority of features by count were small thermokarst pits, however, the largest impact by area was caused by more extensive water tracks. Using the thermokarst classification and eddy covariance we were able to determine that abrupt thaw resulted in higher carbon release at the site. Carbon dioxide release was higher following abrupt thaw as it promoted ecosystem respiration more than photosynthesis on an annual timescale, although there was a larger impact on photosynthesis during the summer. Methane release was also higher following abrupt thaw, as it was promoted nearly year-round. Because the thermokarst detection algorithm does not rely on site-specific relationships or time-dependent imagery, it has the potential to be broadly applicable at sites across the permafrost zone. Although our study relied on high-resolution elevation data, we believe it would be feasible to use lower resolution data to identify the majority of thermokarst features (by area), particularly in locations where larger features such as retrogressive thaw slumps and active layer detachment slides are the prevalent form of thermokarst. Given the importance of abrupt thaw in driving carbon fluxes, and the increasing availability of remotely sensed elevation data, we believe that this method will have great utility in studying thermokarst and carbon fluxes across the circumpolar region.

Relict basal ice from the Laurentide Ice Sheet near Lac de Gras, Slave Geological Province, N.W.T., Canada

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A 2015 drilling campaign of the Slave Province Surficial Materials and Permafrost Study near Lac de Gras has recovered permafrost core interpreted to contain preserved basal ice of the Laurentide Ice Sheet. Previous samples of basal ice from ice sheets originate from coring beneath modern ice divides, modern margins of Arctic icecaps that have preserved basal ice-sheet ice, or from studies near the margins of former ice sheets. The present study may be the first evidence of basal ice a few hundred kilometers from ice divides. In this intermediate zone, rates of erosion beneath an ice sheet increase and the thermal regime at the base varies. Our finding is relevant because it highlights the mosaic character of a landscape that contains terrain types with non-negligible ground-ice content, poised for climate-driven thaw and landscape change. The occurrence and mosaic character of preserved ice can be reconciled with glaciological theory and observations from mineral prospecting using the theory on the genesis of dispersal plumes in till developed by Hooke et al. (2013). The existence of preserved basal ice opens novel basic-research opportunities alongside exploration, mining and infrastructure development in the area.

Related publications:

Subedi, R., Kokelj, S. V., and Gruber, S. 2020: Ground ice, organic carbon and soluble cations in tundra permafrost soils and sediments near a Laurentide ice divide in the Slave Geological Province, Northwest Territories, Canada, The Cryosphere, 14, 4341–4364, https://doi.org/10.5194/tc-14-4341-2020.

Hooke, R. L. B., Cummings, D. I., Lesemann, J. E., and Sharpe, D. R. 2013: Genesis of dispersal plumes in till, Can. Jo. Earth Sci., 50, 847–855, https://doi.org/10.1139/cjes-2013-0018.

Distribution, morphometry, and ice content of ice-wedge polygons, central Yukon, Canada

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Investigations of the regional distribution of ice-wedge polygons and wedge-ice volume allow for the assessment of the vulnerability of permafrost landscapes to thaw-induced disturbances and related ecological feedbacks. Ice-wedge polygons

have been described in multiple studies in flat terrain and low-gradient hillslopes, but few studies have examined ice-wedge polygons in mountainous terrain. This study investigates the distribution, morphometry, and wedge-ice content of ice-wedge

polygons in Tombstone Territorial Park, a mountainous permafrost region in central Yukon. Results show that ice-wedge polygons occupy 2.6% of the park and preferentially develop in woody sedge peat, glaciofluvial, and alluvial deposits along the lower reaches of the Blackstone and East Blackstone rivers on hillslopes ≤1. The morphometry of five of six polygonal sites studied showed statistically similar polygon sizes and trough angles, while showing different development stages based on vegetation type, surface wetness, and spatial pattern. The estimation of wedge-ice volumes in the ice-wedge polygons is 8–22% and is comparable to that of other Arctic regions. However, the estimated wedge-ice volume represents a minimum

value because older generations of ice wedges are truncated 3–4 m below the surface with no evidence of surface polygons, and the polygonal network can be obscured by slope processes, vegetation, and ice-wedge inactivity. This study provides insights into the application of morphometric and soil parameters for the assessment of ice-wedge polygon distribution and development stages.