CANADIAN PERMAFROST ASSOCIATION
ASSOCIATION CANADIENNE DU PERGÉLISOL

Virtual Annual General Meeting

November 15 & 16, 2021

ABSTRACTS

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Content

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A Word from the President

Dear Members of the Canadian Permafrost Association,

When I took over the presidency of the CPA in January 2020, I was looking forward to meeting our members during multiple events and conferences. I never envisioned that for the most part of those two years I would be working from my kitchen office and that staring into a webcam during meetings would be the new norm. Even a year ago, when we held our first virtual AGM, there was a general optimism that we'd soon have the opportunity for in-person meetings again. Unfortunately, the virus had other plans and while some meetings and conference were held in-person, the majority remained online. Nevertheless, 2021 provided significantly more opportunities to carry out field work which allowed researchers to visit their sites to collect critical data. It is exciting to see some of this research being presented during the 2021 virtual AGM. Similar to last year we were unsure how successful this year's AGM event would be. Not only is a general Zoom fatigue noticeable, but our colleagues from the US Permafrost Association had just held a very successful Regional Conference on Permafrost. However, the response we received when we initiated the call for abstracts and the partnership with NSERC PermafrostNet for this meeting demonstrated the ever-increasing interest in permafrost science and engineering.

So, I'm pleased that we have a program, with a total of 16 presentations, as well as one keynote on planetary permafrost and a panel discussion related to the 2022 Dawson Permafrost Meeting. The technical presentations cover a wide variety of topics and about 3/4 are from students and early career members. NSERC PermafrostNet organized a virtual poster session with 22 posters, mainly from students. It is exciting to see all these presentations and I'm confident that this new generation of permafrost scientists and engineers is ready to tackle the growing challenges related to changes in permafrost that lay ahead.

A big thank you goes to my colleagues of the CPA Board for their support during my two years as president and Jen Humphries, Yifeng Wang, Cedelle Pereira, Tabatha Rahman, Rosy Tutton, Kumari Karunaratne, and Peter Morse for their support in making this AGM a success. Finally, thanks to Barb Fortin for correcting my French.

I wish everyone all the best for 2022 and stay healthy.

Lukas Arenson
CPA President

Le mot du président

Chers membres de l'Association canadienne du pergélisol,

Lorsque j'ai pris la présidence de l'ACP en janvier 2020, j'avais hâte de rencontrer nos membres lors de multiples événements et conférences. Je n'avais jamais imaginé que pendant la majeure partie de ces deux années, je travaillerais depuis mon bureau dans la cuisine, et que de regarder fixement une webcam pendant les réunions deviendrait la norme. Lorsque nous avons tenu notre première AGA virtuelle il y a un an, l'optimisme était de mise quant à la possibilité de tenir à nouveau des réunions en personne. Malheureusement, le virus a eu d'autres plans et bien que certaines réunions et conférences aient eu lieu en personne, la plupart se sont tenues en ligne. Néanmoins, 2021 a offert beaucoup plus d'occasions de réaliser des travaux sur le terrain, ce qui a permis aux chercheurs de retourner sur leurs sites et de recueillir des données essentielles. Ce fut passionnant de voir certaines de ces recherches présentées lors de l'AGA virtuelle de 2021. Comme l'an dernier, nous n'étions pas certains, au départ, du succès que nous aurions avec l'AGA de 2021. Non seulement une fatigue générale des plateformes virtuelles était perceptible, mais nos collègues de l'association américaine du pergélisol venaient tout juste d'organiser une conférence régionale sur le pergélisol très réussie. Cependant, la réponse que nous avons reçue lorsque nous avons lancé l'appel et le partenariat avec NSERC PermafrostNet pour cette réunion a démontré l'intérêt toujours croissant pour la science et l'ingénierie du pergélisol.

Je suis donc heureux que nous ayons eu un programme avec 16 présentations, un discours principal sur le pergélisol planétaire et un débat d'experts lié à la réunion sur le pergélisol de Dawson en 2022. Les présentations techniques ont couvert une grande variété de sujets et le 3/4 des présentations ont été faites par des étudiants ou des membres en début de carrière. Le réseau NSERC PermafrostNet a organisé une session d'affiches virtuelles avec 22 affiches, principalement provenant d'étudiants. Ce fut très agréable de voir toutes ces présentations, et j'ai confiance en cette nouvelle génération de scientifiques et d'ingénieurs spécialisés dans le pergélisol qui seront prêts à relever les défis croissants liés aux changements qui s'annoncent dans le pergélisol.

Un grand merci à mes collègues du conseil d'administration de l'ACP pour leur soutien au cours de mes deux années de présidence, et plus particulièrement Jen Humphries, Yifeng Wang, Cedelle Pereira, Tabatha Rahman, Rosy Tutton, Kumari Karunaratne et Peter Morse pour leur aide à faire de cette assemblée générale un succès. Enfin, merci à Barb Fortin pour avoir corrigé mon français.

Je vous souhaite à tous une excellente année 2021 et de rester en bonne santé.

Lukas Arenson
Président de l'ACP

Keynote 1: How does permafrost engineering contribute to future human settlement on the Moon and beyond? | *Richard Boudreault and Pooneh Maghoul*

It is approaching 50 years since the last human walked on another planetary body (Apollo 17, 1972). There is now renewed interest in returning to the Moon, with multiple space agencies and private companies currently planning lunar exploration activities. These include a proposed lunar-orbiting space station (Lunar Gateway) and associated lunar surface (ground) operations. The NASA-led Artemis program intends to send the first woman and the next man to the south pole of the Moon by 2025. The main goals of the 2024 lunar landing are to 1) achieve sustainable exploration by 2028 via collaboration with commercial and international partners, 2) construct a sustainable, long-term human base camp, and 3) lay the foundation for eventual crewed trips to the ultimate human-spaceflight destination, Mars, sometime in the 2030s. The activities will be implemented through a combination of NASA-led operations and public-private partnerships, as well as collaborations with the CSA, ESA, JAXA, and other international partners.

The Government of Canada announced the Lunar Exploration Accelerator Program (LEAP), in February 2019, as part of a new National Space Strategy. The strategy enables Canada and its space sector to grow the economy and create the jobs of the future by advancing science, developing and demonstrating space technologies, and participating in new commercial and science mission opportunities linked to our participation in lunar exploration while generating benefits for Canadians in space and on Earth.

In this presentation, we will present the lunar environment and a host of challenges at multiple levels to overcome to ensure a successful human settlement on the Moon at scales beyond the traditional reconnaissance and exploratory missions. This includes in-situ harvesting of energy, water, and oxygen, as well as scarcity of material resources for sustainable construction. We will discuss how our terrestrial permafrost knowledge and permafrost engineering can contribute to humanity's return to the Moon via advanced physics-based geophysical techniques and the practice commonly known as In-Situ Resource Utilization (ISRU). ISRU refers to the extraction, processing, and generation of materials for energy, construction materials, life support, and propellants from raw materials found in-situ on the Moon or other extraterrestrial objects.

Keynote 2: Discussion on 2022 CPA Meeting in Dawson, Yukon | *Kumari Karunaratne*

The next annual meeting of the Canadian Permafrost Association (CPA) will be held on August 22-26, 2022, in Dawson City, Yukon. The meeting will be co-sponsored by and developed in collaboration with the First Nation of Na-Cho Nyak Dun (FNNND), Tr'ondëk Hwëch'in First Nation (THFN), and Vuntut Gwitchin Government (VGG). In May 2021, FNNND Chief Simon Mervyn, THFN Chief Roberta Joseph and VGG Chief Dana Tizya-Tramm, approved the 2022 event with the condition that the meeting's agenda be developed collaboratively and focused on their communities' concerns. A steering committee with representatives from the CPA and the three Northern Yukon First Nations was established to co-develop an event that will be different from a typical scientific meeting and the first of its kind for the Canadian permafrost community.

The 2022 Dawson Permafrost Meeting was first announced on November 15, 2021. The following day a panel discussion with members of the event's steering committee addressed the permafrost issues facing Northern Yukon First Nations and explored the format of the upcoming gathering. The panellists were Erika Tizya-Tramm, VGG Director of Natural Resources, Jim Taggart, THFN Environmental Sustainability and Climate Change Coordinator, Josee Tremblay, FNNND Lands and Resources Manager, and Kumari Karunaratne, CPA President-Elect. Chris Burn, President of the International Permafrost Association, moderated the discussion, which began with a short introduction from Lukas Arenson, CPA President.

Northern Yukon is experiencing accelerated climate change and the resulting changes to permafrost are already compromising FNNND, THFN, and VGG. Trails traditionally used for hunting and trapping are now impassible, because of changes to wetlands and large landslides. Increased erosion is impacting water quality and fish habitat as large volumes of sediment is released into streams and lakes. The loss of lakes due to sudden drainage means the loss of bird habitat and important hunting sites. Warming and thawing permafrost are also compromising heritage sites, critical infrastructure investments, and increasing maintenance costs and the risk of environmental contamination if engineered containment facilities fail. The Final Agreement rights of the three Northern Yukon First Nations are threatened by climate change. Landscape changes related to permafrost thaw increasingly restrict access to and use of settlement land demarcated in treaty negotiations.

The 2022 Dawson Permafrost Meeting will be framed within the context of reconciliation. To address the First Nations' climate change concerns, it is important to acknowledge the continued impacts of colonialism, understand Indigenous People's relationship with the land and include community and Traditional Knowledge in the discussions. As humans, we understand our world through stories – supported by facts and figures – so storytelling will be a key communication tool used at the meeting to help explain new ideas. Spending time on the land and sharing observations and ideas is part of the Indigenous way of life and is also valued by scientists and engineers. Therefore, the meeting will include multiple field trips such as visits to the Dempster

Highway, the ice-rich Klondike goldfields, and the Top-of-the-World Highway. Time spent together on the land and in small groups will allow for meaningful relationship building which is critical to developing effective collaboration.

The Dawson Permafrost Meeting will be the first opportunity for the CPA to collectively listen to northern community climate change, permafrost management, and reconciliation priorities and co-develop rewarding projects. As participants from diverse backgrounds work to understand each other, challenges are anticipated and it is critical to establish a setting where it is safe to ask questions, offer different perspectives, and correct misunderstandings. Courage and humility will be required to make this meeting a success and to explicitly address the association's mission of bringing communities, researchers, and practitioners together to advance the understanding of permafrost environments. The CPA is very grateful to FNNND, THFN, and VGG for their generous investment in this unique event and for leadership in advancing how Indigenous permafrost concerns are addressed.

An AI-based data-driven framework for forecasting long-term ground surface temperatures | *Ali Fatolahzadeh Gheysari*

Ground surface temperature is an essential parameter in permafrost studies. Long-term forecasts of ground surface can provide valuable insights on the stability of permafrost concerning climate change. The current methods for the estimation/calculation of ground surface temperature have their challenges and limitations. At the Sustainable Infrastructure and Geotechnical Research Group at the University of Manitoba, we are developing an alternative AI-based data-driven framework to forecast long-term ground surface temperatures under different climate change scenarios. The method uses time series forecasting models, such as long short-term memory (LSTM) networks, past climatic data, and projections of atmospheric variables from regional climate models. Despite some limitations, the proposed approach addresses the challenges associated with the physics-based calculation of ground surface temperature, and therefore may be considered an alternative solution in permafrost stability studies.

Deep learning for tracking of Northern infrastructure affected by permafrost degradation using satellite imagery | *Andres Felipe Perez Murcia*

This presentation deals with the identification and tracking of linear infrastructure from satellite imagery of northern Canada in order to estimate deformation of infrastructure affected by permafrost degradation. The purpose is to perform semantic segmentation of linear infrastructure such as roads or railways utilizing deep learning models for multispectral data processing and measuring displacement by means of optical flow methods and SAR interferometry. To this end, a linear infrastructure dataset of three locations with prominent presence of permafrost (Gillam, Thompson, and Yellowknife) has been curated using OpenStreetMap vector data as base layer to label Sentinel-2 high-resolution satellite imagery. An initial assessment of road detection using a variation of the classical U-Net architecture adapted for multispectral images processing that uses bilinear up-sampling instead of transposed convolutions and half as features maps was performed. Both quantitative and qualitative results show that high-resolution satellite imagery can be used for sub-pixel width road detection following a proper approach.

Synthesizing measured soil freezing characteristic curves | *Élise Devoie*

Permafrost is warming globally, and thaw predictions are needed for applications in hydrology, ecology, engineering, and beyond. In thermal models, a soil freezing characteristic curve (SFCC) is needed to relate the temperature of a particular soil to the soil ice content. Phase change from pore ice to liquid water has been measured below zero in many permafrost soils, but these measurements are inadequately incorporated into current permafrost models. To address this gap in our representation of permafrost thaw, SFCC data from literature was compiled and the uncertainty in each SFCC measurement technique was assessed. Metadata was used to categorize the existing SFCCs, pointing to a need for more studies on coarse grained soils, and more SFCC data collected in the field. Given the collected dataset, 'best-guess' models are presented for the common sand, silt, clay and organic soil textures, and an R package to extract SFCC data matching specific characteristics is under construction for use in permafrost modelling.

Field investigations in support of peatland permafrost inventorying activities in coastal Labrador | *Yifeng Wang*

Northern peatlands cover about 4 million km^2, and continental and hemispheric-scale mapping efforts have estimated that half of these peatlands contain permafrost. In northeastern Canada, existing maps of peatland permafrost distribution indicate that relevant landforms (e.g., palsas and peat plateaux) are spatially concentrated in Labrador's western interior and are mostly absent along the coast. However, historical and contemporary observations of palsas throughout sections of the Labrador Sea coastline cast doubt on the reliability of existing permafrost and peatland permafrost distribution maps for the overall region.

Peatland permafrost field investigations were conducted along a north to south transect between Nain, Nunatsiavut (56.5 °N) and Blanc-Sablon, Quebec (51.4 °N) from July to September 2021. Standard field methods including frost probing and instantaneous temperature measurements were combined with low altitude landscape surveys via remotely piloted aircraft, helicopter, and Twin Otter to evaluate the presence or absence of peatland permafrost at over 120 locations along the Labrador Sea coastline. Preliminary analysis of field data suggests that the distribution of peatland permafrost increases in frequency from isolated patches in the south to relatively abundant in the north, with large clusters of features near Cartwright and Black Tickle. These results suggest that existing peatland permafrost maps have dramatically underestimated the frequency of these landforms in coastal Labrador.

These field-based investigations will contribute to an ongoing peatland permafrost landform inventory containing over 1200 wetlands with potential peatland permafrost features in the coastal Labrador region. The full inventory, identified from high-resolution satellite imagery available via ArcGIS Online, will be reviewed and re-assessed via a series of quality control and consensus-building stages to minimize feature misinterpretation. These results will improve our understanding of the contemporary distribution of peatland permafrost along the Labrador Sea coastline and may inform regional infrastructural and land-use planning within and between communities in Nunatsiavut, NunatuKavut, and Nitassinan.

Multi-method approach to inventorying rock glaciers and features of interest in Banff and Jasper National Parks, Alberta, Canada |

Mishélle Wehbe

Rock glaciers are perennially frozen masses of ice and unconsolidated material that creep downslope as a result of cyclic freeze-thaw mechanisms and weight due to gravity. These features are often tongue-shaped, lobate landforms containing longitudinal or transverse flow structures, with a surface that consists of poorly sorted, angular, rock debris. Although rock glaciers are abundant geomorphological features in the alpine periglacial environments of the Rocky Mountains, their spatial distribution and characteristics are largely unknown. As rock glaciers contain frozen fresh water and can be potential geohazards, inventories are crucial in the assessment of the activity status and distribution of these landforms. This inventory will also provide an estimate on the potential cubic meters of water equivalent storage within the rock glaciers for cryospheric reserves as freshwater depletes. Over 800 intact (active/inactive) rock glaciers were identified within the study areas, as well as over 204 features of interest requiring further validation of surface kinematics and morphometric quantification. Grid-based manual inventorying of these features was completed using high-resolution satellite imagery that is readily available through the ESRI World Imagery Base Layer, then subsequently verified manually with Google Earth Pro. Our refined methodology proved crucial and supports the idea of both multi-temporal and multi-method approaches to the inventorying of rock glaciers and features of interest within the alpine terrains of Canada. This work represents the first component of our rock glacier monitoring network within Canada, as there currently are none to date. The inventories completed with this initiative will be shared with the International Permafrost Associations Rock Glacier Inventorying Action Group.

Permafrost mapping and geotechnical data synthesis, Grays Bay - Yellowknife Corridor |

Peter Morse

As a part of the Geological Survey of Canada's GEM-GeoNorth program, we are working on enhancing the understanding of rapidly changing permafrost landscapes to inform transportation infrastructure design in a key economic development region, the Grays Bay–Yellowknife corridor. Knowledge of surficial geology and permafrost is well-synthesized for the southern portion of the corridor within discontinuous permafrost terrain, but remains sparse for the central and northern regions. To begin to fill this knowledge gap, we have acquired an extensive set of high-resolution satellite imagery in 2021 and are mapping key permafrost terrain features within 10 km of the proposed highway corridor, and we are synthesizing existing permafrost and surficial data. The knowledge gained from these activities will support our ground ice modelling, the selection of field sites for future investigation, and validation of ongoing, broad-scale thermokarst mapping with our collaborators. We will present an update on our activities, preliminary results, and future directions.

The Yukon permafrost database | *Derek Cronmiller*

The newly launched Yukon Permafrost Database is a publicly accessible web application for permafrost-related data. The database includes geotechnical data captured from test pit and drilling programs and related sample analyses, temperature data for both ground and air, and geotechnical and permafrost-related reports. The database is a useful resource for a variety of applications, such as hazard and risk identification, climate change modelling, development of community adaptation plans, infrastructure planning and maintenance, and environmental assessments. Contributions to the database are welcomed.

Developing a Canadian database of electrical resistivity tomography surveys of permafrost |

Teddi Herring

Electrical resistivity tomography (ERT) is a method of imaging subsurface resistivity, which can be used to infer the presence/distribution of permafrost. Changes in resistivity observed with repeated ERT surveys can be related to changing temperature and ground ice conditions, which is particularly valuable when assessing risks related to climate change. Although ERT data has been collected at many sites in Northern Canada, there is no existing framework for data sharing, resulting in missed opportunities for large-scale interpretation of changing permafrost conditions. In this PermafrostNet project we are working to create a Canadian database of ERT surveys of permafrost and establish best practices for acquisition, processing, and repetition of surveys. I will present recent progress towards Canadian (and international) databases, including metadata compilation, standardized data processing, and data visualization tools.

Long-term (2000-2017) response of lake-bottom temperatures and talik configuration to changes in climate at two adjacent tundra lakes, western Arctic coast, Canada | *Trevor Andersen*

Lakes, commonly underlain by taliks, are principal agents of disturbance to permafrost. We have measured lake-bottom temperatures with submerged loggers on near-shore terraces and in deep central pools at two tundra lakes on Richards Island, NT, to determine inter-annual lake thermal responses to climate variation. We have modelled associated potential adjustments in talik geometry. In 2000-17, annual mean temperatures varied between -5.7 and 2.8 °C for terraces and 1.1 and 4.5 °C for pools. Permafrost in the terraces is warmer than surrounding the lakes: talik configuration varies with horizontal terrace extent and terrace and pool temperatures. The talik break-through depth declines as terrace size increases. Using the four warmest and coldest years as an analogue for climate change - an adjustment that may occur this century - the increase in talik depth may be up to 100 m, but it may take millennia for talik geometry to reach equilibrium

Thermal modelling of post-fire permafrost change under a warming coastal subarctic climate, eastern Canada | *Yifeng Wang*

Forest fires are known to have lasting thermal impacts on permafrost, but there are no previous studies of such effects along the eastern Canadian coastline. One-dimensional thermal modelling was used to examine the ground thermal regime at a coastal forest fire site in the discontinuous permafrost zone near Nain (56.5°N), Nunatsiavut, eastern Canada. Simulations were undertaken for both the unburned forest and adjacent fire-disturbed area, which were modelled to have an initial permafrost thickness of 15.6 m in 1965. Future scenarios incorporated changes to regional air temperature following Representative Concentration Pathway (RCP) 4.5 and 8.5, as well as variations in surface organic material regeneration. Results varied from permafrost thinning but persisting beyond 2099 under RCP4.5 (unburned) to thawing entirely by 2060 under RCP8.5 (high severity burn, no organic material regeneration). In all burned scenarios, a supra-permafrost talik developed immediately following disturbance, but in most cases, frozen ground re-aggraded after several decades. Our findings are broadly consistent with those from western North America and demonstrate that the main impact of fire is to accelerate permafrost thaw due to climate warming.

Characterization of permafrost cores along the Inuvik-Tuktoyaktuk corridor | *Alejandro Alvarez*

To understand permafrost conditions near the newly developed Inuvik-Tuktoyaktuk Highway, NWT, cores were collected in the winter of 2017 by the NWT Geological Survey. This study analyzed five cores (BH-1, BH-2, BH-3, BH-4, and BH-8) within hilltop, riparian, and peatland terrains, recording various depositional environments. Cores were analyzed for cryostructures, water isotopes, and radiocarbon dating to determine the origin of the sedimentary and ground ice records. Collectively, these results indicate that deposits within low-relief areas (such peatlands and riparian zones) host ice with enriched values comparable to modern-day local precipitation values. BH-1, BH-3, and BH-4 all had an ice-poor diamict present at depth. The ice within these diamicts ranged from δ18O -23‰ to -19‰, with a low co-isotope regression slope; indicative of thawing during the Early Holocene warming, followed by permafrost aggradation. Core BH-8 contained a fine-grained unit with laminations, overlain by ~4 m of peat. Radiocarbon dates and sedimentary structures indicate a shifting landscape: from Husky Lake boundary deposits ~11,500 to 9000 years ago, developing epigenetic permafrost, and transitioning to syngenetic peat early Holocene. Lastly, deposits within high-relief areas, BH-2, show little evidence of being affected by Holocene thaw. This ice displays depleted Pleistocene values ranging between δ18O -30‰ to -27‰; at depths greater than 6-meters below the surface.

Permafrost science capacity in the changing North | *Steve Kokelj*

The Government of Northwest Territories (GNWT) and its partners have recognized that permafrost knowledge and an increase in northern permafrost science capacity are critical to support a resilient territory in the rapidly changing north. In this context, GNWT has supported the establishment of an NTGS Permafrost Science Team and the concurrent development of a strategic plan to communicate its vision, goals, objectives, and implementation strategies. Primary goals were established with input from partners to A) conduct and support research and monitoring that generates NWT relevant permafrost knowledge; B) lead the stewardship of NWT permafrost data; C) provide scientific leadership, mentorship, and advice to advance the state of permafrost knowledge, and to support NWT decision-making; and D) foster a community of permafrost experts who bring positive energy and diverse talents to their work and advance professional and public awareness of permafrost science and its relevance in the NWT. Here we elaborate on the NTGS Permafrost Strategic Plan, provide a brief overview of new permafrost science staff, identify key partnerships, and summarize the research themes, values, and approaches that will guide the future of NWT permafrost science and monitoring activities.

One year of road surface temperatures along the Dempster-ITH corridor | *Emma Stockton*

The design of northern infrastructure relies on accurate predictions of freezing and thawing depths to maintain permafrost and minimize thaw subsidence beneath elevated gravel embankments. Numerical modelling (e.g., TEMP/W) can predict these depths using road surface n-factors, calculated from the ratio of freezing (FDD) and thawing (TDD) degree days for the air and surface. Values for design are typically chosen from the available literature because field measurements may be unobtainable until after construction. Road surface n-factors are considered more spatially uniform than n-factors from the natural environment due to the relative homogeneity of surfacing materials.

This research aims to investigate spatial variability in road surface n-factors to determine whether values from the literature are representative of a 420 km-long section of the Dempster and Inuvik to Tuktoyaktuk Highways (ITH), NT. The route includes both elevational and latitudinal temperature gradients across treeline, with air temperatures (Ta) increasing with elevation and decreasing with proximity to the Beaufort Sea. In October 2020, thirteen thermistors were installed 15 cm depth below the highway centerline between the YT-NT border to the south and its northern terminus at Tuktoyaktuk. Following one year of data collection, mean annual road surface temperatures (Ts) ranged from -4.5 to -7.5 °C, with the warmest Ts recorded along the elevational gradient. The annual sum of FDD for the road surface was greater along the latitudinal gradient than elevational gradient by about 500-degree days. While TDD was about the same for both gradients. The mean road surface n-factor for the freezing season was about 1.0 for all sites along the latitudinal gradient, while n-factors for the thawing season were greater and more varied. Spatial variability during the thawing season may be associated with differences in albedo and thermal properties of the surfacing materials.

Investigating snowpack compaction as a method of preserving permafrost beside highway embankments | *Patrick Jardine*

In Central Yukon, air temperatures are warming rapidly due to climate change. As a result, permafrost degradation is becoming more widespread, increasing the risk of thaw subsidence damaging infrastructure underlain by ice rich permafrost. For roads, this risk is exacerbated by deep snowbanks which accumulate alongside embankments and create an insulative layer, trapping heat within the ground. Simulation results suggest that compaction of the snowpack may reduce this insulative effect by increasing the thermal conductivity of the snowpack and reducing its depth. This would mitigate the risk of thaw subsidence by decreasing ground temperatures.

For this study, field experiments were conducted at several sites along roads in Central Yukon to test this theory by determining how regular compaction influences ground temperatures underneath the embankment snowbanks. Four sites were set up near Mayo, YT, while one site was set up at km 96 of the south Dempster Highway. The sites near Mayo were set up at roads that varied in local vegetation, usage, and plowing schedule to determine how this may influence the effects of snowpack compaction. Each site consisted of two adjacent 50 m by 5 m plots within the right of way of the road. One plot was compacted monthly by land guardians from the Na-Cho Nyak Dun First Nation using snow machines, while the other was left undisturbed. At km 96 of the Dempster Highway, ten adjacent plots of the same dimensions were set up in a tundra environment. Every second plot was compacted by the land guardians following a monthly schedule which varied in timing and frequency, while the remainder were left undisturbed. Ground temperatures were monitored by loggers throughout the winter at all plots, and snow properties were measured during monthly trips to the field.

Air-convection-reflective sheds: A mitigation technique that stopped degradation and promoted permafrost recovery under the Alaska Highway, Yukon, Canada | *Samuel Gagnon*

This study tested the efficacy of air-convection-reflective sheds (ACRS) installed along the Alaska Highway in Yukon (Canada) as a mitigation technique to reduce heat absorption during the thawing season and to increase heat loss during the freezing season. Soil surface, air, and ground temperatures were recorded under the ACRS between 2008 and 2016, which were then compared with values from an unmitigated road embankment and from the natural ground near the road embankment. The design of the ACRS blocked incoming solar radiation, prevented snow accumulation, and promoted air convection through the stack effect, which resulted in a cooling efficiency of 358% compared to the reference site. The net heat loss resulted in a 6.3°C cooling of the average soil surface temperature and caused the active layer thickness to decrease by nearly two meters, thus stopping permafrost warming, promoting permafrost recovery and its upward aggradation in the embankment. Implementations of the ACRS in specific vulnerable or degraded sections of roads and airstrips represents a viable solution to permafrost thaw and embankment failure.

Thermal performance of Diavik's A21 Dike after 4 years | *Lukas Arenson*

In August 2018, a new open pit, accessing kimberlite pipe A21, was officially opened at Rio Tinto's Diavik Diamond Mine site, located approximately 300 km north-east of Yellowknife, NT. To access the pipe, a 2.2 km-long ring dike was constructed, and the pit area dewatered during the winter of 2017/2018. While the site is located within the continuous permafrost region, a talik had formed under Lac de Gras, i.e. the area mine infrastructure is located just offshore South Island. The foundation of the dike therefore had to accommodate permafrost conditions close to the shoreline of South Island and non-permafrost conditions further offshore. In addition, permafrost was expected to aggrade within the dike and its foundation where the upstream side was within shallow water, preventing the preservation of the talik. Where the permafrost foundation transitions into the non-permafrost foundation, thermosyphons were installed along two, approximately 30 m-long sections. Extensive ground temperature monitoring was performed during and post-construction to follow changes in the thermal regime. We present the thermal performance of ring dike A21 following four years post dewatering. The data show that the temperatures continue to decrease, and permafrost is aggrading in the foundation as planned. Specifically on the South Abutment and Island A, ground temperatures are decreasing, naturally expanding the hydraulic barrier within and under the ring dike. The two thermosyphon blocks, which have been operating in a passive mode following a short active phase prior to dewatering, also are behaving as planned, slowly expanding the frozen block in the foundation providing the necessary hydraulic barrier.

Linear infrastructure and permafrost monitoring

| ***Usman Iqbal Ahmed***

We are exploring full spectrum of single platform based airborne SAR and Optical data fusion scenarios for direct / indirect change detection in permafrost regions. We will be high precision photogrammetric DEMs to not only serve as a reference for interferometric and tomographic SAR applications but also to map direct change in the region of interest based on bi-annual aerial surveys. Photogrammetric block adjustment parameters can fine-adjust the flight trajectory for enhanced motion compensation for repeat pass Interferometric SAR, thus producing high precision interferometric change detection maps for as a measure of indirect change detection. The area of interest for our research is a portion of Alaska Canada Highway near the northern end of the Kluane Lake in Yukon Territories.

Quantifying local- to watershed-scale impacts of permafrost thaw-related geohazards on the natural and built environment in the Stewart River watershed, Yukon | *Frederic Brieger*

The central Yukon is warming fast, with major challenges for vulnerable northern communities including the maintenance and adaption of physical infrastructure and dramatic changes in the natural permafrost landscape. My project will investigate impacts of permafrost-related geohazards to the natural and built environment in the traditional territory of the First Nation of Na-Cho Nyäk Dun (FNNND), by applying state-of-the-art high-precision remote sensing technology such as UAV-based photogrammetry and light detection and ranging (lidar). Areas of concern that are already experiencing thaw-related infrastructure damage or subsidence in the Village of Mayo and FNNND settlement land are currently identified by applying point-to-point change detection using public lidar surveys and in collaboration with local stakeholders. The Stewart (Na-Cho Nyäk) River watershed is facing strong thermokarst activity (e.g., retrogressive thaw slumps, active layer detachments, permafrost cliff erosion) which could potentially impact traditional land use and aquatic habitat through increased sediment input. Future field work aims to quantify ground movement at high spatiotemporal resolution and integrate these data with geophysical techniques (ERT and GPR) and knowledge on surface characteristics and disturbance history to help understand underlying (intra- and interannual) permafrost conditions and dynamics.

Ice wedges as winter paleotemperature proxies: is it feasible? | *Kethra Campbell-Heaton*

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 (DOC 14C) from eight ice wedges show peripheral cracking in one-fifth 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 the direct dating of veinlets 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 in the summer. 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.

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

Excess ice, found as massive ice and within icy sediments, is an important variable to quantify as it strongly influences the geotechnical response to permafrost thaw. Thawing of excess ice in the western Canadian Arctic has led to thaw subsidence and retrogressive thaw slumps which increasingly cause issues to Northern infrastructure. 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 significant value to these datasets, a cryostratigraphic dataset collected along the Inuvik-Tuktoyaktuk Highway (n = 566 boreholes) is used to develop a beta regression model which predicts the excess ice content of icy sediments based on interval depth, visible ice content, materials and Quaternary deposits. The resulting 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. Although this study shows the general applicability of this approach, comparable geotechnical data should be collected to reduce uncertainties and apply such models in a wider range of geographic settings and to produce geotechnical variables for quantitative analysis.

Initial investigations of degrading peat plateaus in the central Mackenzie Valley, Northwest Territories | *Alexandre Chiasson*

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 ~3 m per km), and are largely developed on moraine and glaciolacustrine sediments. These sites are often covered by tussocks, reindeer lichens (Cladonia spp.) and varying cover of open black spruce (Picea mariana). Field investigation of three sites in 2021 showed that peat thicknesses were ~2 m with structureless pore ice, which 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.

Centrifuge modelling of axially loaded steel piles in frozen and thawing ground | *Chris Clarkson*

Northern climates possess an increased complexity in soil-foundations compared to temperate regions. The continuous and discontinuous permafrost that varies throughout the arctic has a crucial role in pile foundation design. The uncertain quality of frozen soil, and its interaction with an ad-freeze steel pile provides a strong motive to further understand the strengths and bearing capacities of foundations in frozen soil. Centrifuge modelling was used to simulate in-situ forces acting on a steel ad-freeze pile in both temperate never frozen soils, and frozen soils. In a centrifuge the magnitude of gravity is increased allowing for the experimentation of small-scale models in a laboratory. By increasing the magnitude of gravity, a scaled pile foundation in a frozen soil can be modelled for its entire design life in a fraction of time and space of the full-scale equivalent. The model pile was designed to recreate the soil-structure interface of ad-freeze piles used in permafrost region foundations.

The purpose of these centrifuge experiments was to provide further insight through experimental validation on the strength and bearing capacity of Steel Piles in soils of frozen and thawing conditions. This was documented through load-displacement curves for specific pile sizes, embedment depths, and soil-pile interface designs.

Using numerical thermal modelling techniques to support snow management plans along the ITH | *Jay Cumming*

The modelling of ground temperatures is an important aspect of infrastructure design in regions with large seasonal variations in temperature. This is especially critical in Canada in permafrost and cold region engineering contexts. One of the factors that greatly affect ground temperatures is the seasonal snow cover, which acts as an insulator and impedes the flow of heat from the ground to the air in the winter months. Currently, along the Inuvik-Tuktoyaktuk Highway a snow manipulation research project is being conducted whereby at certain locations the ground snow cover is being manipulated to reduce the snow depth and increase the density. At these sites thermistors are located in the ground recording the resulting impact on ground temperatures. In this study, numerical models calibrated to the manipulated field site are being used to investigate the sensitivity to rate of snow manipulation both seasonally and annually. The results of this study will be used to help inform the design of an effective snow management plan for along linear infrastructure that will facilitate the preservation of underlying permafrost.

Ground ice of eastern Canadian High Arctic polar desert | *Mohammad Hossein Gamshadzaei*

The cryosphere of the polar deserts is strongly affected by climate change, both in terms of permafrost, sea ice, glaciers and nival coverage. For permafrost, the key element of its stability is ground ice. Ground ice can be defined as ice within frozen or partly frozen ground, irrespective of the form of occurrence or the origin of ice. The amount of ground ice within permafrost varies markedly between frozen sediment based on latitude, elevation, and continentality. The permafrost ice of the polar deserts of the Canadian High Arctic has so far been little studied. Having a better knowledge of quantity and distribution of permafrost ice is essential to simulate the future response of polar deserts to climate change and to evaluate its impacts on hydrology, geomorphology, vegetation and biogeochemical cycles.

Constraining soil carbon parameter distributions in CLASSIC using Bayesian inference and field observations | *Charles Gauthier*

The Canadian Land Surface Scheme Including Biogeochemical Cycles (CLASSIC) being a process-based model, many of its parameter values are difficult to obtain from field measurements. Poorly constrained parameter distributions lead to errors in prediction made by the model. This research's objective is to constrain soil carbon parameter distributions in CLASSIC, resulting in better predictions. Using Bayesian Inference, we plan on optimizing the parameter distributions against field observations. Other studies have been conducted on similar models using bulk soil carbon content datasets. Similar data will be used in this study as well as carbon flux data such as soil respiration and isotopic carbon datasets. Using a variety of data types should result in more constrained parameter distributions than those seen in studies using only soil carbon data.

Interpreting ground temperature and subsidence to better quantify permafrost change | *Fereshteh Ghiami Shomami*

Permafrost change is mostly reported based on sensors at single depths. Latent heat consumption upon thawing permafrost perturbs the ground temperature signal. Given that, using only one ground temperature time series of a single depth discards valuable information. This study aims to improve understanding of permafrost state by quantifying thaw-induced changes in ground temperature profile.

Towards simulation-based permafrost climate services | *Galina Jonat*

Simulation-based climate services are aiming to bridge the (scale) gap between atmospheric science and permafrost science. The products generated will complement observations and expert knowledge to support decision-making at local, regional and national scale.

The strength of simulations is their ability to apply future climate scenarios. Using ensembles of climate models and scenarios, as well as ensembles of permafrost models and ground conditions will help quantify confidence in the predictions. By identifying major terrain types and their characteristics, simulations can be run, validated and applied at a local scale.

Within PermafrostNet, simulation-based permafrost climate services aim to complement observations and expert judgement which in turn can help to identify and improve modelling capacities. Furthermore, model outputs are going to be validated in collaboration with members from different themes. Finally, this project is aiming to learn from and contribute to the prediction of hazards.

Stability analysis of drilling waste sumps, western Arctic Canada | *Rae Landriau*

In the 1960s through to 2000s petroleum development projects in the western Arctic used large pits excavated in permafrost to dispose and contain industrial wastes. At the time of development, it was assumed that the permafrost would remain frozen and act to contain waste in these sumps. Following their use, the sumps were capped and abandoned. In the western Arctic there are over 170 sumps, many which are in the Mackenzie Delta region. The ability of permafrost to act as a means of containment is dependent on a relatively cold climate. The integrity of sumps in permafrost is threatened, from rising air temperature and warming permafrost. This may cause the destabilization of sumps making them more susceptible to failure. The purpose of this research is to visit a selection of sumps in various permafrost settings to be able to determine the stability and establish priority orders for continued monitoring by regional agencies. The extent of contamination migration away from sumps will be investigated using electromagnetic surveys and by soil sampling. Thermistors will be installed to characterize the temperatures on the surface of sumps. Data collected will be compared to data collect 15-25 years ago in order to determine the sensitivity of sites to climate change in addition to assessing the integrity of these waste disposal sites. Failure of the permafrost to contain the waste poses a serious health and safety concern for both the environment and humans. Anticipating failure is particularly important for the Inuvialuit people as many of these sumps are present in the Inuvialuit Settlement Region. Overall, there are very few assessments pertaining to the longevity of sumps, causing many gaps in current knowledge, this research aims to address these gaps through fieldwork planned in summer 2022.

Physics in the CLASSIC model | *Rose Lefebvre*

CLASSIC (Canadian Land Surface Scheme including Biogeochemical Cycles) was used for Scotty Creek, Northwest Territories, Canada. This site is characterized by highly discontinuous permafrost and extensive moss coverage. CLASSIC can simulate physical quantities, but also biogeochemical quantities such as NPP. Scotty Creek was a good choice of site for CLASSIC, as there is a lot of field data for Scotty Creek and for moss NPP. The model was ran two times to simulate an upland area (forest on a permafrost plateau) and a wetland area (bogs and fens). There is observation data for a wetland area and for a heterogeneous area (which includes both upland and wetland areas). A partitioning of both simulations was used for comparison with observation data for the heterogenous area. These fractions used for partitioning (already existing data) vary in time with wind speed and direction. A comparison between the observations and simulations of physical quantities such as sensible heat and latent heat suggests that the wetland simulation does not have enough water and that there is too much vegetation simulated by the model.

Revising and updating the Glossary of Permafrost and Related Ground-Ice Terms: a CPA project | *Antoni Lewkowicz*

The Permafrost Terminology Action Group (PTAG) of the Canadian Permafrost Association was formed in January 2021 to update the Glossary. Most of the 400 existing entries are based on knowledge and usage from 1988 or earlier. Using a consensus-based approach, these entries and their associated definitions, comments and references are being systematically reviewed in relation to current use and their suitability for controlled vocabularies and ontologies. Significant advances, reflecting the explosive growth in permafrost research over the past 30-40 years as well as the increasing diversity of scientific disciplines involved, underline the need for a revision. PTAG is committed to operating transparently and all changes will be traceable. An illustrated plain-language version, focussing on key terms, will also be developed for use in education and by non-specialists and the media. The revised version of the Glossary and the plain-language version are planned for completion prior to the 2024 Whitehorse International Conference on Permafrost.

Quantifying confidence in simulations of permafrost variables | *Hannah Macdonell*

Models used to simulate permafrost variables such as ground temperature are important tools for understanding the current state and future conditions of permafrost. However, few objective methods of establishing model accuracy exist for permafrost environments. Additionally, models often range in their performance given different conditions such as terrain type or seasonality. The objective of this research is to (1) identify patterns in ground-temperature model performance under different testing conditions and (2) to develop a quantitative measure of ground-temperature model performance in permafrost zones.

Application of empirical correlations for estimating thaw settlement | *Zakieh Mohammadi*

Climate warming in high latitude regions has impacted permafrost conditions, thus threatening the safety and serviceability of the infrastructures built on permafrost. Thaw-induced settlement is the most common type of geohazard observed in permafrost regions. Reliable estimation of the thaw-settlement is required for designing and maintaining the safety and serviceability standards throughout the life cycle of infrastructures. Current practice for estimating settlement uses empirical correlations relating permafrost and sediment index properties to thaw strain. This study reviews the available thaw settlement correlations and illustrates their applicability by comparing the estimated thaw strain with laboratory thaw settlement results published for approximately 170 samples from the Nunavik region of Quebec. This comparison shows large dispersion between the measured and estimated thaw strain, with the applied correlations underestimating thaw strain for the majority of samples, in particular ice-rich samples. This can be partly attributed to the proposed correlations being established based on a wide scatter of data points covering all sediment and permafrost types. Since the thaw settlement properties of soil are highly dominated by the compositions and fabric of the soil, developing a unique relation between index properties and thaw settlement properties for different soil types and ice conditions would improve the correlation coefficient and our confidence in permafrost thaw settlement predictions.

Measuring surface displacement using winter SAR | *Allison Plourde*

The project goal is to measure the permafrost active layer dynamics simultaneous with snow depth. The dry snowpack is refractive to radar and results in a phase difference in the backscatter. To measure the deformations of the permafrost active layer in winter, this phenomenon must be accounted for. The difference between the snow phase and active layer deformation will be measured using InSAR with corner reflectors at test sites along the Inuvik-Tuktoyaktuk Highway (ITH). The satellite measurements will be validated with in-situ measurements from a snow depth sonic ranger and tilt logger.

Permafrost core characterization using gamma ray attenuation and industrial computed tomography scanning | *Joel Pumple*

The physical properties of permafrost cores are largely measured using destructive methods. These approaches are time-intensive and sacrifice critical samples collected at great expense. The development of rapid, non-destructive methods to quantify permafrost physical properties shows great promise, but is still poorly developed. In this study, we assess the potential of gamma ray attenuation and industrial computed tomography (CT) scanning to measure physical properties, including density and volumetric ice content, in a range of permafrost cores in the newly developed Permafrost Archives Laboratory at the University of Alberta. We describe the development of calibration standards and individual capabilities for both a GEOTEK multi-sensor core logger (MSCL; including imaging, magnetic susceptibility, non-contact resistivity and gamma density), and a Nikon XTH 225 industrial micro CT scanner. These results are compared with established destructive methods for permafrost-core analyses. The MSCL has a higher throughput capacity, and lower cost per metre of core, compared with the micro CT scanner. MSCL, once calibrated, shows the potential for processing 10s of metres per day to generate high quality images, magnetics and density data. Gamma density data is broadly comparable with CT-generated density measurements (derived from linear attenuation of x-rays), but represents a narrow transit of the core compared with the potential for whole core analyses via CT scanning. CT scanning still remains one of the most useful tools, but is limited by the relatively high costs and time required to image cores. We have found that a combination of MSCL for the rapid characterization of cores, complemented by detailed CT imaging, on a more limited subset of samples including quantitative analyses, provides a useful workflow for permafrost projects.

Initialization (spin-up) of permafrost models |

Cameron Ross

Initialization (spin-up) of a numerical ground temperature model is a critical but often neglected step for solving heat transfer problems in permafrost. Improper initialization can lead to significant underlying model drift in subsequent transient simulation, and distort the effects on ground temperature from future climate change or applied infrastructure.

Spin-up equilibrium is often simply declared after a specified number of spin-up cycles, or occasionally when a certain inter-cycle-temperature-change threshold is met simultaneously at all depths, such as $\Delta T \leq 0.01°C$ per cycle. We investigated increasingly refined threshold criteria for determining an equilibrium state in a variety of permafrost models, and found most to prematurely indicate equilibrium in multiple model scenarios. The implications of selected threshold criteria are examined in follow-up transient analyses and show that warm permafrost models can be highly sensitive to initial temperature profiles based on the criterion utilized. A combination of equilibrium criteria and visual confirmation plots is recommended for evaluating and declaring equilibrium in a spin-up simulation.

Numerical analysis of geocell-supported Hudson Bay Railway embankment subjected to the permafrost degradation | *Payam Sharifi*

The Hudson Bay Railway (HBR) is a rail corridor in Northern Manitoba, which passes all permafrost terrain, from continuous to sporadic. Every year, the rail has locations which undergo differential settlements, which HBR refers to as termed "sinkholes" by HBR. Recently, HBR has used geocells, a common reinforcement technique in their soft foundation to improve the support of the degrading permafrost and underlying peat layer. In this study, thermo, hydro and mechanical processes (uncoupled), using the finite element program GeoStudio, are considered to predict thaw settlement of a typical HBR rail embankment subjected to 50-year climate warming scenarios at the locations of Churchill and Gillam.

Increases in costs associated with maintaining highway infrastructure due to climate change in Yukon | *Astrid Schetselaar*

Near-surface permafrost thaw due to increasing temperatures has been a main cause of damage to road infrastructure as the ground's bearing capacity is significantly reduced and subsequently subsides (Nelson et al., 2001). Other road damage is caused by road washouts and landslides from increased precipitation. Such damage to road infrastructure will have significant economic consequences for the North as required maintenance increases.

The highway network in the Yukon traverses both continuous and discontinuous permafrost and is widely used to support both the economic and social development of the territory. The objective of this research is to assess the increases in highway maintenance costs associated with climate change in Yukon and establish the differences in these cost increases among the permafrost zones (e.g., sporadic, discontinuous, extensive discontinuous, and continuous). Through analysis of long-term (1995-2021) financial data associated with road maintenance activity, this research will provide an empirical basis for climate change-induced damage and may guide policy recommendations for sustainable highway infrastructure in northern Canada.

Learning about rock faces in mountain permafrost regions of western Canada | *Emilie Stewart-Jones*

The link between climate change, permafrost degradation and rock falls is undeniable. In the event of a rock fall event, we want to know how and why it occurred, prompting questions around its relationship to permafrost degradation or warming. However, without a permafrost probability map or merely a general understanding of permafrost distribution in the area, it is difficult to even begin to address these questions. Using a process-based model, the environment-permafrost relationship in rock walls of Western Canada is explored to improve estimations of permafrost existence and its thermal condition, and by extension our understanding of rock wall stability in the context of climate change. The project aims to understand: (1) how environmental conditions such as slope, aspect, altitude, and latitude affect thermal conditions of rock walls, and (2) how the depth of thaw or of unstable permafrost of rock walls has changed over the last 40 years.

Constructing a 3D ground ice map from training on a limited borehole data set | *Bingqian Zhang*

The thawing of sub-surface ice affects neighborhood ecosystems and infrastructures. Knowing where ice exists underground is crucial, but borehole measurements are expensive. With limited data and three types of predictor models, we interpolate and predict the existence of ground ice to form a 3D map.