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Frozen Ground

THE ANNUAL NEWS BULLETIN OF THE
INTERNATIONAL PERMAFROST ASSOCIATION
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Words from the President

BY CHRIS BURN,
CARLETON UNIVERSITY, CANADA

Measuring greenhouse gas fluxes at sunset in Churchill, MB, Canada (August 2022). **IPA Photography Contest Winner: Geert Hensgens** (Vrije Universiteit Amsterdam, Netherlands).

The President's Letter is normally an upbeat message, full of gratitude for the past year and excitement about the next. This one is different, but not by choice.

We have reached a juncture that I had hoped this time last year, in late February, we would not meet. All politics are local and in this case barriers of language, propaganda, distance, and history make it impossible to comprehend the specific contexts that are represented in our news feeds by a horrific reality. In North America we are distant from the European theatres of war. We may have relations and close friends who feel the chill of fear and experience the intense anger that stories from the front lines evoke. But we are mentally apart, though perhaps only a few miscalculations away from that changing. It may make possible a greater objectivity towards the overwhelming subjectivity of grief, pain, and destruction, but no end seems in sight. In contrast, European members of the IPA find war on their doorstep.

This is the first war during the IPA's existence that has involved many of our member countries indirectly. There is conflict with one of our founding nations, and this is deeply regretted by all permafrost scientists and engineers that I have spoken with. The challenges facing permafrost science and engineering in our encounter with climate change that is more rapid and deleterious to permafrost conditions than at any point in the recent past are not defined by national boundaries. Permafrost scientists and engineers in many countries value and respect the knowledge, contributions, and experience of our Russian colleagues. We recognize the critical role that Russian permafrost regions will play in changes to the global carbon cycle, to understanding hazard development in ice-rich terrain, and in access to resources in the Arctic Ocean as the sea ice-free season extends. But we are present in a very difficult reality.

Many European and other governments have imposed sanctions and restricted or forbidden institutional contacts with Russian agencies. In Canada, for example, federal government scientists and agencies are prohibited from participating in any meeting involving Russian

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agencies or their representatives. This includes our adhering body to the IPA. There does not appear to be any prospect of a swift resolution to the situation. In fact, our umbrella body, the International Union of Geological Sciences (IUGS), has frozen its activities with Russia.

The IPA's constitution makes clear that we are not to obstruct participation in our scientific activities on many grounds, including nationality. Our purpose is advancement of scientific and engineering knowledge and practice. At our conferences, we meet as individuals focused on improving our ability to manage permafrost terrain conditions and behaviour, irrespective of location. The growth of interest in our fields and subdisciplines during the last 15 years indicates recognition of the key role of polar regions and permafrost in our changing climate and its effects. This is not the time to erect further impediments to participation by individuals in IPA activities.

Membership in the IPA Council is not, however, open to individuals. Instead, each country is represented by an adhering body. These bodies have a range of affiliations with their country's government. Our challenge is to find a path that will allow the IPA Council to continue to do its work and will facilitate resumption of normal conditions once the present situation is resolved. This means that in April we must make decisions that will allow the Council to meet in person at EUCOP6 in Puigcerdà, Catalonia, Spain. There is a lot of consultation to take place before then, but I would like to thank all the Council representatives who are contributing most constructively to reaching a resolution.

In the midst of this turmoil, we eagerly await EUCOP6 organized by Marc Oliva and his team (see p. 5). There have been national gatherings as the pandemic restrictions have eased, but this will be the first in-person IPA conference since 2019. If the number of abstracts received is a good guide, many of us are looking forward to renewing our collaborations and friendships in June. In Canada we also look forward to the ICOP in Whitehorse, Yukon, next year (see p. 5). Planning for this conference is well underway with a Proceedings volume once again. The papers of record will need to be prepared this year.

For various reasons we have a better financial situation than anticipated, and we will principally use these funds to support our early career researchers through PYRN, such as their attendance at EUCOP6. Finally, the IPA recently approved two new Action Groups on the Himachal Himalaya and Arctic-boreal carbon flux (see p. 12).

I hope to see you soon, and I hope for cessation of the war and a lasting peace.

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North Yukon Permafrost Conference

BY CHRIS BURN (PRESIDENT, IPA) & KUMARI KARUNARATNE (PRESIDENT, CPA)

In August 2022, the North Yukon Permafrost Conference was held in Dawson City, in joint collaboration and organization by the First Nation of Na Cho Nyak Dun (FNNND), the Tr'ondëk Hwëtch'in First Nation (THFN), the Vuntut Gwitchin First Nation (VGFN) and the Canadian Permafrost Association (CPA).

This was the first science and engineering conference organized by self-governing First Nations with a national geoscience organization. Chief Simon Mervyn (FNNND) enthusiastically responded to the idea in December 2020 and a steering committee with members from all four organizations initiated the event planning in 2021. The program and field excursions were explicitly arranged to hear First Nations' perspectives on the effects of climate change in central and northern Yukon, and to facilitate engagement by all participants.

We are familiar with the anticipated consequences of permafrost thaw. These include the increasing costs of infrastructure rehabilitation and the enhancement of climate change due to the impacts on carbon budgets. Relationships with Indigenous people, both formal and personal, and are critical in the long run for research and development projects. In northern Canada, we entered a new era with the signing of land claims and self-governance agreements. Heritage, interpreted as knowledge of a peoples' land, is considered in all of the modern treaties. In this context, heritage is not a purely historical concept as it is created daily. Research, the production of knowledge, generates heritage. Since heritage is under the jurisdiction of Indigenous governments, hence also is research within and about the traditional territories of First Nations.

The traditional territories in northern Yukon span continuous and extensive discontinuous permafrost. The terrain is ice-rich and thaw sensitive in places, and the physiography ranges from rugged mountains to flat plains. The traditional territory of FNNND is ~164,000 km^2 and crosses the border between Yukon and Northwest

Dawson City, YT, on the banks of the Yukon River, is the centre of the Traditional Territory of the Tr'ondëk Hwëch'in First Nation (THFN). The Moosehide Slide is visible in the background (see p. 38).

Field trip to the Klondike Goldfields; guided by Duane Froese (University of Alberta), Deputy Chief Simon Nagano (Tr'ondëk Hwëch'in Government), Elizabeth Hall (Government of Yukon), and Derek Cronmiller (Yukon Geological Survey).

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Territories. Northern parts of the traditional territory are the focus of research on widespread thaw slumping in Pleistocene basal glacier ice. The traditional territory of THFN includes the ice-rich yedoma deposits of the Klondike "mucks" that contain the oldest permafrost in North America. The cryostratigraphy of this permafrost is relatively well known from exposures in placer gold mines, which have also yielded many Pleistocene fossils, including *Nun Cho Ga*, the infant mammoth, found in June 2022. VGFN has the most northerly traditional territory, overlapping with the Inuvialuit Settlement Region to reach the Yukon coast. Permafrost research was initiated there in 2006 at the invitation of the community, and the lakes and lake-basins of Old Crow Flats have been foci of investigation.

The conference was graciously opened by Chief Roberta Joseph, of THFN, who outlined the many challenges faced with respect to management of a changing permafrost environment. Chief Simon Mervyn's remarks made clear that discussions should be focussed on achieving solutions to some of these issues.

The conference sessions began with addresses by Debbie Nagano of THFN, who emphasized heritage as described above, and Elder Mark Wedge of Carcross-Tagish First Nation, who spoke in refreshing detail about research as a process, development of relationships, and the relations between western science and traditional knowledge.

The conference then heard a contextualizing overview of permafrost in the region as preparation for field trips, which occupied the second half of the first day. The participants visited either the Klondike "muck" deposits, the unglaciated periglacial landscape on the westside of Yukon River, or to the southern Dempster Highway. The field excursions were led by First Nations' Citizens and scientists together.

Two days with five sessions followed, considering:

- Impacts of climate change on First Nations;
- Geohazards (including carbon);
- Climate change adaptation;
- Community infrastructure;
- Transportation infrastructure.

Each session began with keynote addresses and a panel discussion that was rooted in the practicality of managing changing permafrost terrain. The participants were then divided into small groups to inform the session topic with examples from regional experience and to consider approaches that lead to progress. Reports from these discussions were presented at the end of the meeting.

Field trip along the Top-of-the World Highway to visit the Moosehide Slide; guided by Antoni Lewkowicz (University of Ottawa), Debbie Nagano (Tr'ondëk Hwëch'in Government), and Peggy Kormendy (Tr'ondëk Hwëch'in First Nation).

Central Yukon has the prospect of substantial mineral development. The meeting emphasized the importance of:

1. Adequate site investigation for project planning;
2. Land use planning to provide the framework for development; and
3. The need to create carbon budgets for land within the footprint of mining activities, particularly with respect to wetland management.

The conference sessions were live-streamed and recorded throughout. These recordings are hosted on the CPA website and accessible with a CPA membership. The principal sponsor of the conference was the Climate Change Preparedness in the North Program of the federal government. This, and related, support, enabled a large delegation of Citizens from six Yukon First Nations to attend the meeting.

Breakout discussion groups at the Palace Grand Theatre, conducted after each theme panel.

CONFERENCES

6th European Conference on Permafrost (EUCOP6)

BY MARC OLIVA (UNIVERSITY OF BARCELONA, CATALONIA, SPAIN), LOCAL ORGANIZING COMMITTEE

The 6th European Conference on Permafrost (EUCOP6) will be held in Puigcerdà, Catalonia, Spain from **18-23 June 2023**. The conference, promoted by IPA-Spain, will provide interdisciplinary collaboration and joint initiatives between different research groups working on periglacial and permafrost subjects. The conference will include three days of plenary lectures, oral presentations and posters, combined with several local field trips across the eastern Pyrenees (Cerdanya, Núria, Andorra, etc). Two 3-day-long regional field trips across the Pyrenees will be organized before and after the conference.

Puigcerdà in the valley floor of the Cerdanya basin.

CONFERENCES

12th International Conference on Permafrost (ICOP2024)

BY LUKAS ARENSON (BGC ENGINEERING INC., CANADA), CONFERENCE CHAIR

The 12th International Conference on Permafrost (ICOP2024) will be held in Whitehorse, YT, Canada from **16-20 June 2024**. Whitehorse is the capital of the Yukon and is situated on the banks of the historic Yukon River in the Traditional Territory of the Ta'an Kwäch'än Council and the Kwanlin Dün First Nation.

The conference theme, *"Permafrost Thaw, Change and Adaptation: Integrating Perspectives"*, will address, through general and parallel sessions, keynote lectures, specific presentations, workshops, PYRN meetings, short courses and field trips, the most recent developments and stimulate technical and scientific discussions among academics, professionals, contractors, manufacturers, and students. 1-6 day, pre- and post-conference excursions are being planned along the Alaska Highway, the Dempster Highway, the Inuvik to Tuktoyaktuk Highway, and in the Takhini, Dawson, and Whitehorse areas.

Dempster Highway, Richardson Mountains, NT. Photo: Greg Elias (ARI).

The ICOP2024 organizing com-

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mittees are working towards a hybrid conference model with virtual access to selected elements of the conference with the main objective to bring together leading researchers, scientists, and engineers from around the world to discuss the latest developments and advancements in permafrost. Attendees may submit full-length peer-reviewed papers (6-8 pages) or extended abstracts by August 2023 and January 2024, respectively.

ACTION GROUPS

Rock glacier inventories and kinematics (RGIK)

BY REYNALD DELALOYE & SEBASTIÀN VIVERO (UNIVERSITY OF FRIBOURG, SWITZERLAND)

The *'Rock glacier inventories and kinematics (RGIK)'* Action Group launched at EUCOP5 in Chamonix, France, is entering the final phase of development with the support of the IPA (2018–2023).

Its intended actions are to (1) coordinate the definition of standard guidelines for inventorying rock glaciers globally, including refined indications on the activity rate, and (2) promote Rock Glacier Velocities (RGV) as a new associated parameter of the GCOS ECV Permafrost, representative of the evolution of mountain permafrost.

In 2022, final versions of the baseline (RGI_BC) and practical concepts (RGI_PC), as well as an illustrated atlas for the inventory of rock glaciers were thoroughly revised by the Rock Glacier Inventory (RoGI) Committee. In parallel, the document for assigning a semi-quantitative kinematic attribute to inventoried rock glaciers (RGI_KA) was also updated thanks to the support provided by the ESA CCI+ Permafrost project. The integration of these RoGI guidelines into a single document is expected to be completed before June 2023.

Rock Glacier Velocity (RGV) has been officially accepted as a new associated parameter to the ECV Permafrost under the framework of GTN-P and GCOS in 2022. RGV is now included in the current GTN-P and GCOS implementation plans.

Since March 2022, RGIK online seminars have been scheduled every month (1st and 2nd semesters).

Participants on the 2nd day of the hybrid RGIK committees meeting in Fribourg, Switzerland (24-25 November 2022).

The goal of these seminars is to open the floor to members of the Action Group to share their research, create a community event and foster informal exchanges. Around 30 participants attended each seminar. This success has prompted its continuation with new speakers confirmed for the 1st semester in 2023.

The RoGI and RGV committees met in November 2022 for two days to discuss the formal governance structure, long-term strategy, and scientific goals of RGIK. An RGIK workshop will be held at EUCOP6 to support the elaboration of a roadmap for the future of RGIK activities after June 2023.

Anyone engaged in rock glacier research or curious about these spectacular landforms is welcome to participate in the Action Group via its mailing list, which comprises 195 subscribers from 25 countries in Asia, North and South America, and Europe (as of 2022).

Yettes Condjà rock glaciers (2600-2800 m.a.s.l.), western Swiss Alps. The rock glacier on the left is currently moving >3 m/yr at its lower central part.

Standardized methods across Permafrost Landscapes: from Arctic Soils to Hydrosystems (SPLASH)

BY FRÉDÉRIC BOUCHARD (UNIVERSITÉ DE SHERBROOKE, CANADA), ON BEHALF OF THE 'SPLASH' TEAM

Permafrost thawing - from localized and abrupt to gradual and widespread - impacts Arctic hydrology and the mobilization of mineral and organic materials, from formerly frozen soils to terrestrial ecosystems and surface water bodies. Mineral and organic components interact along the 'lateral continuum' (from soils to aquatic systems), affecting biogeochemical cycles with strong spatial and temporal heterogeneities. Thus, there is a need for a set of unified protocols to capture changes in the lateral transport of both mineral and organic matter across Arctic permafrost landscapes.

The main objective of the *'SPLASH'* Action Group is to provide a suite of standardized field approaches for sampling soil, sediment, and water across different types of permafrost landscapes. SPLASH is a transdisciplinary initiative bringing together researchers from 11 countries (both ECRs and senior experts, referred to as the SPLASH team). We aim to coordinate sampling strategies along the lateral continuum used by existing research initiatives and networks (e.g., T-MOSAiC, Permafrost Carbon Network). This will contribute to the ongoing effort on standardizing sampling strategies, improving data comparison, synthesis, and upscaling of results.

Lake water sampling near Beaver Creek, YT (August 2022). Photo: Frédéric Bouchard.

After two years of slower-than-expected fieldwork progress, many of us were finally able to collect samples from soils and aquatic systems (lakes, streams, and groundwater) based on the SPLASH approach. Some examples include:

- Mackenzie River Delta, NT, Canada: collected lake sediments to investigate organic matter from the river and permafrost degradation dynamics;
- Beaver Creek, YT, Canada: PRISMARCTYC, supported by the Belmont Forum, has started to study multiple impacts of permafrost degradation on soils, human societies, water resources and carbon cycle;
- Eight Mile Lake, AK, USA: collected samples from headwater streams, groundwater wells and a larger river to investigate the degradation of organic carbon and its association with mineral elements along the aquatic continuum;
- Abisko, Sweden: collected soil, vegetation and water samples in summer and fall to investigate geochemical coupling between organic matter (carbon & nitrogen) and mineral elements (vanadium & molybdenum) and controls of soil hydric status and vegetation communities on organic carbon stocks and stabilization.

Like everyone in the permafrost community and beyond, we cross our fingers to be able to conduct field sampling at 'full throttle' in 2023. We are working on a practical, hands-on manuscript focused on field protocols, which we hope will be submitted by the end of this year. Finally, we plan to gather the SPLASH 'community' (members and non-members) at EUCOP6. We hope to see you there and fully engage in 'splashy' discussions!

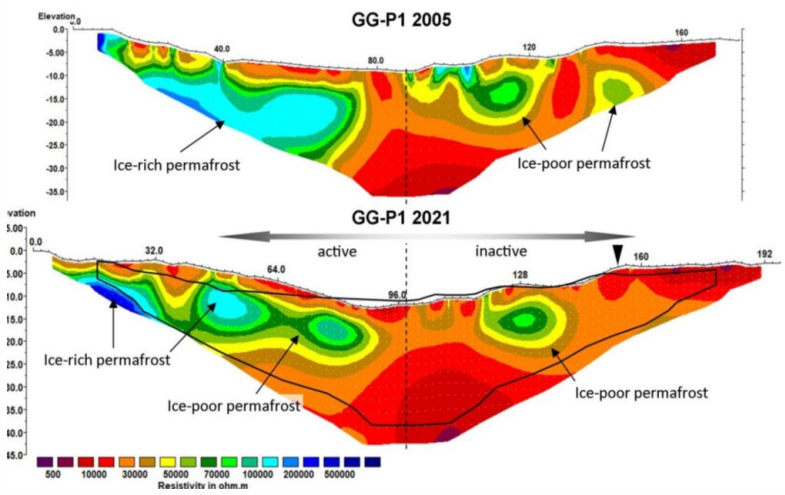
Lake sediment sampling in the Mackenzie Delta, NT (March 2022). Photo: Maarten Lupker.

Towards an International Database of Geoelectrical Surveys on Permafrost (IDGSP)

BY CHRISTIAN HAUCK & COLINE MOLLARET (UNIVERSITY OF FRIBOURG, SWITZERLAND)

'Towards an International Database of Geoelectrical Surveys on Permafrost (IDGSP)' launched in 2021 with the main objective to bring together the international community interested in geoelectrical measurements on permafrost and laying the foundations for an operational IDGSP. We aim to initiate a database for geoelectrical data and develop guidelines for Electrical Resistivity Tomography (ERT) survey repetition and data processing. We promote and support the repetition of existing legacy geoelectrical measurements to yield the resistivity evolution over time and detect temperature and ground ice/water changes in response to climate changes. By archiving geoelectrical data on permafrost, the long-term goal is the reanalysis of the full database and its climatic interpretation.

The database structure initially contained tables with metadata and data (raw and inverted). In 2022, we improved and enlarged it to include tables with information about filtering parameters, inversion parameters and data quality. Further tables may be modified or added according to the need, as it is flexible enough to allow modification.

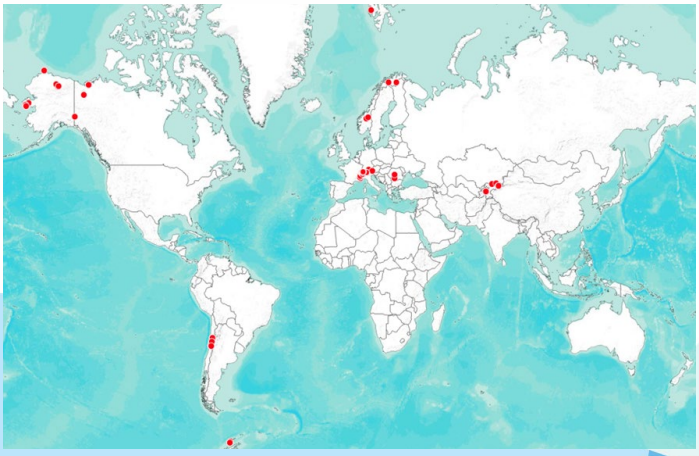


Tomograms of historical (2005) and repeated (2021) profiles GG-P1 on an active (left) and inactive (right) part of the Gianda Grischa rock glacier (taken from Buckel *et al.* submitted).

The international metadata call launched in 2021 was well received with metadata from 20 different principal investigators (PI) archived in the database. PIs come from 14 different affiliations and 10 countries. The database now includes metadata from ~360 profiles, including ~500 surveys in 15 countries.

The call for resistivity metadata is still open and metadata are continuously added to the database (old and new data are valuable).

In mid 2022, we launched the call for resistivity data, and started to receive a few contributions but are expecting to receive more data contributions in 2023 and plan to include the new resistivity data.



Locations of single surveys on permafrost which have been included in the IDGSP database.

Several IDGSP members gathered at the EGU General Assembly in May 2022, with an informal meeting of the physically present members of the Action Group. At the 6th International Workshop on "Geoelectric Monitoring" (GELMON) in November 2022, we had an exciting online session entitled *"Monitoring Permafrost"* including 6 talks linked with the Action Group and mostly presented by members of the steering committee. In 2023, we will hold the first official physical meeting of the Action Group prior to the ice-breaker dinner at EUCOP6. Numerous action group members will be actively present as session conveners. A session dedicated to the Action Group is entitled: *"Monitoring of electrical and electromagnetic properties in frozen ground (including the IPA Action Group IDGSP)"*.

RTS InTrain: Retrogressive thaw slump inventory and machine learning training-data development

BY ANNA LILJEDAHL (WOODWELL CLIMATE RESEARCH CENTER, USA), INGMAR NITZE (AWI, GERMANY), JURJEN VAN DER SLUIJS (NWT CENTRE FOR GEOMATICS, CANADA), NINA NESTEROVA (AWI, GERMANY), MARINA LIEBMAN (EARTH CRYOSPHERE INSTITUTE, RUSSIA), ASHLEY RUDY (NTGS, CANADA) & ALEXANDRA RUNGE (AWI, GERMANY)

The *'Retrogressive thaw slump inventory and machine learning training-data development (RTS InTrain)'* Action Group has 44 members from China, Canada, USA, Russia, Switzerland, Finland, and Germany, and a range of organizational backgrounds, scientific disciplines and career stages. RTS InTrain is organized through five subgroups:

1. Inventory of active RTS research sites, including field and remote sensing studies. Lead: Nina Nesterova.
2. Definitions. Revisiting and clarifying basic definitions and provision of the classic RTS case and end-members of the RTS process and form. Leads: Ashley Rudy, Steve Kokelj, Marina Leibman.
3. Standard protocol for RTS mapping. Create a common protocol for digitizing footprints of RTS for use in machine learning (ML) applications e.g., minimal requirements/attribution and reliability assessment. Leads: Ingmar Nitze, Jurjen van der Sluijs.
4. Cyberinfrastructure to support ML applications. Computing infrastructure to enable community development and leveraging of RTS inventories for machine learning purposes. Leads: Anna Liljedahl and the Permafrost Discovery Gateway development team.
5. Video tutorials. Information resources on how to digitize RTS footprints according to the established protocol and how use various PDG tools. Leads: Tabea Rettelbach and Anna Liljedahl.

The subgroups have been working independently and in different manners. Subgroup (2) elaborates extensively on the different use of RTS terms and identifies common definitions, especially combining Russian and Canadian expertise. We discussed what type of features should be described and in terms that are accepted by the international RTS research community. A summary of terminology used in the literature was compiled that characterizes RTS as a landform and includes RTS sub-elements and describes RTS as a relief-forming process. So far, six researchers from Germany and Russia discussed terminology and prepared a summary to be evaluated further by Canadian and US experts. Subgroup (1) continuously collected RTS study sites and the growing inventory highlights RTS research efforts and their regional focus. The mapping team (3) conducted an experiment where contributors were asked to digitize the footprints of RTS on remote sensing imagery at two different sites, to understand the consistency of manually labelled data and uncertainty if these were pooled for pan-Arctic ML applications. The experiment results, based on the effort of 12 different researchers, highlighted the

Example of RTS showing active, inactive, reactivated, and ancient sections that challenge the creation of robust geospatial inventories and ML detections. Source: Northwest Territories Geological survey and NWT Centre for Geomatics (Thermokarst Mapping Collective, 2023).

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commonalities and differences of the researcher's approaches with clear differences between scientific backgrounds and local knowledge of the analyzed locations. It further shows the need for clear guidelines how to create training labels for ML approaches compliant with geomorphological definitions. The setup and outcome of the digitization experiment will be presented at EUCOP6. Alexandra Runge is also organizing an RTS InTrain workshop that welcomes anyone interested in mapping of permafrost thaw features using ML applications.

ACTION GROUPS

Development of a pan-Arctic drained lake basin product

BY HELENA BERGSTEDT (B.GEOS, AUSTRIA) & BENJAMIN M. JONES (UNIVERSITY OF ALASKA FAIRBANKS, USA)

Lakes and drained lake basins (DLB) are ubiquitous landforms in permafrost regions. Despite the recognition by local to regional studies of the long-term dynamics of lake formation and drainage evident in the abundance of DLBs in Arctic permafrost lowlands in parts of Arctic Alaska, Russia, and Canada, a pan-Arctic assessment of DLB distribution and their carbon stores has never been attempted. The *'Development of a pan-Arctic drained lake basin product'* Action Group was established to coordinate a pan-Arctic scale effort needed to better understand the importance of DLBs in permafrost-regions.

Since 2020, we have focussed on the development of a pan-Arctic DLB product that aims to fill this knowledge gap in permafrost-region landscapes with implications for global-scale climate feedbacks. An extensive pan-Arctic DLB dataset for remote sensing and field data will improve the representation of Arctic landscapes in global models, aid upscaling efforts, and enhance our understanding of DLBs in the context of permafrost landscapes.

We include several early career researchers (ECRs) with multi-disciplinary skills in field studies, carbon science, permafrost science, and remote sensing. Helena Bergstedt, Benjamin Jones, Ingmar Nitze, and Alexandra Veremeeva are co-leading the DLB remote sensing effort. Guido Grosse is co-leading the basin age and carbon stock database development with Juliane Wolter, Louise Farquharson, and Benjamin Gaglioti. Additional leadership is provided by Mikhail Kanevskiy, Amy Breen, Anna Liljedahl, Annett Bartsch, Pascale Roy-Lévéillee, Trevor Lantz, Frédéric Bouchard, Matthias Fuchs, and Gustaf Hugelius. Dr. Kenneth Hinkel is providing guidance based on his many years of research on DLBs in northern Alaska.

A remote sensing based DLB data product of the Alaska North Slope was published in 2021 and forms the basis for ongoing efforts to develop the pan-Arctic DLB data product for lowland permafrost regions.

- Bergstedt, H., *et al.* (2021). Remote sensing-based statistical approach for defining drained lake basins in a continuous permafrost region, North Slope of Alaska. *Remote Sensing*, 13(13). DOI: 10.3390/rs13132539.

A first version of the pan-Arctic data set, including regions in Siberia, Canada and Alaska was presented at the 2022 AGU Fall Meeting.

- Bergstedt, H. *et al.* (2022). Mapping Drained Lake Basins in Permafrost Lowlands on a Circumpolar Scale. *AGU Fall Meeting*, Chicago, IL & Online, 12-16 December 2022.

A comprehensive review of lakes and DLB systems in lowland permafrost regions was also published.

- Jones, B.M., *et al.* (2022). Lake and drained lake basin systems in lowland permafrost regions. *Nature Reviews Earth & Environment*, 3(1), 85-98. DOI: 10.1038/s43017-021-00238-9.

This review, published by a multidisciplinary team of experts was led by Benjamin Jones and contextualizes an extensive body of international research concerning L-DLB systems in the pan-Arctic, focusing primarily on research during the last decade.

In 2022, we held several online meetings with external researchers interested in DLB systems, focussing on the development of the pan-Arctic data product, and compiling a comprehensive DLB age database.

During the 16th International Circumpolar Remote Sensing Symposium in Fairbanks, AK, in May 2022, we held a side meeting to discuss the integration of dates from literature into the DLB age database. As a finale to the Action Group, a DLB session was held at the 2022 AGU Fall Meeting. The session received 9 abstracts of which four were presented by students/ECRs. We provided 1500€ in student travel support for AGU. We hosted a social event for 26 attendees in the 2twenty2 Tavern in Chicago. The event gave researchers and ECRs a chance to exchange ideas related to DLBs in permafrost areas.

While the time of the DLB Action Group is coming to an end, future outcomes include the publication of the pan-Arctic dataset and database with the accompanying publications, more sessions dedicated to DLBs, and conferences such as EUCOP6 and ICOP2024.

The Permafrost-Agroecosystems Action Group

BY MELISSA WARD JONES (UNIVERSITY OF ALASKA FAIRBANKS, USA) AND MATHIAS ULRICH (GERMANY ENVIRONMENTAL AGENCY, GERMANY)

Permafrost-agroecosystems are highly heterogenous socio-ecological systems that include animal husbandry practices (e.g., reindeer and yak herding) and crop cultivation in areas that contain permafrost. These systems affect food security, culture and livelihoods and are therefore particularly sensitive to permafrost degradation processes, surface stability, erosion, water availability and other ecological changes. The goals of the action group are (1) to provide a venue where an international group of scientists spanning many disciplines within the physical and social sciences can network and exchange ideas, and (2) develop a global map of permafrost-agroecosystems.

The *'Permafrost-Agroecosystems'* Action Group is currently composed of 33 members from seven countries. We met virtually 5 times throughout the 1st year and hosted two webinars. The 1st webinar was by PhD student Mindy Price (University of California Berkely) titled *"Developing a framework for agroecology in the North"* and the second by Dr. J. Otto Habeck (Universität Hamburg) titled *"Land improvement in permafrost areas: melioratsiia and intended forms of environmental change in the Republic of Sakha (Yakutia)"*.

We are currently collaborating on a manuscript focused on providing an overview of the Northern Hemisphere permafrost-agroecosystems with a series of case studies including reindeer herding in Fennoscandia and western Siberia, horse and cattle husbandry in the Sakha Republic, pastoralism in the central Himalayas and Mongolia, Indigenous agriculture in the Northwest Territories, and crop cultivation in Alaska.

A joint poster presentation in the *"Permafrost and Society"* session at EUCOP6 will be focused on the manuscript outcomes. The session will be co-convened by Melissa Ward Jones and J. Otto Habeck. Session topics include research that intersects permafrost and land use, including permafrost-agroecosystems.

In 2023, we will continue to create the permafrost-agroecosystem map product and finalize the manuscript. Additional webinars and virtual meetings are planned for networking and knowledge exchange.

Right: farm field in Fairbanks, AK, showing signs of permafrost degradation and ice wedge melt, including mounds, depressions and thaw ponds. Source: 2017 Pictometry image mosaic by the Fairbanks North Star Borough GIS Web Services.

Bottom: Yak by an aufeis sheet near Terelj, north-central Mongolia, an area with discontinuous permafrost. Photo: J. Otto Habeck.

NEW ACTION GROUPS

Himalayan PERmafrost Consortium (HiPERC)

BY MILAP C. SHARMA (JAWAHARLAL NEHRU UNIVERSITY, INDIA)

HiPERC comprises several international institutions working collaboratively on geophysical research in the Himalayan cryosphere, including Jawaharlal Nehru University and Inter-University Accelerator Centre (India), Universität Heidelberg (Germany), North Carolina State University (USA), and University of Dundee (UK).

HiPERC will use micro-devices to monitor fluctuations in permafrost-related parameters in the Himalayas. This study will incorporate and highlight the socio-economic importance of permafrost with regard to availability of water for vulnerable Trans-Himalayan mountain communities and their long-term survival in a changing environment. The research will provide insight into the dynamics of permafrost in the water-scarce arid and semi-arid Himalayan regions.

From June-July 2022 permafrost was identified at several locations in the Higher and Trans-Himalayan region of Himachal Pradesh. Fieldwork from June-September 2023 will include instrumentation to ground truth remote sensing-GIS techniques used to assess permafrost processes. We will provide a detailed regional inventory of permafrost landform features, geophysical assessments of permafrost parameters, and an understanding of the regional thermal regime.

HiPERC is also working towards developing an evolutionary history of the permafrost landscape using various methods, including Total Organic Content (TOC), AMS ^{14}C dating, carbon isotopic ratio, X-ray fluorescence spectroscopy (XRF) and exposure ages. We will also collect water samples to measure stable water isotopes of hydrogen and oxygen in order to obtain more information on the different sources of water in the study area (e.g., glaciers, seasonal snow cover, permafrost and rainfall). This work will further strengthen and augment the few existing studies on the occurrence of permafrost in the region.

- Brombierstäudl D. *et al.* (2022). Spatial and temporal dynamics of aufeis in the Tso Moriri basin, eastern Ladakh, India. *Permafrost and Periglacial Processes*, 34(1). DOI: 10.1002/ppp.2173.

HiPERC will present its aims, objectives and outcomes at international conferences. We aim to solidify and promote permafrost research in India.

NEW ACTION GROUPS

ABCflux v2

BY ANNA-MARIA VIRKKALA & SUE NATALI (WOODWELL CLIMATE RESEARCH CENTRE, USA)

ABCflux v2 is focused around an Arctic-boreal carbon flux data compilation and synthesis activity.

- Virkkala, A.-M. *et al.* (2022). The ABCflux database: Arctic–boreal CO2 flux observations and ancillary information aggregated to monthly time steps across terrestrial ecosystems. *Earth Systems Science Data*, 14. DOI: 10.5194/essd-14-179-2022.

The activity is important because it supports research to better understand carbon cycling across the permafrost region, which is critical for predicting current and future carbon emissions from thawing permafrost - a key unknown driver in global climate feedbacks. Our main objective is to produce and publish a database which will include monthly carbon flux data measured with various techniques (i.e., eddy covariance and chamber) as well as environmental and ecological site-level data relevant to understanding the drivers of ecosystem carbon exchange (e.g., air temperatures, vegetation type, permafrost conditions). We invite all permafrost researchers working in Arctic and boreal regions; in terrestrial and aquatic environments; and studying CO_2 and CH_4 fluxes to contribute to this effort. Beyond the data compilation, we aim to provide a networking platform that encourages collaboration across a range of ecosystems and research questions.

To disseminate this new synthesis information, we will pro-

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duce documents summarizing the best practices for flux data compilation and research ideas that can be asked based on the database, and a map that visualizes the existing sites and their flux magnitudes and trends across the Arctic-boreal region. To reach our goals, we will (1) advertise the Action Group activities at key conferences (e.g., AGU and EGU), (2) organize online mini-workshops to help researchers prepare their data for the synthesis and share their site-level knowledge to the community, and (3) organize a side event at a conference to plan and produce the flux synthesis map and start discussions related to potential research ideas using the database.

A research scientist, Anna-Maria Virkkala, and research assistant, Isabel Wargovsky, working at Woodwell Climate Research Center, USA, supported by the Action Group team, will work full time to produce the database and other deliverables. Over all, this Action Group will provide critical resources for estimating and understanding the magnitude, drivers, and changes of ecosystem carbon exchange across the entire permafrost region.

INTEREST GROUPS

Permafrost & Carbon Budgets (IPaC)

BY GUSTAF HUGELIUS & JUSTINE RAMAGE (STOCKHOLM UNIVERSITY, SWEDEN), ANNETT BARTSCH (B.GEOS, AUSTRIA), JOHANNA TAMMINEN (FINNISH METEOROLOGICAL INSTITUTE, FINLAND) KIMBERLEY MINER & CHARLES MILLER (JET PROPULSION LABORATORY, CALIFORNIA INSTITUTE OF TECHNOLOGY, USA)

Following an earlier IPaC interest group survey, an updated review of carbon and nitrogen budgets in permafrost regions was identified as a key research priority. In 2022, the IPaC team worked towards this goal within two international efforts: REgional Carbon Cycle Assessment and Processes-2 (RECCAP2) and Arctic Methane and Permafrost Challenge (AMPAC). RECCAP2 aims to collect and integrate regional carbon and nitrogen budgets for 10 land regions around the world, e.g., the permafrost region. Within RECCAP2-permafrost a large community effort has been made to assess carbon and nitrogen budgets for the time period 2000-2020, using both top-down (atmospheric inversion models) and bottom-up (process models and ecosystem upscaling) approaches. The coordination of this work has been co-funded by Nunataryuk and the Bolin Centre for Climate Research, Stockholm University.

AMPAC is an ESA and NASA collaborative community initiative to help tackle the scientific challenges in estimating current and future methane fluxes from the Arctic region. Under this umbrella, *"AMPAC-Net"* is a ESA funded project to foster collaborations and scientific exchange on the Arctic methane challenge.

AMPAC-Net hosted a virtual workshop in connection with the ESA 4th Carbon from Space (25 October 2022) and the 1st physical workshop at the Finnish Meteorological Institute (FMI) in Helsinki (16-18 January 2023). The workshop included >50 participants from >5 countries and >10 different disciplines. Discussion covered all six guiding AMPAC goals: (1) Engaging the Community, Workshops, Dialogue (2) Advancing EO products, novel methods, algorithms (3) Reconciling bottom-up & top-down approaches (4) Data catalogues, Open science and data sharing (5) Summer schools, training, outreach and education and (6) Networking, Visiting Scientist, Scientific Exchanges.

More activities and community efforts will follow in 2023!

Participants at the AMPAC-Net workshop at FMI, Helsinki, Finland (16-18 January 2023).

STANDING COMMITTEES

The Global Terrestrial Network for Permafrost (GTN-P)

BY DMITRY STRELETSKIY (GEORGE WASHINGTON UNIVERSITY, USA) & ANNA IRRGANG (AWI, GERMANY)

GTN-P 2ND GENERAL ASSEMBLY

Following the success of 2021, GTN-P held its 2nd Virtual General Assembly in November 2022 with over 30 participants. We focused on important news concerning the network, such as our plans for EUCOP6 and the release of the 2022 GCOS Implementation Plan. In a highlight presentation, Filip Hrbacek shared findings on permafrost temperature and active layer changes in Antarctica. The GTN-P Office collected the GTN-P country reports and will present a summary during the GTN-P workshop at EUCOP6.

GTN-P DATA SERVICE

Thanks to our international data providers and users, the GTN-P database is a primary database for the storage and retrieval of permafrost monitoring data. It was frequented 200-300 times per month in 2022 with the majority of users from USA, China, Germany, Canada and Russia, with many visitors connecting from Moscow, Washington D.C., Potsdam, Paris and Ottawa.

GTN-P AND WMO

Several standing committee (SC) members participated in the Permafrost Best Practice Task Team - established to define best practices for permafrost measurements that will be included in the updated WMO Guide no. 8. We enlarged our team with additional experts from the field of rock glacier velocity measurements, permafrost monitoring in the Arctic tundra and permafrost monitoring of the Third Pole region. We finished writing a first draft of most chapters and plan to release the Permafrost Best Practices for public review in summer 2023.

GTN-P AT EUOCOP6

We invite all national and young national correspondents and GTN-P friends to our GTN-P workshop. We look forward to bringing the GTN-P community together to discuss plans for our network and database development. We will use the workshop to elect new GTN-P SC members. If you would like to actively engage in the future of GTN-P, please submit your self-nomination.

We will also have a GTN-P session entitled *"Permafrost temperature changes and active layer dynamics: from local observations to global assessments of the permafrost system"* at EUCOP6 which aims to provide a forum for discussing, assessing, and planning permafrost observational activities in both hemispheres, progress in data preservation, management and dissemination.

STANDING COMMITTEES

Glacier and Permafrost Hazards in Mountains (GAPHAZ)

BY MARTA CHIARLE (CNR-IRPI, ITALY), MICHELE KOPPES (UNIVERSITY OF BRITISH COLUMBIA, CANADA), & HOLGER FREY (UNIVERSITY OF ZURICH, SWITZERLAND)

In 2022 GAPHAZ continued to play an active role in promoting the exchange of information and experience on glacial and permafrost hazards in mountains within the international scientific community and between the scientific and governmental communities, at the same time dedicating specific attention to correct and timely communication towards media. We pursue these objectives by:

- Keeping an open structure and inclusive orientation;
- Maintaining a list of experts on various topics of glacial and permafrost hazards; and
- Promoting and patronizing workshops and scientific sessions at conferences.

There are currently 192 subscribers to the GAPHAZ mailing list. In 2022 GAPHAZ members made major contributions to EGU 2022 (in particular to session *CR3.4 "Risks from a changing cryosphere"* co-sponsored by IACS and IPA). GAPHAZ also pro-

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moted a successful session on *ID21 "Glacier and permafrost risks in a changing climate"* at the International Mountain Conference (IMC22) in Innsbruck, Austria, with 13 contributions addressing a variety of hazards (glacial lake outburst floods, rockfalls and other permafrost-related hazards, ice aprons, rock glaciers and combined hazards). A lively open discussion on the relationship between scientists, local authorities, the media, and the public highlighted:

- Research is advancing rapidly, providing new tools and methods for hazard assessment and monitoring;
- Authorities are ready to receive the message, and scientists need to make further efforts to make scientific information easily accessible and understandable;
- Efforts are needed to move from hazard to risk;
- Scientists should engage more to communicate their research outcomes to journalists, media and the general public, and by taking better advantage of social media.

In 2022, GAPHAZ patronized the GLOF conference & workshop in Graz, Austria, and online, and supported the publication of a paper that summarizes its outcomes.

- Emmer, A. *et al.* (2022). Progress and challenges in glacial lake outburst flood research (2017–2021): a research community perspective. *Natural Hazards Earth System Science*, 22(9). DOI: 10.5194/nhess-22-3041-2022.

Moreover, based on the "GAPHAZ Technical Guidance Document for the Assessment of Glacier and Permafrost Hazards in Mountain Regions", an article was published in the Oxford Research Encyclopedia of Natural Hazard Science (ORE NHS). This article can be seen as an extended summary of the Technical Guidance Document with updated references, including recent works published after 2017.

- Allen, S. *et al.* (2022). Assessment Principles for Glacier and Permafrost Hazards in Mountain Regions. *Natural Hazard Science*. DOI: 10.1093/acrefore/9780199389407.013.356.

The promotion of GAPHAZ within the scientific community will continue in 2023 with members contributing to the EGU General Assembly in Vienna, Austria and online, in particular to the session *CR6.1 "Risks from a changing cryosphere"*, as well as at the *JC06 "Mountain Cryosphere Hazards"* session at the 28th IUGG General Assembly, in Berlin, Germany.

STANDING COMMITTEES

Permafrost Young Researchers Network (PYRN)

BY EMMA LATHROP (NORTHERN ARIZONA UNIVERSITY, USA) ON BEHALF OF THE 2022-2024 PYRN EXCOM

The 2022-2024 PYRN executive committee (ExCom) began its tenure in June 2022 and is excited to organize events while continuing the legacy of previous ExComs.

5TH NATIONAL YOUTH ACADEMIC FORUM ON GEOTECHNICS & ENGINEERING IN COLD REGIONS

The 5th National Cold Region Geomechanics and Engineering Youth Academic Forum held in Harbin, China, in July 2022 was co-organized by several Chinese cold regions scientific research organizations. The conference was shared online and attracted a range of cryospheric researchers from across China, with 6,266 scholars viewing and communicating the content. The theme was *"Low Carbon Sustainable Development of Geotechnics and Environment in Cold Regions"*. ExCom members Xianglong Li and Jinbang Zhai introduced and promoted PYRN to young scholars.

PYRN ExCom members Xianglong Li and Jinbang Zhai introduce PYRN at the 5th National Youth Academic Forum on Geotechnics and Engineering in Cold Regions in Harbin, China (July 2022).

2022 AGU FALL MEETING

Several PYRN members attended the 2022 AGU Fall Meeting in Chicago, IL. Thanks to generous support from the U.S. Permafrost Association (USPA), several PYRN members were awarded travel grants to attend the meeting. Recipients received their awards at the USPA's annual meeting, which was well-attended by young researchers. Awardees: Joel Eklof, Ahman Tourei, Soumitra Sakhalkar, Lingcao Huang, Katie Braun, Kristina Levine,

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Nicole Guinn, Brad Gay, Vasily Tolmanov, Anna Lekso, Sean Schaefer, Zena Robert, and Josie Arcuri. Many congratulations to the recipients!

FUTURE MEETINGS

The coming years are important for collaboration in permafrost research, with the upcoming EUCOP6 and ICOP2024; some of the first events in several years that will allow early career researchers (ECRs) to come together in person. In conjunction with previous ExCom leaders, the new ExCom is organizing the PYRN-IPA workshop at EUCOP6. The workshop will feature icebreakers, science talks, and soft skills workshops for ECRs. Invited speakers at the workshop include Hugues Lantuit, McKenzie Khun, Daniel Draebing, Julia Boike, Birgit Wild, and Claire Treat. Additionally, we will be overseeing travel grants for the workshop, five of which are kindly funded by the International Association of Geomorphologists (IAG) and Swiss Polar Institut.

We will host a similar workshop at ICOP2024 in Whitehorse, YT, Canada. The 2022-2024 ExCom is working closely with members of the local organising committee to organize travel grants, presentation awards, and PYRN invited speakers.

SERVICES TO ECRS

As well as in-person events, we will continue to provide online resources to the community. In 2022, we continued to host the virtual PYRN seminar series. Speakers included Adam Kirkwood, Robin Zweigel, and Torben Windirsch. We will be continuing the seminar series as well as hosting several short courses on skills that are necessary for conducting permafrost science, such as planning a safe and inclusive field campaign, and coding and data management skills.

We are looking forward to a productive year ahead!

Recipients of the USPA/PYRN Education Fund travel grants and the Andrew Slater Memorial Award at the USPA's annual meeting during the 2022 AGU Fall Meeting (December 2022).

STANDING COMMITTEES

Education & Outreach

BY ANNA KLENE (UNIVERSITY OF MONTANA, USA) & YLVA SJÖBERG (UNIVERSITY OF COPENHAGEN, DENMARK)

The Standing Committee on Education and Outreach coordinates and promotes permafrost education and outreach to all generations across the globe. The SC also coordinates with the University of the Arctic Thematic Network for Permafrost (TNP).

NEW: PERMAFROST INTERNSHIPS

TNP has received funding for a two year project called *"PermaIntern"* aiming to develop a platform for permafrost internships at BSc, MSc, and PhD levels, starting with the Nordic countries as a pilot region. An online platform will be created for connecting students and supervisors with internship hosts, and providing disciplinary and pedagogical resources to help structure the internship learning experience. A kickoff workshop was held in Copenhagen, Denmark, in November 2022 during which Nordic participants shared experiences and identified a common ambition for an international online internship program resource. A 2nd workshop will be held at EUCOP6 to share the progress so far with international colleagues and find ways to broaden the scope beyond the Nordic region.

FROZEN-GROUND CARTOONS

The project began as an IPA Action Group (2016-2018) and is now known as *"Permafrost on All Channels"*. Cartoons have been released

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in nine languages (Danish, French, German, English, Greenlandic/Kalaallisut, Inuktitut, Luxembourgish, Russian, and Swedish). The materials include an augmented reality app for smartphones and tablets, a board game, and videos on permafrost topics. Following the presentation at the online *"Ice(St)Ages: Experiencing Environments in Science, Arts and Spectacle"* they are working on a book chapter.

- Bouchard, F. *et al.* (2022). Redrawing permafrost outreach. *Nature Reviews Earth & Environment*, 3. DOI: 10.1038/s43017-021-00255-8.

ERL SPECIAL ISSUE

Following a session at the 2020 EGU General Assembly, a special issue has been published in Environmental Research Letters (ERL). It includes several papers focusing on permafrost and collaboration between indigenous people and researchers, and coproduction of knowledge.

- Sjöberg, Y. *et al.* (2023). Focus on Arctic change: transdisciplinary research and communication. *Environmental Research Letters*, 18. DOI: 10.1088/1748-9326/acabd7.

PermaIntern dinner after a productive 1st day of the kickoff workshop, Copenhagen, Denmark.

OPPORTUNITIES AT EUCOP6

Please join us at our session, *"Cartoons, Communities, and Cooperation"*, at EUCOP6.

STANDING COMMITTEES

Antarctic Permafrost, Periglacial Environments and Soils (ANTPAS)

BY MARC OLIVA (UNIVERSITAT DE BARCELONA, CATALONIA, SPAIN) & MAURO GUGLIELMIN (UNIVERSITÀ DEGLI STUDI DELL'INSUBRIA, ITALY)

In 2022, several ANTPAS researchers carried out field activities in Antarctica focusing on permafrost monitoring and active layer boreholes at several sites from Maritime and Continental Antarctica. ANTPAS also opened three grants for early career researchers (ECRs) to promote internships with senior scientists working with Antarctic permafrost. Three ECRs were granted (Maria Eliza Sotille, Ivan Alekseev and Flávia Ferrari). ANTPAS has a session on *"Periglacial and paraglacial environments in Antarctica"* at EUCOP6. We will organize a Special Issue based on the contributions received at the session. In 2023 we expect the situation to go back to normality and ANTPAS will continue to foster permafrost research in Antarctica promoting sessions and seminars in regional and international meetings.

PROJECTS

NSERC PermafrostNet

BY TRISTAN MACLEAN (CARLETON UNIVERSITY, CANADA)

NSERC PermafrostNet passed the halfway point of the networks' planned duration (2019-2024) in early 2022 and now hosts 25 graduate students and three postdoctoral fellows.

With most restrictions lifted our students could embrace fieldwork again. For some, it was their first opportunity to travel to the North and experience thawing permafrost and its impact first-hand. A 3-day network retreat to Kluane Lake Research Station, YT, in August 2022 was such an opportunity. The retreat was followed by the North Yukon Permafrost Conference in Dawson City, YT (see p. 3). The event gave students an opportunity to hear from members of the Indigenous communities impacted by permafrost thaw and share their work at a poster session. Congratulations to Hannah Macdonell, Alexandre Chi-

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asson and Teddi Herring for being awarded best MSc, PhD, and Early Career Level posters, respectively!

The hard work of our graduate students and staff is paying off with the publication of several papers and data tools over the last year, such as by Nick Brown, Andrew Clark, Teddi Herring, Erika Hille, and Joseph Young. See a full list of our associated publications on our website.

- Brown, N. (2022). tsp ("Teaspoon"): A library for ground temperature data. *Journal of Open Source Software*, 7(77). DOI: 10.21105/joss.04704.
- Clark, A. *et al.* (2022). Multiscale object-based classification and feature extraction along Arctic coasts. *Remote Sensing*, 14(13). DOI: 10.3390/rs14132982.
- Herring T. & Lewkowicz, A. (2022). A systematic evaluation of electrical resistivity tomography for permafrost interface detection using forward modeling. *Permafrost and Periglacial Processes*, 33(2). DOI: 10.1002/ppp.2141.
- Hille, E. (2022). Using river geochemistry to monitor the hydrology of Arctic watersheds. *Nature Reviews Earth & Environment*, 3. DOI: 10.1038/s43017-021-00257-6.
- Young, J. *et al.* (2022). Recent intensification (2004–2020) of permafrost mass-wasting in the central Mackenzie Valley foothills is a legacy of past forest fire disturbances. *Geophysical Research Letters*, 49(24). DOI: 10.1029/2022GL100559.

Staff and students at the 3-day network retreat, Kluane Research Station, YT (August 2022).

We're also disseminating network research findings through our monthly online seminar series.

In November, we held the 4th network AGM at the Tree of Peace Friendship Centre in Yellowknife, NT. Thank you to the Tree of Peace for hosting the event and encouraging cross-cultural understanding and awareness between Dene, Metis, Inuvialuit, and non-aboriginals. The AGM was held in conjunction with the 50th Yellowknife Geoscience forum. The meeting focused on the progress of the network projects, the synthesis of theme progress, publications, and future activities. In addition, we hosted an Open House for the public to find out more about the thawing permafrost and the researchers studying it. The Geoscience forum featured two permafrost specific technical sessions on *"Changing Permafrost Landscapes"* and *"Permafrost Monitoring Networks"* co-chaired by network members. The forum gave network members an opportunity to give presentations and posters about their current research. Congratulations to Hannah Macdonnell for being awarded best poster!

In December 2022, the network hosted sessions on permafrost and its consequences on northern environments and communities at the ArcticNet Annual Scientific Meeting in Toronto, ON, and students presented their work in the poster sessions. Congratulations to Tabatha Rahman for being awarded best student poster in terrestrial sciences!

Efforts to facilitate the development of a strategy for permafrost in Canada have been continuing with development of an infographic to stimulate discussion along with micro-engagements and presentations. The network also hosted an interdisciplinary panel discussion at the Canadian Science Policy Conference in Ottawa, ON, in November 2022, focusing on priorities and considerations of permafrost thaw within a broad policy framework.

Staff and students in Yellowknife, NT, for the 4th network AGM (November, 2022).

PROJECTS

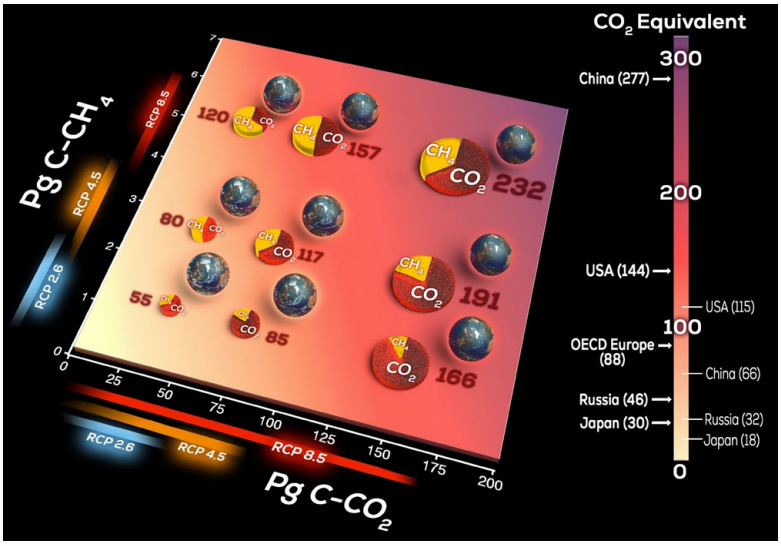
Permafrost Carbon Network

BY TED SCHUUR AND CHRISTINA SCHÄDEL (NORTHERN ARIZONA UNIVERSITY, USA)

After two highly successful virtual meetings during the pandemic (2020 & 2021), the Permafrost Carbon Network did not convene an all-scientist meeting in Fall 2022. Instead, we focused efforts at the 2022 AGU Fall Meeting, hosting an organized oral session, *"Vulnerability of Permafrost Carbon to Climate Change"*. Talks included research ranging from site level studies to global syntheses. The steering committee will meet multiple times in spring 2023 to discuss future directions for our growing network and plan another all-scientist meeting later this year coincident with the 2023 AGU Fall Meeting in San Francisco, CA. Please contact the Permafrost Carbon Network if you are interested in participating or contributing to a workshop. In October 2022, we published the most recent Permafrost Carbon Network synthesis.

- Schuur, E.A.G. *et al.* (2022). Permafrost and climate change: carbon cycle feedbacks from the warming Arctic. *Annual Review of Environment and Resources*, 47. DOI: 10.1146/annurev-environ-012220-011847.

Figures and content were workshopped during the online all-scientist meeting in 2021, and bring together a decade of permafrost carbon science conducted by the wider community. Updated estimates in this paper highlight that the permafrost region stores a third of the world's soil carbon (from 0-3 m), despite representing only 15% of the global land area, and this is likely a minimum. The paper considers a range of future trajectories, and concludes that Arctic carbon emissions will likely accelerate climate change by adding 10-15% to future fossil fuel emissions, roughly the equivalent of an industrialized nation.



Future fossil fuel emissions will determine the magnitude of the permafrost carbon feedback to the climate system.

PROJECTS

ESA CCI+ Permafrost

BY ANNETT BARTSCH (B.GEOS, AUSTRIA) & TAZIO STROZZI (GAMMA REMOTE SENSING, SWITZERLAND)

In November 2022, CCI+ Permafrost initiated phase 2 that will enable the release of the 4th version of the climate data records of Mean Annual Ground Temperature and Active Layer Thickness for the northern hemisphere in 2023. At least two more years will be added. Phase 2 also includes an extended part related to mountain permafrost with the objective to work further with the generation of rock glacier inventories (RoGI) and rock glacier velocity (RGV) time series exploiting spaceborne interferometric synthetic aperture radar (InSAR) data. During the 1st year (2023), the main objective is to consolidate the procedure and the 12 initial inventories from phase 1 in close cooperation with *'Rockglacier inventories and kinematics (RGIK)'* (see p. 6).

For dissemination we foresee the development of hands-on exercis-

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es on how to access and work with the data with open source tools during the 1st year of phase 2. Further on, RoGIs over small subareas in each region will be made available together with the input remote sensing data as training material for interested users. Release of this material is planned in the framework of EUCOP6. In addition, we contributed to the ESA Training Course on Arctic Methane and Permafrost on 19-23 September 2022, which was part of the AMPAC initiative (NASA/ESA collaboration – Arctic Methane and Permafrost Challenge). 24 students from 12 countries participated in the theoretical and practical exercises.

Participants of the ESA Training Course on Arctic Methane and Permafrost, Andøya Space Centre, Norway (September 2022). Photo: Aleksandra Efimova.

PROJECTS

Permafrost Pathways

BY SUE NATALI (WOODWELL CLIMATE RESEARCH CENTRE, USA)

Permafrost Pathways is a multidisciplinary project that brings together scientists, Arctic residents, Indigenous knowledge holders, and environmental justice, human rights and policy experts to improve permafrost science and to inform and develop adaptation and mitigation strategies to address the hazards of permafrost thaw. The project, which was launched in April 2022 with funding through the TED Audacious Project, is led by Woodwell Climate Research Center in partnership with the Arctic Initiative at Harvard Kennedy School (HKS), Alaska Institute for Justice, and Alaska Native Science Commission, along with 10 Alaska Native tribes and more than a dozen collaborators. The project aims to better incorporate permafrost carbon feedbacks into climate policy by (1) reducing scientific uncertainty about the current and future carbon balance of the permafrost region, (2) bringing the latest permafrost science to decision makers, and (3) co-creating an Indigenous-led adaptation framework.

MONITORING

To reduce uncertainty in carbon cycling in the northern permafrost region, we are coordinating a pan-Arctic carbon flux network, guided by a steering committee of leading carbon flux scientists across the permafrost domain. We aim to install 10 new eddy covariance sites across the permafrost region and expand measurements at existing sites. We will link in situ flux data with statistical upscaling and process modeling to assess the current and future carbon balance of the permafrost region. In 2022, we installed a new eddy covariance flux tower in Churchill, MB, and supported five existing eddy covariance sites across Canada by providing instrumentation to expand measurement capacity to include both carbon dioxide and methane measurements throughout the year.

MODELLING

In collaboration with the University of Alaska Fairbanks, we started building necessary infrastructure to support a data assimilation model for Arctic carbon cycling using DVM-DOS-TEM (Dynamic Vegetation Model and Dynamic Organic Soil version of the Terrestrial Ecosystem Model). We are incorporating relevant processes into the model, including thermokarst and wildfire-thaw interactions, and we will be running the model at high spatial resolution (1-2 km) across the Arctic-boreal regions.

ADAPTATION

In the past year, five Alaska Native tribal governments signed resolutions to partner on this project (Kuig ilnguq/Kwigillingok, Nunapicuaq/Nunapitchuk, Chinik/Golovin, Chevak, and Akiak). In 2022, partner communities started monitoring permafrost thaw-impacted water and surface permafrost temperatures; tracked storm and permafrost thaw impacts; and worked with the project team to assess monitoring and modeling needs.

MITIGATION POLICY

A major policy objective of this project is to get the permafrost carbon feedback fully accounted for in global policy. In the past year, members

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of our project team attended and presented at UNFCCC in Bonn, Germany and in Sharm El-Sheik, Egypt; testified before to the U.S. House Committee on Science, Space, and Technology on science needs in response to a rapidly changing Arctic; presented at the Arctic Circle Assembly in Reykjavík, Iceland; and organized a policy convening at HKS that included representatives from the White House, State Department, U.S. federal agencies, Alaska Native communities and organizations, and Arctic science institutions.

PROJECTS

Permafrost Coastal Systems Network (PerCS-Net)

BY BENJAMIN M. JONES (UNIVERSITY OF ALASKA FAIRBANKS, USA), SASHA V. PETERSON (UNIVERSITY OF TEXAS AT EL PASO, USA), CANSU DEMIR (UNIVERSITY OF TEXAS AT AUSTIN, USA)

Researchers from the University of Alaska Fairbanks led an International Arctic Coastal Network (IACN) retreat in Mystic, CT, in October 2022, with funding from the NSF's Accelerating Research through International Network-to-Network Collaborations (AccelNet) program. The IACN retreat brought together 42 researchers from 22 different research institutions located in eight different countries to focus on the unprecedented climate and land use change issues impacting Arctic coasts and the communities located there. More than half of the attendees were graduate students or early career researchers (ECRs).

The IACN retreat included panels focused on insights and updates in the aftermath of the recent Merbok storm in western Alaska; overviews from pan-Arctic coastal networks and research projects; and a series of breakout group discussions focusing on local and Indigenous observations, field studies and instrumentation, remote sensing and modeling, and coastal hazard assessments. The international gathering wrapped up with a discussion of ways to better share our observations with Arctic coastal communities and aspects of coastal permafrost changes in the context of the entire permafrost region.

The pace of environmental change in the Arctic is increasing because of sea-ice loss and warming permafrost, resulting in a rapidly evolving coastal system experiencing a complex series of responses. Future Arctic coastal system dynamics will challenge conventional wisdom impacting human decision-making and adaptation planning, impacts to cultural heritage resources and communities, and likely result in unforeseen social and environmental challenges. The effort required to realize and address the scale and complexity of future challenges is far greater than any single institution, network, or typical funding allocation is capable of fully accomplishing. The IACN retreat promoted synergy across networks to foster the next generation of students, postdoctoral scholars, and ECRs faced with the known and unknown challenges of future Arctic coastal systems.

One such outcome is the formation of the Arctic Coastal Observations, Research, and Networking series (ACORN). ACORN is a monthly webinar series on topics related to Arctic coastal research. Presenters from every career stage and diverse scientific backgrounds are able to share their expertise, encouraging synergy and collaboration between attendees. ACORN is a recurring series, scheduled the 4th Wednesday of each month and recordings of past talks are available online.

Attendees of the IACN retreat in Mystic, CT (October 2022). Photo: Aimee Harvey.

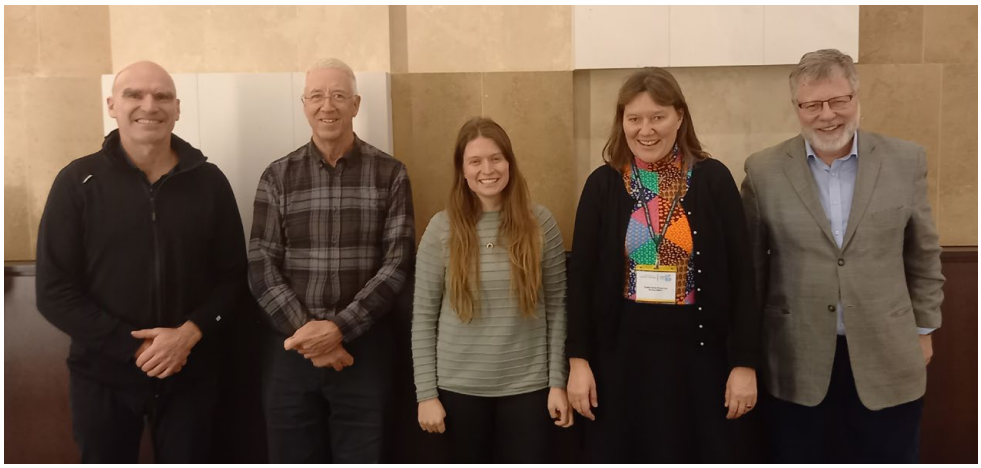
Frozen Canoes

BY HANNE CHRISTIANSEN (UNIVERSITY CENTRE IN SVALBARD, UNIS)

FROZEN CANOES, short for '*Landscape & infrastructure dynamics of frozen environments undergoing climate change in Canada, Norway, and Svalbard*' ended its project operation in 2022. It has been funded by the INTPART program of the Norwegian Research Council. The focus has been on exchange within research and higher education. In 2022 full project activity resumed after the COVID-19 pandemic, including physical courses.

We ran four university courses in 2022. The AG-352 *'Geohazards and geotechnics of high Arctic Permafrost regions'* (10 ECTS) Masters course, developed in 2019 by the FROZEN CANOES project group, ran full with 16 students at University Centre in Svalbard (UNIS) for five weeks in early summer 2022. Young researcher Graham Gilbert (UNIS) was responsible for the course and hired by the project. At Yukon University, Whitehorse, Canada the GEOG 001 *'Advanced Permafrost Engineering Applied to Transportation Infrastructure'* (7.5 ECTS) Masters course ran in late summer with five students taught by Chris Burn (Carleton University) and Guy Dore (Université Laval). At the Norwegian University of Science and Technology (NTNU) in Trondheim, the BA6067 *'Design of roads and railways in cold climate'* (7.5 ECTS) Masters course had 12 students for two-weeks in autumn 2022. Young researcher Julie Malenfant Lepage (NTNU) was responsible for the course and hired by the project.

Students on the AG-352 course drilling into permafrost of the lower slopes of Longyearbyen (June 2022). Photo: Knut Tveit.



Participants at the exit workshop in Toronto, ON. L-R: Arne Instanes (Instanes A/S), Guy Dore (Université Laval), Marjolaine Verret (UNIS), Hanne H. Christiansen (UNIS) and Chris Burn (Carleton University). Also in attendance was Brian Horton (Yukon University).

In 2022, the AG-218 *'International Bachelor Permafrost Summer Field School'* bachelor course at UNIS ran with 20 students for five weeks in early summer. We supported young researcher Marjolaine Verret (UNIS) who was responsible for the course.

Many proposed physical activities didn't take place due to the pandemic, so we focussed on developing online permafrost teaching resources. Chris Burn developed three educational video modules on the ground thermal regime, ground ice and application and implications. Each module contains many short summary videos and several longer videos. We also had two video modules on remote sensing of permafrost developed in collaboration with young researcher Line Rouyet (NORCE), a module on cryostratigraphy by Marjolaine Verret, and a module on how to drill into permafrost by the Longyearbyen based local research support company Kolibri Geoservices. These videos will be important for the legacy of the project and will be available as online resources for permafrost education through UNIS educational resources. We also plan to offer these through the IPA Education and Outreach committee and UArctic Thematic Network for Permafrost (TNP).

The project ended with an exit strategy workshop at ArcticNet in Toronto, ON, in December 2022. We decided to share our experiences from the project by planning a publication on the need for risk analyses of climate change and permafrost in Northern communities. We also discussed the possibility for further developing internships in permafrost, as is in the applications by the UArctic *PermaIntern* project (see p. 16).

PROJECTS

Permafrost & Periglacial Processes

BY MAURO GUGLIELMIN (UNIVERSITÀ DEGLI STUDI DELL'INSUBRIA, ITALY)

Permafrost and Periglacial Processes continues to be edited by Mauro Guglielmin (Università degli Studi dell'Insubria) with the assistance of Nic Jelinski (Minnesota University). In 2022, the journal's impact factor was 4.262, placing it 3rd out of 49 journals for Geology and 17th out of 52 journals for Physical Geography.

Thirty-two papers were accepted covering many topics in permafrost science, including paleo-permafrost features, rock-glacier evolution, ice-wedge paleoclimate reconstruction, ice wedge dynamics and origin, and permafrost coastal and fluvial features. The papers covered many periglacial environments from Arctic and Antarctic permafrost to patchy high mountain permafrost. The rate of acceptance is ~58%.

Authors were predominantly from China, Canada, and Europe. In 2023, two Special Issues focused on cryosols and permafrost research in China will be published , as well as at least two others with selected papers from EUCOP6.

- Formation and melting of ground-ice and sustainable permafrost engineering under a warming climate: A Chinese contribution devoted to Academician Guodong Cheng's 80th birthday.
- Characteristic Upland Periglacial Landscapes: Reality or 'Geomorphic Chimera'?

PROJECTS

Permafrost Discovery Gateway

BY ANNA LILJEDAHL (WOODWELL CLIMATE RESEARCH CENTER, USA)

The Permafrost Discovery Gateway (PDG) is an online resource to enable big data creation and discovery, mainly for the permafrost science community and also for school teachers and the public. In 2022, our efforts centered on (1) automating the post-processing workflows that enable the visualization of large (TB-sized) geospatial datasets in the ImageryViewer tool, (2) cleaning of the pan-Arctic ice-wedge polygon dataset, (3) development of a virtual online tour of the Permafrost Tunnel near Fairbanks, AK, (4) connecting the permafrost community on machine learning (ML) techniques through the PDG webinar series, (5) further refining the workflows for data creation from various satellite imagery (Landsat, Sentinel, Maxar, and Planet), and (6) the initial ingestion of various geospatial datasets published by the permafrost science community as well as observations recorded by the Local Environmental Observers Network (LEO Network).

Entrance to the USACE Permafrost Tunnel Research Facility near Fairbanks, AK.

The PDG development team appreciated the responses received on the ice-wedge polygon dataset and the ImageryViewer layout.

A new collaboration organically grew out of co-mingling lake-change geospatial datasets and a lake drainage LEO post from NW Alaska. This resulted in field visits by the researchers to meet local observers. Everyone's observations, whether done via remote sensing analyses or simply walking around the lake, resulted in the co-production of a manuscript led by Benjamin M. Jones.

The Navigating the New Arctic funding ends in 2024 and researchers outside the original PDG development team have already taken

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the initiative to include PDG in proposals. The National Science Foundation recently awarded Wenwen Li to lead an effort building training resources within the PDG on AI and ML techniques for the next generation of Arctic scientists. We welcome you all to shape the future growth of the PDG, whose long-term "home" is the Arctic Data Center.

PROJECTS

Permafrost Grown

BY MELISSA WARD JONES (UNIVERSITY OF ALASKA FAIRBANKS, USA)

Climate warming is introducing new agricultural opportunities to high latitude areas by increasing air temperatures required for growing a greater range of crops and extending the growing season. A warming Arctic is also causing degradation of near-surface permafrost, including from land surface disturbances, that has cascading effects on high-latitude ecosystems and communities.

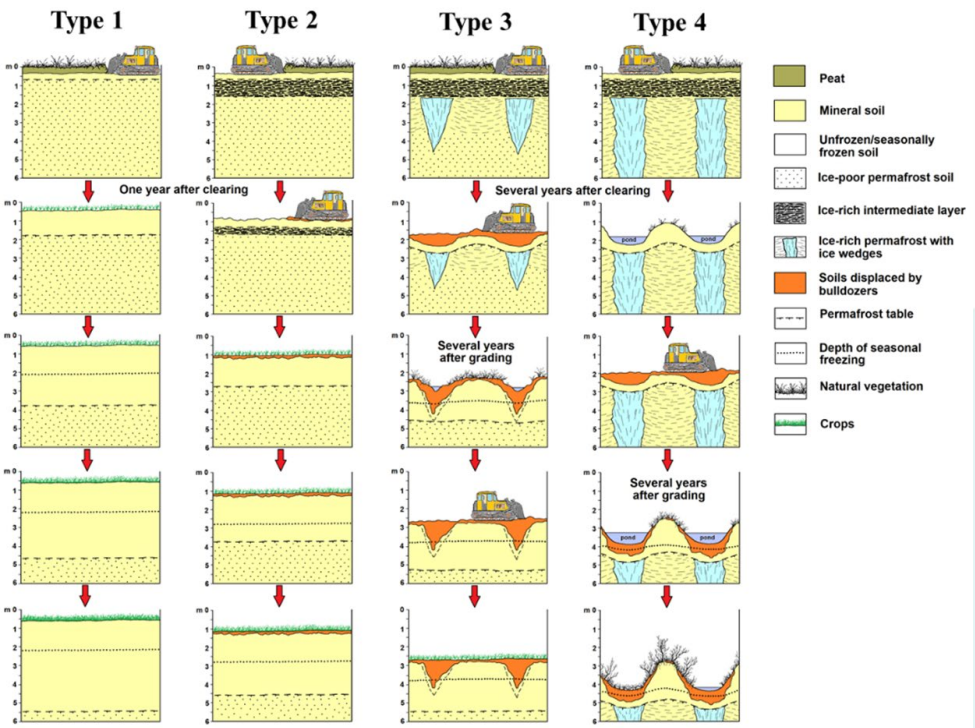
The Permafrost Grown project is co-producing knowledge with researchers at the University of Alaska Fairbanks and farmers in Alaska to understand (1) interactions and feedbacks between agricultural activities and permafrost, (2) legacy effects of land clearing for agriculture over the last 100 years, (3) socio-economic trade-offs related to intensifying permafrost-agroecosystems and to provide decision tools for farmers, and (4) to develop education and outreach participation to advance knowledge and provide opportunities for farmers and the public to increase food security.

Permafrost Grown is a $3 million, 5-year (2022-2027) project, funded by the US National Science Foundation's Navigating the New Arctic Initiative. Methods include using a combination of sensor networks, remote sensing, cultivar trials, field data collection, interviews, surveys, and economic risk modelling. Our team developed and published four potential permafrost degradation scenarios considering the range of thaw responses depending on ground ice content and cultivation practices.

- Ward Jones, M. *et al.* (2022). Climate-driven expansion of northern agriculture must consider permafrost. *Nature Climate Change*, 12 DOI: 10.1038/s41558-022-01436-z.

Farmers cultivating soils in a field with thaw stable, ice-poor permafrost can likely manage their agricultural activities differently than farmers faced with thermokarst from degradation of ice-rich permafrost. Our team suggests four science-based adaptations for ensuring the sustainable development of high latitude agriculture: (1) increasing transdisciplinary research, (2) developing techniques specifically for high latitude agriculture and cultivating on permafrost, (3) generating science and research with farmers, and (4) developing government permafrost-conscious policies mindful of social and economic demographics and focus on land development respectful of Indigenous lands.

Preliminary information from farmer-knowledge surveys shows



Permafrost degradation scenarios with common management strategy of surface grading with 4 types of permafrost: (1) thaw stable ice-poor permafrost, (2) permafrost with an ice-rich intermediate layer overlaying ice-poor permafrost, (3) permafrost with epigenic ice wedges, and (4) permafrost with syngenetic ice wedges.

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the three most common permafrost-induced problems in agricultural fields are changes to surface water flow, abandoning whole or parts of fields to farming and problems relating to fencing. We found that while farmers know what permafrost is, there remains large knowledge gaps with how to manage it in farm fields. We also found that typical management strategies, such as using infrared plastic mulch for weed suppression could inadvertently thaw permafrost through soil warming and likely should be avoided as a weed suppression strategy in fields with ice-rich permafrost.

Permafrost Grown will be developing best practice guides for cultivating on permafrost-affected soils to support the sustainable development of high-latitude agriculture and increasing both food security and economic resilience.

Melissa Ward Jones drills to install ground temperature sensors at a peonies farm in Two Rivers, AK, while her 3-year-old daughter waits to place the site marker.

PROJECTS

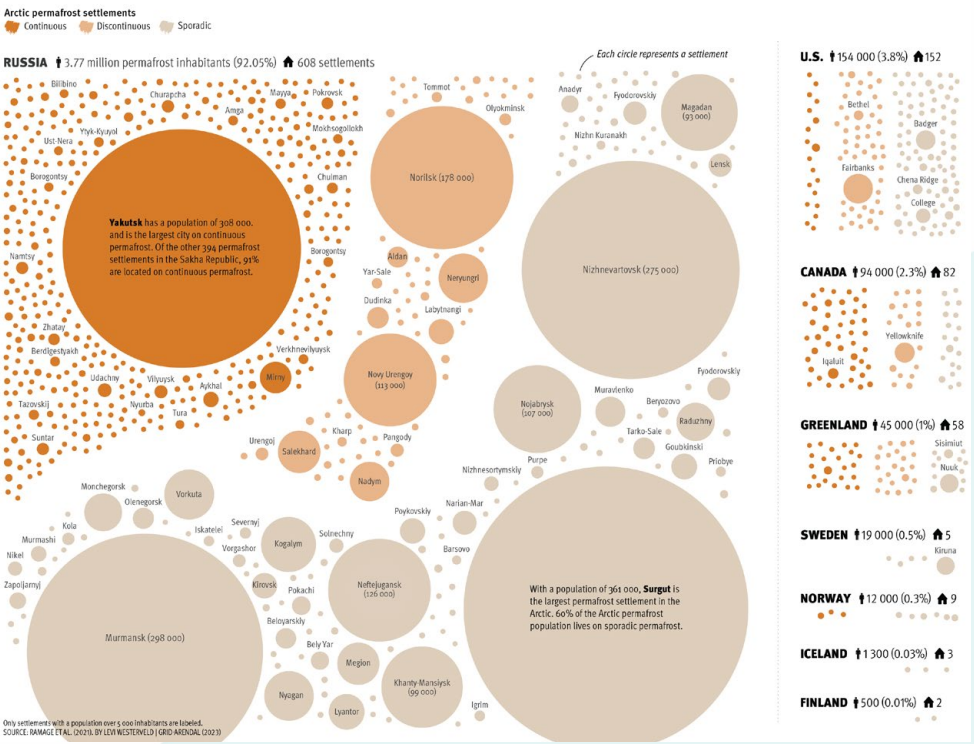
Atlas of Arctic Permafrost

BY TIINA KURVITS, TINA SCHOOLMEESTER & LEVI WESTERVELD (GRID-ARENDAL, NORWAY)

The atlas is going through extensive external review (by scientists and the advisory board for cartography and design that we established for the publication) and will be ready for launch in May 2023.

The goal of the atlas is to illustrate state-of-the-art knowledge about the distribution, status, and trends of permafrost in the Arctic (and elsewhere), the consequences and implications of permafrost thaw for Arctic societies and the global climate, and forward-looking strategies to adapt to thawing permafrost. As well as maps, the atlas will present portraits of people living on permafrost accompanied by artistic interpretations of the portraits.

Fewer people will live on permafrost in the future because permafrost is thawing and disappearing. As per today, about 5 million people in 1,162 settlements live in the Arctic circumpolar permafrost region (ACPR). Almost 90% or 1,045 of these settlements, have <5000 inhabitants. Most people in this region (~4 million) live in the larger 123 settlements that range in size from 5,000 to 360,000 inhabitants. About 85% of the large settlements are found in the Russian Arctic. Most settlements are in sporadic permafrost and will be less affected by discontinuous permafrost degradation, but settlements in continuous and extensive discontinuous permafrost, may experience substantial impacts as the underlying permafrost thaws due to climate warming. This includes Ya-



>5 million people live in the ACPR, primarily in Russia. While there are over 1,100 settlements across the ACPR, most are small with <5,000 inhabitants.

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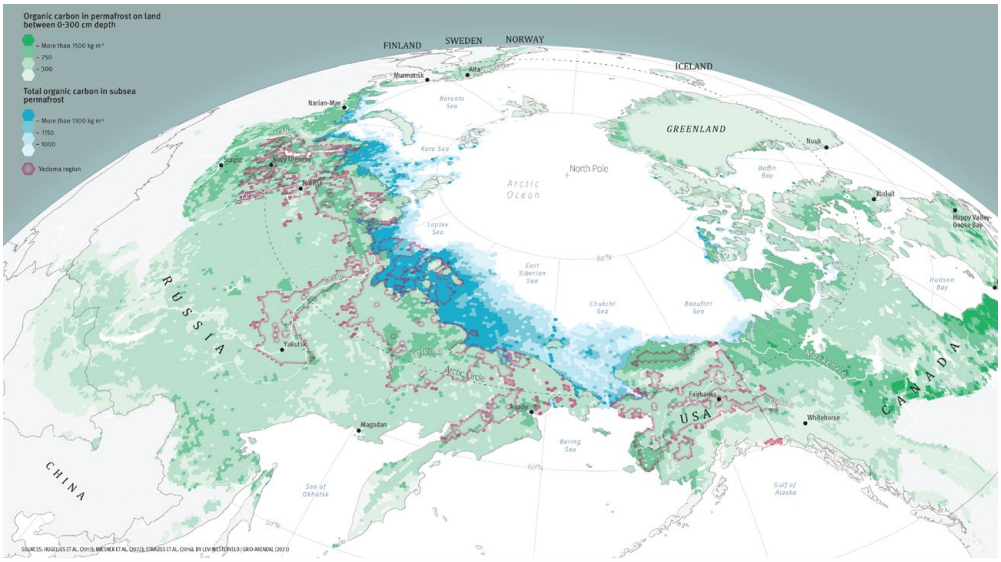
kutsk and Norilsk, two of the largest settlements in the Arctic, which have a combined population of 486,000.

- Ramage, J. *et al.* (2021). Population living on permafrost in the Arctic. *Population and Environment*, 43. DOI: 10.1007/s11111-020-00370-6.

Arctic permafrost soils are one of the largest carbon sinks in the world. Despite representing 15% of the total global soil area, they contain almost half of all the world's soil carbon, which is nearly double the amount of carbon currently found in the atmosphere. Research suggests the amount of carbon stored in permafrost is four times higher than from anthropogenic CO_2 emissions. The surface layer (0-3 m deep) contains 65-70% of the total permafrost soil carbon. Another 25-30% of permafrost carbon is stored at depths greater than 3 m. The Yedoma region of Siberia, Alaska and Yukon, which remained ice free during the last glaciation, has rich carbon stores in deep, thick deposits. Arctic river deltas account for the remainder of the permafrost soil carbon, <10% of the total. Subsea permafrost also contains carbon, stored as organic carbon frozen in the permafrost and as pockets of free gas or trapped in gas hydrates. But most of the gas found in this setting is methane.



Carbon stored in permafrost varies in the ACPR. The largest stores are in the Yedoma region (red outline) and Kara, Laptev, and East Siberian Seas for subsea permafrost (dark blue areas).

PROJECTS

PRISMARCTYC

BY ANTOINE SÉJOURNÉ (UNIVERSITÉ PARIS-SACLAY, FRANCE)

PRISMARCTYC aims to better understand the impacts of permafrost thaw on soils, surface/groundwater fluxes and carbon cycle, as well as their controlling factors. Our study focuses on small inland Arctic watersheds where localized and rapid thermokarst occurrences remain under-studied. The objectives are to understand the hydrogeomorphological, geochemical, and microbiological changes on the near-surface permafrost-hydrosystem continuum, as well as socio-economic impacts on local communities. This will be achieved by comparing different sites in Siberia and Yukon with different permafrost settings, climate-sensitivity, vegetation, and permafrost degradation types along a latitudinal and longitudinal gradient.

Sampling of ground ice in a thaw slump in the northern Indigirka region. Photo: Nikita Tananaev.

Initially one of the main sites was in central Yakutia near Yakutsk. However, a new site in eastern Yukon near Alaska was selected and an extensive field campaign took place in summer 2022. The team of French, Canadian, American and Japanese researchers studied several thermokarst lakes that are actively developing as the permafrost thaws. The aim of the mission was to collect water, GHG gas, soil and permafrost samples. This area of boreal forest, subject to frequent forest fires, is little studied compared to the tundra to the north. This new site will be compared with sites in Siberia studied by Russian team members (Melnikov Permafrost Institute, MPI). They conducted a field study in northern Indigirka region to sample different major wa-

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ter features including water tracks, floodplain thermokarst lakes, rivers and ground ice. Contemporary permafrost degradation in the region is limited to hillslopes where water tracks of various size and morphology are abundant, conveying water and dissolved components toward the Indigirka River.

Thermokarst lakes in a burned area, YT, Canada (2019). Photo: Antoine Séjourné.

ASSOCIATED ORGANIZATIONS

Swiss Permafrost Monitoring Network (PERMOS)

BY JEANNETTE NOETZLI (WSL INSTITUTE FOR SNOW & AVALANCHE RESEARCH SLF, SWITZERLAND) & CÉCILE PELLET (UNIVERSITY OF FRIBOURG, SWITZERLAND)

PERMOS documents the state and changes of permafrost in the Swiss Alps based on ground temperatures in boreholes, changes in ground ice content by Electrical Resistivity Tomography (ERT), and rock glacier velocity by terrestrial geodetic surveys. PERMOS is carried by six partner institutions.

The network's activities and its partners focused on the continuation of the long time series, data processing and reporting. In summer 2022, renovations were conducted at several sites to secure the continuation of the time series. A new borehole was drilled at Gentianes and ERT cables on Murtèl-Corvatsch rock glacier were renewed.

The PERMOS Office continues to develop the data management system by processing routines for permafrost field data, which is an increasingly important part of the network operation. On behalf of the federal financing partners, PERMOS underwent an evaluation of its organization and strategy in 2022. Based on an external expert review and a comprehensive self-assessment report the foci for the next years were defined: the continuation and securing of the time series and their quality control and systematic processing.

Our new website launched in 2022 and includes information on mountain permafrost, the network and its activities. It provides access to publications and the data portal.

In 2023, two new observation types will become permanent in the network, (1) automatic weather stations at six sites, and (2) permanent GNSS measurements to complement annual rock glacier velocity surveys.

Borehole replacement at the Gentianes PERMOS Site, Swiss Alps (summer 2022) by UNIL to ensure the continuation of the 20-year temperature time series. Photo: Christophe Lambiel.

United States Permafrost Association (USPA)

BY ANNA WAGNER (CRREL, USA), USPA PRESIDENT

The main activities for the year focused on the preparation and implementation of the 20th anniversary of the U.S. Permafrost Association (2002-2022). In fall 2022, a book of 255 abstracts was published from the 2021 Regional Conference on Permafrost (RCOP) and 19th International Conference on Cold Regions Engineering (ICCRE.

- Douglas, T.A. *et al.* (2022). *Abstracts: 2021 Regional Conference on Permafrost and 19th International Conference on Cold Regions Engineering.* USPA. DOI: 10.52381/RCOP2021.abstracts.1.

Membership totaled 263 (159 regular/sustaining, 69 students, 15 Lifetime, 20 corporate/institutional members). About 60 are also members of PYRN. Activities for the 20th anniversary included:

- A Permafrost Science-Engineering Workshop in Anchorage and organized by John Thornley and Ed Yarmak.
- A virtual presentation to the Interagency Arctic Research Policy Committee (IARPC) Permafrost Collaboration Team.
- Week-long activities at the 2022 AGU Fall Meeting in Chicago, IL.

Forty engineers and researchers attended the day-long workshop to review past and current problems and approaches associated with permafrost under a warming climate.

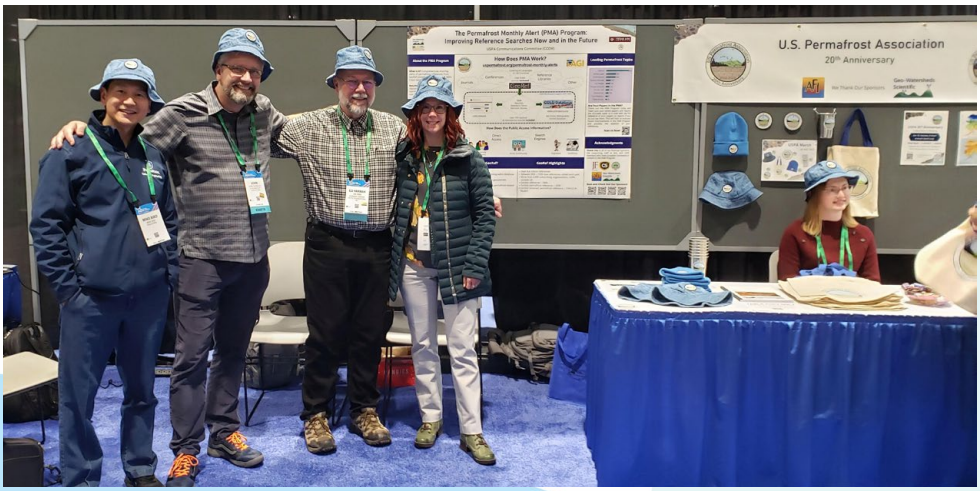
The IARPC presentation was organized by Michael Lilly (Chair, USPA Communication Committee) and its ad hoc 20th Anniversary Subcommittee and Student Team members. It included an introduction by Larry Hinzman, who recounted early USPA activities that proceeded the 2008 ICOP in Fairbanks, AK. A final series of USPA commemorative activities took place at the 2022 AGU Fall Meeting, including:

- 2022 USPA Board Meeting.
- A well-attended USPA booth, organized by Lilly, that displayed a number of current and past Association activities, and provided complimentary and saleable memorabilia.
- The Annual Meeting and Awards Ceremony and social event, attended by 125 members and guests. 13 awards totaling $10,000 were presented (USPA Permafrost Young Research's Network Education Fund (UPEF), Permafrost Engineering Education Program (PEEP) and Andrew Slater student award.
- The USPA Diversity, Equity, and Inclusion (DEI) Committee organized a mentoring lunch activity for 21 participants (10 mentees and 11 mentors).
- The week culminated with an AGU session on Alaskan permafrost and infrastructure organized by Anna Wagner, Jerry Brown, and Emma Lathrop. The session included 29 in-person and online oral and poster presentations attended by over ~100 participants.

The AGU events and abstracts of the 417 permafrost-related presentations can be found in the USPA AGU Fall 2022 Permafrost Guide.

Finally, at the 2022 Annual Meeting John Thornley (USPA President) announced the newly elected board members:

- Ming Xiao, President-elect (Penn State University);
- Katherine Schexneider, Secretary (retired U.S. Navy);
- Jessica Ernakovich, Board Member, re-elected for second term (University of New Hampshire);
- Melissa Ward Jones, Board Member (University of Alaska, Fairbanks).



L-R: Ming Xiao, John Thornley, Ed Yarmak and Anna Wagner; and seated Elizabeth Kubacki.

ASSOCIATED ORGANIZATIONS

Chinese Academy of Sciences (CAS)

BY MU YANHU & NIU FUJUN (CAS, CHINA)

In China, latitudinal permafrost is located in the Da and Xiao Xing'anling Mountains in northeastern China. Permafrost in the Da and Xiao Xing'anling Mountains is warm, thin and sensitive to climate warming. In past decades, the economy of the Northeastern China has become important for the whole country, and permafrost degradation has been of considerable concern as it affects almost all aspects related to regional social-economic development, e.g., resource exploitation, engineering construction, and environmental protection. Research on permafrost in northeastern China began in the 1950s - earlier than permafrost research on the Qinghai-Tibet Plateau. Previous permafrost research in northeastern China had specific purposes to meet the needs of economic development, cold regions engineering, water supply and coal-mining. From the 1970s to 2020s, permafrost in northeastern China degraded rapidly. Meanwhile, along with implementation of the strategy of revitalizing northeast China, numerous major engineering infrastructure projects were constructed or planned. Great changes in permafrost and the significant needs of regional sustainable development necessitate an understanding of the status and future of permafrost in the Xing'anling Mountains.

The new field station for permafrost research in northeastern China.

Chinese researchers started a program aiming to (1) investigate the status of permafrost, (2) predict future changes in permafrost, (3) evaluate impacts of permafrost degradation, and (4) propose adaption strategies and methods. This program is planned to be conducted over the next three years and researchers and engineers will participate in field investigations, integrated space and earth observations, model-based simulations, and predictions.

ASSOCIATED ORGANIZATIONS

Canadian Permafrost Association (CPA)

BY KUMARI KARUNARATNE (NTGS, CANADA), CPA PRESIDENT

Canada has a long legacy of excellence in permafrost science and engineering and several noteworthy changes to the research community have occurred in the last few years. First, the establishment of the CPA in 2018 and the funding of NSERC PermafrostNet from 2019-2025 (see p. 17) have enabled frequent and effective networking between people working with and living on permafrost. Both organizations strive to coordinate efforts to advance permafrost knowledge and the CPA is grateful for PermafrostNet's leadership in initiating a strategy for permafrost in Canada and coordinating permafrost related feedback on Canada's first National Adaptation Strategy (NAS).

In the south, Kingston, ON, has quietly and quickly become a hub of permafrost research. There are now several established and early-career permafrost researchers at the city's two research institutions: Queen's University and Royal Military College (RMC). Research expertise, facilities, and activities are bridged between the Department of Civil Engineering at RMC and the Departments of Civil Engineering and Geography and Planning at Queen's

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University. Our colleagues in Kingston are members of CPA standing committees and action groups, as well as PermafrostNet, and are leading the program development for the next International Conference on Permafrost (ICOP2024) (see p. 5). We are excited to see what this growing team will accomplish and are grateful for their contributions.

In northern Canada, the territorial governments have established permafrost research programs. Currently, both Yukon and Northwest Territories have 6 employees dedicated to permafrost research. These researchers can be found at the Yukon Geological Survey and Yukon University in Whitehorse, YT, and the Northwest Territories Geological Survey in Yellowknife, NT, and Aurora Research Institute in Inuvik, NT. The Canada-Nunavut Geoscience Office in Iqaluit, NU, has also recently employed a Permafrost Scientist. Territorially based scientists bring Northern insight to collaborative projects which ensures that research outcomes are meaningful to those living on permafrost. The permafrost research, engineering, and stakeholder community in Canada continues to expand and strengthen and we look forward to hosting our international colleagues in Whitehorse, YT, for ICOP2024.

ASSOCIATED ORGANIZATIONS

University Centre in Svalbard (UNIS)

BY HANNE H. CHRISTIANSEN (UNIS, NORWAY)

In summer 2021, the 3-year educational and strategical project *'Developing a permafrost and meteorological climate change response system to build resilience in Arctic communities' (PermaMeteoCommunity)* started at UNIS. The project aims to build the best response system for permafrost- and meteorological-conditioned landsliding. This is needed because Svalbard is experiencing rapid climatic warming. Autumn and winter air temperature have increased by up to seven times more than the global average over the last few decades. This increases the autumn period with an unfrozen active layer, which is then more prone to landsliding during rainstorms, such as in 2016.

In 2022, Marius Jonassen and Hanne H. Christiansen were awarded the Frederik Paulsen Arctic Academic Action Award for their work in this project and their close collaboration with several UNIS colleagues and local and national partners. We have started to obtain key, real-time observations of air and ground temperatures from the slopes of Longyearbyen and underneath buildings. The aim is to build a response system consisting of observations from a wide range of methods, to provide the best tool for authorities to make decisions when extreme weather hits Svalbard.

UNIS participates in the UArctic network project *PermaIntern* led by København Universitet, Denmark (see p. 16). In this Nordic project we will promote real-world working-life permafrost competence through internships, by developing an international permafrost online internship service. The project will generate a network linking professionals, academic staff, and students around the topic of permafrost, which may serve as a pan-Arctic resource of permafrost competence in a thawing Arctic.

Landslide deposits crossing a road in Longyearbyen after a 20 mm rainstorm (mid-October 2016). The road was closed for traffic for a longer period. Photo: Hanne H. Christiansen.

Aurora Research Institute (ARI)

BY JEN HUMPHRIES (ARI, CANADA)

ARI continued to support permafrost research in the western Arctic – and expand its own programs – while adapting to the evolving public health crisis. ARI delivers a range of support to partners – promoting communication between communities and researchers, fostering a respectful scientific community, administering licenses, coordinating logistical support, and deploying equipment. Support was provided to national and international academic institutions, Parks Canada, the Geological Survey of Canada (GSC), Government of Northwest Territories (GNWT), Department of Fisheries and Oceans (DFO), Joint Secretariat, and several others. Some examples of ARI contributions in 2022 include monthly thaw depth, snow depth and vegetation data to T-MOSAIC (see p. 32), maintaining two long-term permafrost monitoring sites near Inuvik, NT, in collaboration with Carleton University, and mapping for the NWT Thermokarst Mapping Collective.

Permafrost research programs led by the ARI focused on:

- Using water geochemistry to study the effects of permafrost degradation on the hydrology of Arctic watersheds;
- A monitoring and mitigation project with the Inuvik Community Corporation to assess the land at Reindeer Station;
- Examining multi-decadal trends in retrogressive thaw slumping and coastal erosion along Kugmallit Bay with a focus on key sites identified by the Tuktoyaktuk Hunters and Trappers Committee.

Water jet drilling at Reindeer Station, NT, by monitors from the Inuvik Community Corporation (September 2021). Photo: Alice Wilson (NTGS).

ARI continued to co-manage the ground temperature monitoring network in the Beaufort Delta Region with GNWT departments focused on the Dempster and Inuvik-Tuktoyaktuk Highways. ARI also co-delivered a range of presentations and training opportunities, such as 2 separate snow survey workshops, one with the Inuvik Community Corporation, and another with Inuvialuit Lands Administration (ILA) and Government of Northwest Territories.

The projects described herein rely on permafrost and environmental monitoring networks. Knowledge exchange and workshops are important for developing technical capacity and setting relevant monitoring objectives.

For more information see:

Hille, E. & Ferguson, C. (2022). *"Kugmallit Bay: A Landscape in Flux"*. Aurora Research Institute Virtual Speaker Series, 1 February 2022.

Hille, E. (2023). *"Characterizing the Response of Fluvial Systems to Changes in Landscape and Permafrost Conditions"*. Virtual Knowledge Sharing Series: Permafrost thaw, Climate, and Monitoring Change in Flow Regimes and Sediment Loads, Mackenzie River Basin Board, 12 January 2023.

Snow survey at a drilling waste sump with participants from the ILA, Carleton University, GNWT, and ARI (March 2022). Photo: Tim Ensom (GNWT).

ASSOCIATED ORGANIZATIONS

T-MOSAiC Permafrost Thaw

BY JULIA BOIKE (AWI, GERMANY)

The former T-MOSAiC permafrost thaw action group continues to work on the project. We released an update of the myThaw app (available in Apple & Google stores) to include image exporting and bug fixes. We released our interactive website with news on recent projects and data sets for download. It visualizes the location and environment of our participating stations and provides information and imagery of the sites. In 2022, 12 pan-Arctic sites contributed to our multiparameter data collection. We are finalizing the publication of the 2021 and 2022 data sets on the PANGAEA platform.

ASSOCIATED ORGANIZATIONS

Yukon University (YukonU)

BY FABRICE CALMELS, LOUIS-PHILIPPE ROY, FANNY AMYOT, CYRIELLE LAURENT, CATHY KOOT & CASEY BUCHANAN (YUKONU RESEARCH CENTRE, CANADA)

In 2022, the Permafrost & Geoscience Research team (PGR), led by Chair, Dr. Fabrice Calmels, conducted research across the Yukon Territory. The team, in partnership with the YukonU Climate Change Research team, began the 4.2-year National Trade Corridors Fund project, focusing on enhancing Yukon highway resilience to northern geohazards. Addressing permafrost and surficial hydrology, this project supports the efforts of the territory's department of Highways and Public Works to better prepare for current and future impacts of changing climate on road infrastructure. Field work for this project occurred on the Dempster and Alaska Highways and focused on modernizing and enhancing PGR's ground temperature monitoring network with high-performing data-loggers and thermistor strings. New sites were drilled for permafrost samples and the boreholes were instrumented with data loggers to monitor ground temperatures. 2-D electrical resistivity and tomography (ERT) profiling and drone surveys were conducted at many geohazard-sensitive sites to monitor their evolution on a yearly basis. The team also continued monitoring at the Alaska Highway Retrogressive Thaw Slump located at km 1456 using geotechnical and drone approaches.

The partnership between Champagne & Aishihik First Nations continues for another two years, evaluating the impact of a thawing landscape on traditional territory land-use and way of living, while creating new permafrost monitoring capacities. YukonU students gained research skills with new drones acquired specifically for training.

The following agencies contributed to the research program: Transport Canada, Crown-Indigenous Relations and Northern Affairs Canada, ArcticNet (including NorthxNorth), Polar Knowledge Canada, and BMO Foundation.

L-R: Fanny and Louis-Philippe coring permafrost along the Dempster Highway; Pearl (YukonU student) hunting for permafrost in Champagne and Aishihik First Nation's lands; and PGR team investigating a sunken culvert on the Dempster Highway.

Melnikov Permafrost Institute (MPI)

BY ANNA KUT (MPI, RUSSIA)

THERMAL CONTROL METHOD & DEVICE FOR PAVEMENTS & SUBGRADES ON PERMAFROST

A new method for active thermal protection of engineering structures on permafrost has been theoretically demonstrated and a device has been developed utilizing the method (Heat Protection Element, Russian Federation Patent for Utility Model No. 212670 publ. 02.08.2022, Bull. No. 22). This innovative device can change its heat transfer resistance (increase at temperatures above 0°C and decrease at temperatures below 0°C) depending on ambient air temperature. This allows effective cooling of the active layer in winter and reduction of thaw penetration in summer.

- Galkin, A.F. *et al.* (2022). Selection of thermal insulation material for the structural layer of road clothing. *Advances in Current Natural Sciences*, 8.
- Galkin A.F. (2022). Equivalent thermal resistance of road pavements. *Arktika i Antarktika*, 3. DOI: 10.17513/use.37875.
- Galkin A.F. (2022). Controlling the thermal regime of the road surface in the cryolithic zone. *Transportation Research Procedia*, 63. DOI: 10.1016/j.trpro.2022.06.128.

Tyalychyma yedoma exposure, east bank of the Vilyui River. Photo: N. Torgovkinin.

- Galkin, A.F. *et al.* (2022). Increasing thermal stability of the roads in cryolithic zone. *Transportation Research Procedia*, 63. DOI: 10.1016/j.trpro.2022.06.029.
- Galkin, A.F. (2022). The depth of the zone of thermal influence of roads. *Urbanistika*, 4. DOI: 10.7256/2310-8673.2022.4.38879.

Yedoma exposed on the east bank of the Indigirka River, Abyi lowland.

RESTORATION OF THERMOKARST-AFFECTED AREAS ON ICE-RICH PERMAFROST

A new method of thermal protection was proposed to rehabilitate lands deteriorated by thermokarst. The method involves a combination of insulating (restoring the vegetation) and high heat capacity (increasing the ground ice content) layers to provide optimal heat exchange in the ground-atmosphere system on an annual basis. Results of numerical modeling and field experiments with several variants suggest that the method is effective and applicable to the areas underlain by ice-rich permafrost

- Zhirkov, A.F., & Sivtsev, M.A. (2022). Assessing the feasibility of restoring the transient layer in Central Yakutia. In: *Proceedings of the 6th Conference of Russian Geocryologists*, Moscow, 14-17 June 2022. DOI: 10.31453/kdu.ru.978-5-7913-1231-0-2022-1130.
- Sivtsev, M.A. & Zhirkov, A.F. (2022). Numerical modeling of land rehabilitation in ice-rich permafrost terrain, Central Yakutia. In: *Proceedings of the 12th Russian Conference devoted to 65th Anniversary of the Institute of Diamond and Precious Metal Geology*, Yakutsk, 23-25 March 2022.
- Aleksandr, Z. *et al.* (2023). Assessment of the possibility of restoration and protection of territories disturbed by thermokarst in Central Yakutia, eastern Siberia. *Land*, 12(1). DOI: 10.3390/land12010197.

EXPEDITIONS

In summer 2022, field teams from MPI SB RAS examined several yedoma exposures for the MPI basic research projects *"Structure and Key Phases of Continental Permafrost during the Neopleistocene and Holocene"* and *"Cryolithogenesis of Quaternary Sediments in Northern Yakutia: Indigirka River Basin"*. Cryostratigraphic studies were performed at the Tyalychyma natural exposure on the Vilyui River and the Mamontova Gora stratotype on the Aldan River, as well as in the Indigirka River basin. The teams included undergraduate students from Moscow State University.

INDUSTRY

Arctic Foundations, Inc. (AFI)

BY AUSTEN WHITNEY, TERESA SANTOFERRARA & ED YARMAK

RETROFITTING A PASSIVELY COOLED AT-GRADE FOUNDATION IN QUINHAGAK, AK, USA

As the climate warms in northern latitudes, the heat removal capacity of passive subgrade cooling systems is decreasing and jeopardizing the stability of structures being protected on permafrost. The original thermosyphon system at the water treatment plant in Quinhagak, AK, was installed in 1995 and has always been fully operational. However, warming from areas beyond the perimeter of the foundation had started to impact the stability of the structure. To maintain structural stability and usability, AFI worked with the Alaska Native Tribal Health Consortium (ANTHC) and the Quinhagak community to upgrade the foundation.

Upgraded thermosyphons at the Water Treatment Plant, Quinhagak, AK.

In summer 2022, the passive heat removal capacity of the thermosyphon system was increased by retrofitting the 11 existing sloping evaporator thermosyphons with larger condensers and hybrid heat exchangers. Additionally, a hybrid flat-loop evaporator thermosyphon (FLET) was installed on the north, east, and south perimeter of the structure. Where the gravel pad was excavated for the FLET, new subgrade insulation and fill material were added, and now the subgrade insulation skirt extends 3.7 m from the edge of the structure.

Once the upgrade work was completed, the mechanical refrigeration capability of the hybrid FLET was deployed to refreeze and stabilize the soils around the perimeter of the structure. Temperature sensors are attached to the more than 128 m of FLET to monitor ground temperatures and refrigeration performance. By upgrading the thermosyphons and monitoring the subsurface temperatures, the community now has a system in place to prevent and mitigate movement for many years.

Quinhagak community members and ANTHC installing the flat-loop evaporator thermosyphons.

INDUSTRY

Beadedstream Inc.

BY HAYLEY CROTEAU (BEADEDSTREAM INC.), JUSTIN PANAGAPKO & MIKE WATT (ARCTIC FOUNDATIONS OF CANADA)

FOUNDATION MONITORING AT IQALUIT INTERNATIONAL AIRPORT, NU, CANADA

The new airport terminal and services buildings at Iqaluit International Airport, NU, were constructed between 2014-2017 and are founded on continuous permafrost. To prevent permafrost thaw under the new buildings and the potential for damaging differential settlement, a Flat Loop Thermosyphon foundation system, installed by Arctic Foundations of Canada, utilizes a proprietary two-phase heat transfer system to ensure the sub-grade remains frozen for the life of these important structures.

To monitor the heat transfer through the thermosyphon loops over time, a monitoring system was required within the foundations of the buildings. Fourteen beadedstream digital temperature cables were installed horizontally adjacent to the loops and vertically into the ground. These temperature cables

CONTINUED FROM PAGE 34

had 5-35 sensors each.

The temperature cables were terminated into 4x D405 Data Loggers with direct-to-orbit telemetry and multiple temperature cables connected to each data logger. The data is accessible via the beaded-cloud web browser for stakeholders such as contractors, engineering firms and the airport authority to have easy viewing of the latest data regardless of where they are in the world, with monitoring starting in 2014 and continuing to present day.

The data collected over the 8+ years of monitoring has been used to verify the operation of each of the flat-loop thermosyphons. By accessing the data remotely and viewing real-time temperature profiles, time-series plots or plan view of the site, issues can be identified early and maintenance can be scheduled for the system, ensuring long-term operation of the buildings as designed.

A radiator bank with a D405 Data Logger installed near the base.

INDUSTRY

Naviq Consulting Inc.

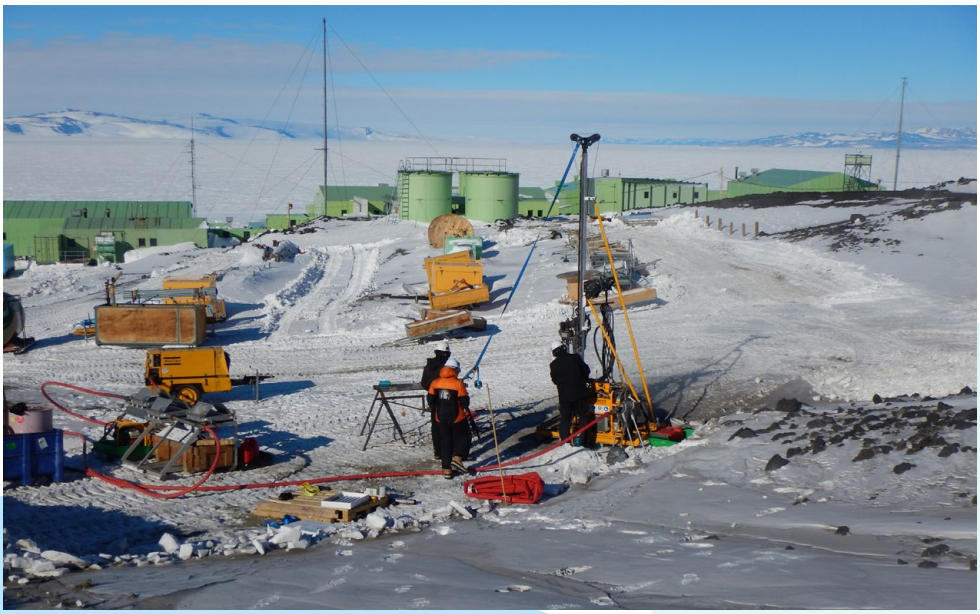
BY JIM OSWELL

REDEVELOPMENT OF SCOTT BASE, ROSS ISLAND, ANTARCTICA

Naviq Consulting Inc. (Naviq) is supporting Antarctica New Zealand in the redevelopment of the Scott Base facility on Ross Island (77.8° S). The overall project includes a complete reconstruction of the facility to replace the existing structures that are now at the end of their life and effectiveness to support research activities in this hostile environment. The ground conditions consist of interlayers of scoria and basalt bedrock with voids, often filled with ice. The mean annual ground temperature is below -15°C.

Naviq specializes in permafrost engineering, including geotechnical investigations, foundation design, and supports geothermal modelling to assess impacts of development on permafrost. As a sub-consultant to WSP, the primary civil and structural engineers for the new facility, Naviq oversaw geotechnical investigations in 2019 and provided technical knowledge transfer to other consultants supporting the work. Naviq also developed an adapted pile foundation system that will provide long-term foundation stability and meet the requirements of the Antarctic Treaty that all foundations be removed at the eventual time of abandonment. Naviq is presently supporting foundation designs for new high-capacity wind turbines and providing geothermal modeling of a new seawater intake that will be trenched into the shoreline.

Mount Erebus, an active volcano near Scott Base, Antartica.



Geotechnical investigations to support the Scott Base redevelopment (2019).

Initial site grading and preparation of laydown areas began in late 2022 and continued into early 2023. Foundation work will take place from late 2023 through 2024. The project will be completed by about 2030.

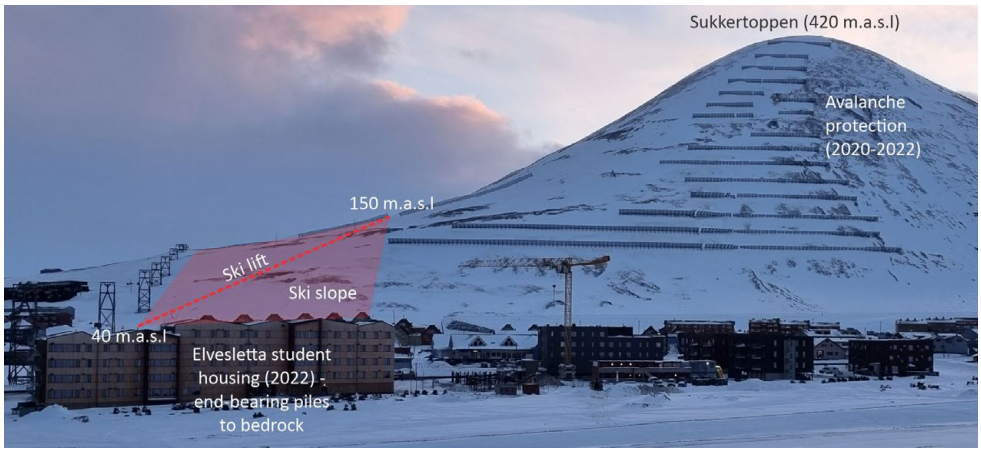
INDUSTRY

Instanes AS Consulting Engineers

BY ARNE INSTANES

SKI LIFT, LONGYEARBYEN

The local government in Longyearbyen, Svalbard, is planning to build the world's northernmost ski lift. The ski lift will be located on the east sloping hills of the Longyear valley (78° N). The lower station will be at approximately 38 m.a.s.l., and the 460 m long lift will take skiers up to ~153 m.a.s.l. The lift consists of a loading station, an unloading station on the top, and 7 masts that support the tow cable. The design and construction of the ski lift itself is carried out by Doppelmayr Seilbahnen GmbH, Austria. In the Doppelmayr foundation system each station and mast must have a foundation consisting of a concrete slab buried minimum 1.6 m below the terrain surface. Due to the presence of permafrost, the standard foundation system could not be used due to the risk of thaw settlement and possible lateral loads acting on the shallow foundations from slope processes. Instanes AS Consulting Engineers are responsible for a revised foundation design taking the permafrost conditions at site into consideration. A piled foundation system has been designed where the piles are to be drilled to bedrock. The soil investigations indicate that the soils on the slope consist of relatively coarse frictional materials and moraine. The water content (by mass) was found to decrease from approximately 30% in the surface layers to less than 10% at 5 m depth. Active layer thickness is generally <2 m.



Proposed ski lift in the Longyear Valley, Svalbard. When completed it will be the world's northernmost ski lift at 78° N.

INDUSTRY

Palmer

BY ROBIN MCKILLOP & SHIRLEY MCCUAIG

SURFICIAL GEOLOGY & PERMAFROST INVESTIGATIONS ALONG THE PROPOSED KIVALLIQ HYDRO-FIBRE LINK

The proposed corridor for the 1200-km long Kivalliq Hydro-Fibre Link (KHFL), being advanced by the Kivalliq Inuit Association, extends from Gillam, MB, to Baker Lake, NU.

Palmer has been leading mapping of surficial geology and investigations of permafrost along the corridor since 2020, with collaborative support from a research group led by Pascale Roy-Léveillée (Université Laval). Work prior to August 2022 included surficial geology mapping, compilation of historical data collected for the Polar Gas Project, geophysical surveys (GPR), Talon shallow drilling, and installation of shallow ground thermistors.

In August 2022, additional helicopter-supported field investigations were conducted with bear safety monitors from local communities. Surficial deposits in hand-dug test-pits and representative thaw depths were documented, and ground temperature data were downloaded.

Bouldery till is most common, with active layers ~0.7-1.2 m thick. Glaciomarine deposits comprise


Left: bear monitor at work. Right: downloading ground temperature sensor data. Opened sensor is visible in background.

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both fine- or coarse-grained material. Marine fossils are rare, but beach ridges are abundant. Active layers are 0.7 m thick in silt to >1 m thick in coarser-grained glaciomarine material. Ice-wedge polygons are common in glaciofluvial deposits.

Shallow ground temperatures range from -3 to -7°C in NU and northern MB and from -1.6 to +1.4°C in southern MB, where the permafrost is warm and more sensitive to climate change and disturbance.

Palmer is supporting a geotechnical program with Northern Permafrost Consulting to characterize permafrost at greater depths.

For more information see:

McCuaig, S. *et al.* (2022). Mapping and Investigating Permafrost along the Proposed Kivalliq Hydro-Fibre Link, Manitoba to Nunavut. In: *Proceedings of GeoCalgary 2022*, 2-5 October 2022, Paper No. 311.

Marine fossils from glaciomarine sandy silt.

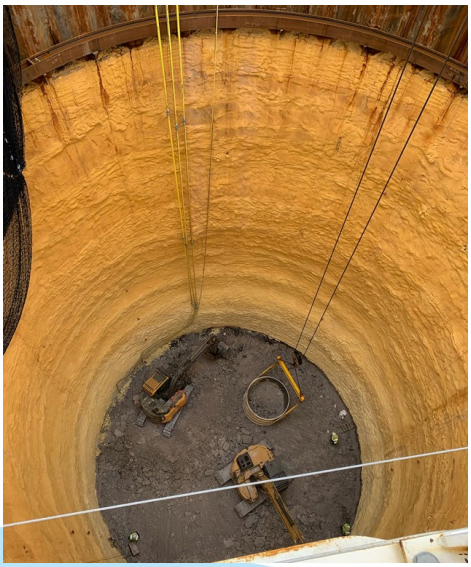
INDUSTRY

Keller | Ground Freezing

BY JOSEPH SOPKO

MECHANICAL PROPERTIES OF FROZEN CLAY

Artificial ground freezing was the specified method to provide temporary earth support and groundwater control for two deep shafts (38 m & 40 m) associated with the New York DEP Water Tunnel No. 3 project. A series of pipes were installed around the perimeter of the excavation, converting the porewater to ice. Three shafts were constructed using this method in the 1990s. During phase excavation these shafts experienced significant time dependent creep deformation in New York's Raritan clay that complicated construction.



Shaft during excavation with polyurethane insulation protecting the frozen earth, before installation of the final concrete liner.

On the current project, extensive laboratory testing was conducted on Raritan clay to evaluate potential creep movement during excavation. Supplementary boreholes were drilled at each shaft location and relatively undisturbed samples of the clay were retrieved with a Pitcher sampler. These samples were tested in the laboratory for unconfined compressive strength and creep deformation at temperatures of -10 and -15°C. Results yielded an average unconfined compressive strength of 3.2 MPa at -10°C and 5.1 MPa at -15°C.

The constant stress creep tests were run at stress levels of 1.0, 1.2, 1.68 and 3.0 MPa. In these tests, the time versus axial strain was measured as well as the rate of creep. The tests were run until failure, six percent strain, or 1000 hours where there was minimal strain. Results of these tests led to the development of the Klein creep parameters that could be used to evaluate the required thickness of the frozen earth structure for the time dependent deformation of each shaft.

The shaft was supported with a 6.8 m frozen earth wall at an average temperature of -10°C. Three rows of freeze pipes, spaced at ~1.25 m were drilled and installed to circulate calcium chloride at -25°C. The required freezing time was about eight weeks.

A conventional sheet pile support system was required in the unsaturated zone from the ground surface to the groundwater table. The unsaturated soils do not have sufficient strength when frozen to support the excavation. The formation of the frozen earth wall was confirmed with temperature monitoring pipes as well as pumping tests to ensure there was no communication between the groundwater levels on the interior and exterior of the frozen wall. Following the confirmation of the continuous frozen earth structure, excavation began.

BGC Engineering Inc.

BY LUKAS ARENSON & MATTHIEU STURZENEGGER

RISK ASSESSMENT OF MOOSEHIDE SLIDE (ËDDHÄ DÄDHËCHĄ), DAWSON CITY, YT, CANADA

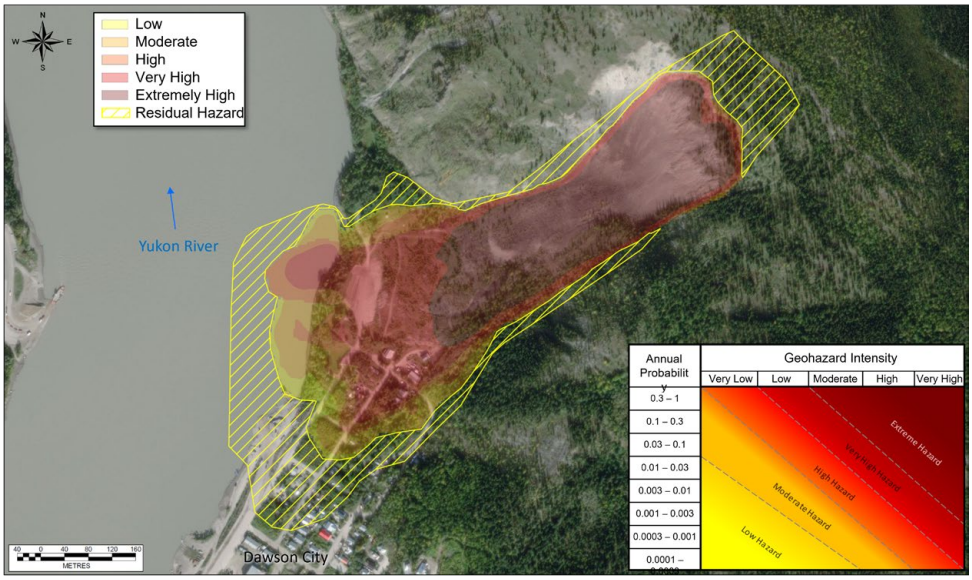
The Moosehide Slide is a rockslide located on the northern end of Dawson City, YT, and features a prominent headscarp, corresponding to the initiation zone of a pre-historic landslide. Field evidence, such as tension cracks and split trees, and airborne lidar indicate retrogressive instability in the headscarp zone. The debris of the slide extends from the base of the headscarp to the Yukon River and includes a rock glacier in the central portions, which transitions into an earthflow in the lower parts. A risk assessment was completed to quantify hazard and risk associated with a potential rock avalanche and associated runout. The assessment included:

- Quantification of potential source volumes and hazard probabilities at the headscarp;
- Modelling of the rock avalanche runout;
- Assessment of the influence of permafrost degradation on the likelihood and intensity of the rock avalanche; and
- Quantitative risk assessment.

Two types of maps were generated to communicate landslide hazard and risk to the public and decision makers. These form the basis for the development of a monitoring program, that has recently been initiated, and emergency response plan to mitigate life-loss risk in existing developments. Data validation and development of a better slope deformation understanding are currently ongoing. Once completed, the monitoring program may be integrated in an early warning system, consisting of pre-defined alert levels, associated with an emergency response plan to evacuate individuals at risk if a threshold is reached and a rock avalanche is considered to occur imminently.

We acknowledge the Yukon Government (Yukon Geological Survey and Community Services) for allowing us to present this assessment, and Matthias Jakob who played a fundamental role in the risk assessment of this project and tragically passed away last October.

Composite hazard map of impact intensity with event probability for all scenarios considered at the Moose Hill Slide, Dawson City, YT. Inset: a matrix with flow intensity and annual hazard probability.



Mooshide slide located at the North end of Dawson City, YT. Photo: Lukas Arenson.

Tetra Tech Canada Inc.

BY ED HOEVE & BARB FORTIN

A REVIEW OF GROUND TEMPERATURES AT THE HANS CREEK BRIDGE FOUNDATION

The Inuvik to Tuktoyaktuk Highway (ITH) was built over four winter construction seasons (2014-2017) and includes eight bridges along its 140 km length. The bridge foundations were designed by Tetra Tech Canada Inc. and its Inuvialuit partner company, Kiggiak-EBA Consulting Ltd.

The highway crosses continuous permafrost terrain with excess ice (ice-rich). Bedrock is generally too deep to access for foundation support at the bridge locations. Consequently, all bridge abutments and piers are supported on adfreeze steel pipe piles in permafrost. Adfreeze piles support loads through the strength of the frozen bond between the pile and the permafrost soil. The capacity of adfreeze piles is strongly dependent on the temperature of the permafrost, among other factors, and pile capacity decreases as the permafrost warms.

The pile design was based on two sets of ground temperature measurements collected in the winter and spring following the geotechnical investigation. Overall warming of the permafrost in response to projected climate warming was anticipated during design and it was recognized that some of the permafrost could approach the onset of thaw over the 75-year design life of the bridges. A means to facilitate future pier pile stabilization was incorporated into the design and construction.

Hans Creek Bridge (ITH km 57.3).

The Hans Creek Bridge (ITH km 57.3) is constructed on two abutments and two piers. Piles were installed in March-April 2016. Initial post-construction ground temperature monitoring confirmed the design assumptions at the abutment locations, but ground temperatures at the bottom of the pier piles were found to be significantly warmer than assumed and the warmest observed at any of the ITH bridges.

In 2022 a review of ground temperature monitoring data from the initial six years following construction was undertaken and compared with the design assumptions. The design and practical implications are being considered and it is expected that intervention to increase the capacity of the pier piles may be required sooner than estimated at the time of design. A summary was presented at the 2022 Yellowknife Geoscience Forum and a paper is being prepared for presentation in the fall of 2023.

Ground temperture cables cased in white capped PVC pipe below Hans Creek Bridge.

- Hoeve, E. (2022). A review of ground temperatures at the Hans Creek bridge foundation. In: *50th Annual Yellowknife Geoscience Forum - Abstract Volume*; Northwest Territories Geological Survey, p. 19.

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THE INUVIK HOSPITAL – ON THE ROAD TO RECOVERY

The Inuvik Regional Hospital, NT, was constructed from 2001-2003. It is founded on concrete spread footings on permafrost that is stabilized with a flat-loop thermosyphon system and insulation. The hospital has a below grade temperate crawlspace to facilitate mechanical systems and access. Soon after construction two operational concerns were identified:

- Some pipes supplied to the project and used for thermosyphon evaporators were faulty in that the seams in the pipe leaked so that pressure in some of the evaporators dropped, reducing their effectiveness.
- Some seepage persistently found its way into the crawlspace, despite efforts to intercept and block it. This supply of water would freeze when contacting the chilled ground from the thermosyphons, causing ice to accumulate (which some have referred to as "pingos") in the crawlspace.

North facing view of the Inuvik Regional Hospital, NT, with flat-loop thermosyphon system.

Some cracks were noticed in the building about four years ago, and it was subsequently determined that settlement had occurred. The thermosyphons were checked and recharged where needed in 2020. The building has since been releveled.

While it's not evident the seepage had contributed to permafrost degradation and settlement, it may have. The building owner has implemented surface drainage improvements and more intentional snow management, which seems to have effectively controlled the seepage.

Tetra Tech recently completed an evaluation of the thermal performance of the foundation system, among other facets of site assessment, and concluded that the thermosyphon system is working. Provided it is maintained, the system should maintain relatively stable permafrost for at least another 30 years. Details of the maintenance program are still being defined.

IN MEMORIAM

Michael W. Smith

(1944-2022)

BY CHRIS BURN (CARLETON UNIVERSITY, CANADA)

Mike Smith's *The Frozen Earth: Fundamentals of geocryology*, written with his Carleton colleague, Peter Williams, remains the most helpful textbook for geotechnical aspects of permafrost science more than 30 years after its publication in 1989. It is one of several signal contributions that Mike made to our field, the first being his analysis of microclimatic influences on permafrost distribution in the Mackenzie Delta. He developed the use of time-domain reflectometry (TDR) for determination of the unfrozen water content of freezing soils with Dan Patterson and had a long and productive collaboration with the late Daniel Riseborough investigating climate-permafrost relations. Mike was in the vanguard of numerical simulation of permafrost thermal regimes in North America.

He took his PhD with Ross Mackay at the University of British Columbia, which led him into work associated with northern energy projects, first with respect to modelling the thermal effects of ground disturbance and then to consider frost heave at field scale. He contributed an unusually well-rounded body of research involving field, laboratory, and modelling studies. Its impact is demonstrated, for example, by the 384 citations his 2002 paper has received.

Mike was an insightful, support-

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ive, and astute graduate supervisor, and quick-witted, ethical, and effective as an academic administrator. He was greatly respected when he served as Dean of his Faculty. He spent his retirement in rural Ontario involved in activities for his community. On 12 May 2022, Mike passed away peacefully in his sleep at his home in Picton, ON. He is survived by his wife Pauline and their four children. We will remember him for his warm consideration of others' welfare, his Pythonian sense of humour, and his penetrating intellect.

Smith, M.W. & Riseborough, D.W. (2002). Climate and the limits of permafrost: a zonal analysis. *Permafrost and Periglacial Processes*, 13(1). DOI: 10.1002/ppp.410.

IN MEMORIAM

Tingjun Zhang

(1956-2022)

BY OLIVER W. FRAUENFELD (TEXAS A&M UNIVERSITY, USA)

Tingjun came as a student from China to the University of Alaska Fairbanks (UAF), where he earned his MS (1989) and PhD (1993). After a postdoc at the UAF Geophysical Institute, he spent the next stage of his career at the University of Colorado Boulder's National Snow and Ice Data Center (NSIDC) and was elected to the Council of Fellows of the Cooperative Institute for Research in Environmental Sciences in 2008. He always maintained strong collaborations with China, and eventually returned to become professor of physical geography and dean of the College of Earth and Environmental Sciences at Lanzhou University.

His contributions to permafrost and seasonally frozen ground research range from theoretical work and model simulations, applied and observational studies, to fieldwork both in Alaska and across the Tibetan Plateau. His early research focused on Alaska but, while at NSIDC, his data rescue efforts from the former Soviet Union, together with Roger Barry and David Gilichinsky, were instrumental in establishing the observational soil thermal response to climate change and its feedbacks in high-latitude Eurasia.

At Lanzhou, his research focused primarily on permafrost and seasonally frozen ground in the high elevation regions of China. In addition to over 200 articles, Tingjun contributed his expertise in permafrost and seasonally frozen ground as lead author on the cryospheric chapters of the IPCC's 4th and 5th assessment reports.

Tingjun Zhang passed away on 18 January 2022, at the age of 65, after a short period of illness. Those who knew Tingjun will remember him for his exuberance and generosity, and as a great mentor, colleague, and friend.

Photo: Xiaoqing Peng (Lanzhou University).

Zhang, T., *et al.* (1999): Statistics and characteristics of permafrost and ground-ice distribution in the Northern Hemisphere. *Polar Geography*, 23(2). DOI: 10.1080/10889379909377670.

IN MEMORIAM

Alan Heginbottom

(1943-2022)

BY ANTONI LEWKOWICZ (UNIVERSITY OF OTTAWA, CANADA)

Alan Heginbottom was a Canadian geomorphologist and geocryologist who made significant contributions to permafrost mapping. After emigrating to Canada from the UK, he joined the Geological Survey of Canada (GSC) in 1968 and remained there until early retirement in 1995 when he was named emeritus scientist. His efforts were recognized by the Royal Geographical Society and the Royal Canadian Geographical Society, both of which made him a Fellow.

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Alan thought deeply and wrote about the cartographic challenge of portraying permafrost, by its nature an invisible phenomenon and one that has variable contiguity. He was the lead author on the extant official map of permafrost in Canada and was the Canadian co-author of the IPA's circum-Arctic map of permafrost and ground ice.

Alan took on significant roles in the organisation of permafrost science and engineering, serving as Secretary of the Canadian National Committee for the IPA and of the National Organizing Committee for the 7th International Conference on Permafrost, held in Yellowknife, NT, in 1998. He was ahead of his time in his work on the IPA's Working Group on Permafrost Data and Information (1993-1998), a group that set the stage for methods of standardization, permafrost data rescue, and data sharing, which have led in the last few years to numerous circumpolar syntheses relating to permafrost.

Alan generally stood out as the tallest person in the room, and with his dry sense of humour, is greatly missed by his many friends in the Canadian and international permafrost communities. Alan died in Wakefield, QC, on 4 July 2022. He is survived by his wife Gillian, son James, sister Linda, and two grandchildren.

Heginbottom, J.A., *et al.* (1995). Canada, Permafrost. In: *The National Atlas of Canada*. Natural Resources Canada, Geomatics Canada, MCR Series no. 4177, (ed. 5). DOI: 10.4095/294672.

The International Permafrost Association's

PHOTOGRAPHY Contest

Theme:

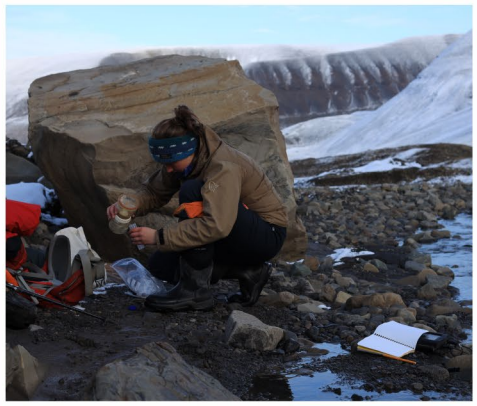
Return to Fieldwork

Winner (€100)

Geert Hensgens
(Vrije Universiteit Amsterdam, Netherlands)

Runner-up (€50)

Marjolaine Verret
(University Centre in Svalbard, UNIS, Norway)



Runner-up (€50)

Wilson (Wai-Yin) Cheung
(Queen's University, Canada)

After a 2-year hiatus due to the COVID-19 pandemic, many of us were able to return to fieldwork in 2022. This year, our Photography Contest celebrates the international permafrost community's impressive breadth of field skills and team work. ***Congratulations*** to the winners and thank you to everyone who submitted!

Visit **permafrost.org** to see all the contest entries.

THE INTERNATIONAL PERMAFROST ASSOCIATION

The mission of the International Permafrost Association is to promote research in permafrost and permafrost-related fields within the global scientific and engineering communities, to support the activities of researchers in these disciplines, and to disseminate findings concerning permafrost to decision-makers, the general public, and educators.

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