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Stockton, E.J., Burn, C.R., Humphries, J. (eds.) 2021. Frozen Ground 44 (2020). *International Permafrost Association (IPA).* DOI: 10.52381/IPA.FG442020.1.

Frozen Ground

THE ANNUAL NEWS BULLETIN OF THE INTERNATIONAL PERMAFROST ASSOCIATION
WWW.PERMAFROST.ORG

Words from the President

BY CHRIS BURN,
CARLETON UNIVERSITY,
CANADA

Frost hummocks along the south coast of Saunders Island, Falkland Islands, February 2017. IPA photo contest winner: *Francesco Malfasi*.

2020 has been an extraordinary year for the IPA and for all of us. The 12th ICOP, hosted by China and scheduled for June, had to be postponed and, as a result, the IPA Council held its first virtual meeting instead of the normal in person deliberations. The Council is currently scheduled to gather next in Lanzhou at the 2022 ICOP that we hope will be able to take place as expected.

For the time being, our activities, like those of most others, have moved online. A new Executive Committee was elected in June that has begun its work. We are all grateful to those who stood for election and I am now thankful that each member of the executive has assumed responsibility for an aspect of the IPA's operations: Gonçalo Vieira for GTN-P; Isabelle Gärtner-Roer for developing a policy on membership dues; Kjersti Gisnås for liaison with PYRN; Fritz Nelson for publications; Michael Krautblatter for a webinar series; and Yuanming Lai for liaison with the ICOP organization. I am personally grateful to Fujun Niu for assistance with communication between the IPA and Chinese permafrost organizations and to Andrey Abramov for similar assistance with Russian organizations. We have also been fortunate to have assistance from Emma Stockton and Jennifer Humphries as Executive Directors, supported by funds available at Carleton University. They are normally the first point of contact with the IPA.

In this issue of *Frozen Ground* you will see that our activities have been modified but not stopped by the pandemic. Most importantly, the RCOP hosted by USPA will go ahead as planned, but at the end of October. All current Action Groups have had their terms extended by one year. The new online environment has forced innovation, and I am delighted that we have seized the chance to develop a webinar series, illustrating the links between permafrost engineering and science.

The IPA faces one structural problem that every President must address: our revenues fall far short of

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the costs of running the Association. Many recent presidents have secured institutional or grant support to maintain the central office, which handles requests for assistance, executive committee correspondence, administration of programs, and other matters. A major effort is put into the preparation and production of *Frozen Ground*. You will see innovation in the bulletin this year, because it is sponsored by Transport Canada through reporting on the Northern Transportation Adaptation Initiative (NTAI). This is a major program of preparation for the effects of climate change in permafrost regions that has ended a 10-year term. While many scientists have concentrated upon aspects of the carbon problem, the NTAI has addressed issues concerned with infrastructure issues that are as immediate.

The IPA Executive Committee is working on several topics to strengthen the Association. We will have a new website in a few months. In this issue of Frozen Ground we celebrate and congratulate the winners of the photo competition held for the site: Francesco Malfasi, Ludwig Jardillier, and David Olefeldt. The other interesting and attractive photos will adorn the website as well. We will also establish a DOI identity so that our publications may be located digitally with ease. We will collaborate with our members and their associations to make their publications accessible this way and most importantly research abstracts and papers from our conferences.

I hope every member of the IPA stays safe through the pandemic until we can meet again.

First sunrise of 2021 in Inuvik, NT, Canada. Photo: Alice Wilson.

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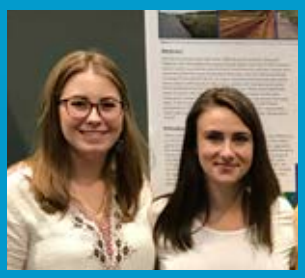


EXECUTIVE DIRECTORS
Emma Stockton (L) &
Jen Humphries (R),
Carleton University,
Canada

CONFERENCE UPDATES

2021 Regional Conference on Permafrost (RCOP)

BY TOM DOUGLAS (U.S. ARMY CRREL), CONFERENCE CHAIR

The U.S. Permafrost Association (USPA) is co-organizing the next IPA Regional Conference on Permafrost (RCOP) with the American Society of Civil Engineers (ASCE). The combined RCOP and 19th International Conference on Cold Regions Engineering (ICCRE) will be held online from **24-29 October 2021**. It will provide a venue for permafrost science and a wide range of cold regions engineering topics to be merged for the first time.

Planning includes substantial efforts to expand student and early career participation, as well as initiatives focused on equity, diversity, and inclusion. Sunday 24 October will include IPA, USPA, and ASCE meetings, along with a program developed by the Permafrost Young Researchers Network (PYRN).

As currently envisioned, there will be four to five hours of presentations each day, Monday through Friday. The USPA is looking into potential virtual communication platforms to support the events.

Sixty-five proceedings papers, following ASCE's format, have been reviewed and manuscripts are in preparation for final editing, envisioned in the early summer 2021. Thirty session topics have been submitted and reviewed. The call for short abstracts is anticipated in March 2021, with registration opening at the same time. We expect 200-250 participants.

A Technical Conference committee is developing the format. Following recent virtual platforms, we anticipate short talks to be the preferred presentation style. Some small in-person events may be encouraged if COVID-19 safety and health requirements can be followed. These would be likely held at labs and universities where small groups of local presenters and attendees could meet.

For more information visit usermafrost.org/21rcop/index.shtml.

CONFERENCE UPDATES

12th International Conference on Permafrost (ICOP2022)

BY FUJUN NIU (CHINESE ACADEMY OF SCIENCES), SECRETARY GENERAL

The 12th International Conference on Permafrost (ICOP2022) will be held in Lanzhou, China from **20-24 June 2022** and hosted by Lanzhou University. The conference theme is "*Permafrost environments under persistent warming: Challenges for scientific assessment and engineering practice*". This conference will focus on permafrost changes and the corresponding environmental affects under the climate warming, share experiences in cold regions engineering construction, and exchange recent experience in all fields of permafrost research around the world.

ICOP2022 provides 8 sessions covering 26 topics for attendees to show and exchange their research achievements and experiences. The conference program will operate with 4 days of scientific sessions, including the conference opening and closing ceremonies, plenary, oral and poster sessions, IPA council and executive committee meetings, PYRN activities, GTN-P meeting.

The conference will include 1 day of local field trips and 4-6 days of post-conference field trips, such as:

- Interior Qinghai-Tibet Plateau
- Eastern Qinghai-Tibet Plateau
- Northeastern China
- Qilian Mountains
- Ordos Loess Plateau

Social events and field trips provided with more options may be available for individuals or group interests.

The local Organizing Committee looks forward to warmly welcoming you in Lanzhou to attend the conference. The call for sessions is already open and online registration will open in March 2021.

For more information visit icop2022.scimeeting.cn or contact icop2020@lzb.ac.cn.

CONFERENCE UPDATES

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 **19-22 June 2023**. The conference, originally scheduled for June 2022, was postponed due to COVID-19.

The small city of Puigcerdà (pop. 9,000), is located in the center of the Cerdanya district, a wide tectonic basin in the Eastern Pyreenes. The area lies between Catalonia (south) and French (north), and is a good example of shared services between two countries. The city lies at the foot of a terminal moraine system built by some of the longest glaciers in the Pyrenees during the Last Glaciation.

In this calm mountain setting, the conference venue and all major attractions will be close to the city. Most hotels are within walking distance, or otherwise served by a good transportation system. Puigcerdà is about two hours by bus and train from Barcelona. The Cerdanya district is also rich in monuments and local culture. Activities will be prepared for participants and accompanying persons.

The conference will be hosted by the University of Barcelona and count on the support of several other Spanish universities and research centers. The Local Organizing Committee has already advanced on the logistics, accommodation, transportation, sponsors, and organization of field trips. A conference website will be available in early 2021.

The Local Organizing Committee is honored to host EUCOP6. We encourage the permafrost community to attend the meeting and enjoy the beautiful landscapes of the Catalan Pyrenees.

CONFERENCE UPDATES

13th International Conference on Permafrost (ICOP2024)

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

The 13th International Conference on Permafrost (ICOP2024) will be held in Whitehorse, Yukon, Canada from **16-20 June 2024**. The city 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 will run from Sunday evening to Thursday night and feature scientific sessions (keynotes, plenary discussions, public events, oral and poster sessions), IPA council and executive committee meetings, PYRN meetings, a trade show, local excursions and social events for participants, partners and young researchers. Longer field trips and short courses will be offered prior to and immediately following the conference.

The Technical Committee is planning for a hybrid conference model with virtual access to the oral and poster presentations, as well as workshops and exhibitions. The call for technical sessions is expected to open in January 2023. Full-length papers and extended abstracts can be submitted, all of which will be subject to review, and only submissions relevant to the conference will be accepted for the proceedings.

Whitehorse, Yukon

The Local Organizing Committee looks forward to warmly welcoming you in Canada's North and encourages the whole scientific community, specifically young researchers, practitioners and students to get involved and attend.

For more information contact Local Organizing Committee Chair, Brian Horton (bhorton@yukonu.ca) or the National Organizing Committee Chair and Conference Chair, Lukas Arenson (larenson@bgcengineering.ca). Information will soon be available on www.icop2024.com.

Development of a pan-Arctic drained lake basin product

BY ACTION GROUP LEADERS, HELENA BERGSTEDT AND BENJAMIN JONES
(UNIVERSITY OF ALASKA FAIRBANKS, USA)

Local and regional assessments indicate that drained lake basins (DLBs) are a prominent landscape feature in lowland permafrost regions around the pan-Arctic. Despite this recognition, a pan-Arctic assessment of DLB distribution and their carbon stores has never been attempted. A coordinated pan-Arctic scale effort is needed to better understand the importance of DLBs in permafrost-regions across the pan-Arctic.

Our Action Group will focus on the development of a pan-Arctic DLB product that will fill a fundamental knowledge gap in permafrost-region landscapes with implications for global-scale climate feedbacks. A comprehensive pan-Arctic DLB dataset will be of great interest to the scientific community and will benefit researchers working on projects from many different disciplines (e.g., hydrological modelling, engineering, and carbon cycling).

Our Action Group brings together three generations of researchers from six IPA member countries with diverse skills in linking spatial and temporal data across broad regions. The DLB Action Group includes several early career researchers 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 Matthias Fuchs, Louise Farquharson, and Benjamin Gaglioti. Additional leadership of the Action Group is being provided by Mikhail Kanevskiy, Amy Breen, Anna Liljedahl, Annett Bartsch, Pascale Roy-Lévéillee, Trevor Lantz, Frédéric Bouchard, and Gustaf Hugelius. Dr. Kenneth Hinkel is providing guidance based on his many years of research on DLBs in northern Alaska.

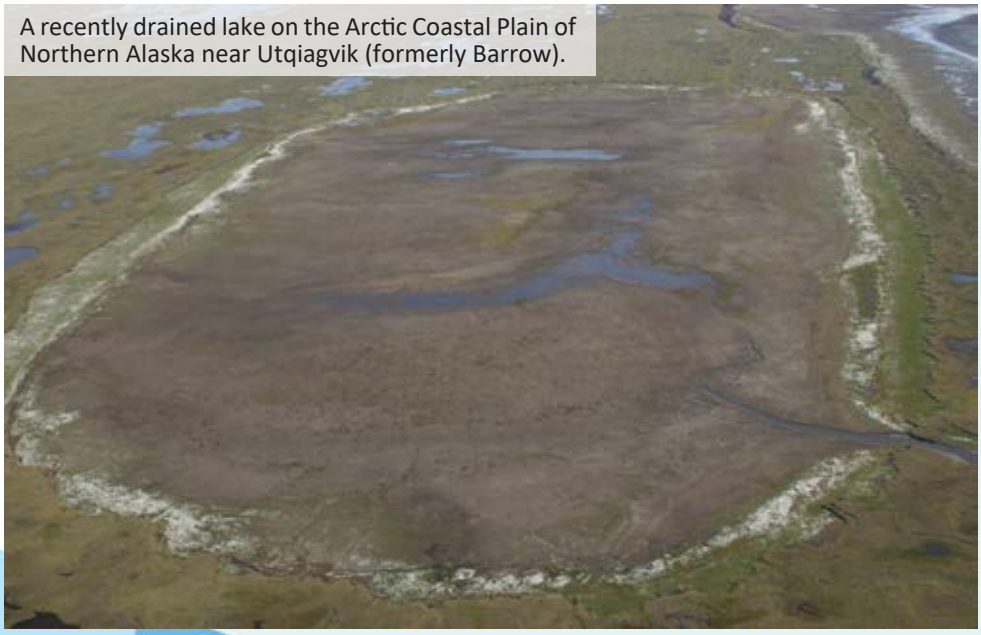
Due to COVID-19 and the cancellation of in-person meetings in 2020, Action Group gatherings planned for various conferences were cancelled. However, the Action Group was able to make progress towards the creation of a pan-Arctic DLB inventory and comprehensive DLB radiocarbon database. The first results of the remote sensing-based mapping approach were presented at EGU 2020 and an updated version, including the North Slope of Alaska and selected areas in Canada and Russia, was presented by Action Group members at the virtual AGU 2020 annual fall meeting.

In 2021, the Action Group plans to hold virtual meetings in conjunction with conferences like the virtual EGU (vEGU) 2021, and a one-day workshop to bring Action Group members together and plan for the next stages of the work. Helena Bergstedt is leading a paper focused on dynamic permafrost regions that will be submitted to a special issue in the journal *Remote Sensing*. Benjamin Jones is leading a review paper focused on the important role of lakes and drained lakes in the Arctic system for the journal, *Nature Reviews Earth and Environment*. Action Group members will also submit a session proposal for AGU 2021, covering DLBs on a pan-Arctic scale. The team is very much looking forward to in-person meetings and collaborative activities.

For more information see:

Bergstedt, H., Jones, B., Walker, D., Farquharson, L., Breen, A. and Hinkel, K. (2020). Mapping lake drainage and drained lake basins around Point Lay, Alaska using multi-source remote sensing data. *EGU General Assembly Conference Abstracts*, 11919, May 2020, Virtual Online.

Bergstedt, H., Jones, B.M., Farquharson, L.M., Gaglioti, B., Parsekian, A., Kanevskiy, M.Z., Hinkel, K.M., Rangel, R.C., Ohara, N., Breen, A.L. and Walker, D.A., (2020). Towards panarctic mapping of drained lake basins in permafrost regions. *AGU Fall Meeting 2020*, December 2020, Virtual Online.



A recently drained lake on the Arctic Coastal Plain of Northern Alaska near Utqiagvik (formerly Barrow).

Rock glacier inventories and kinematics

BY ACTION GROUP LEADER, REYNALD DELALOYE (UNIVERSITY OF FRIBOURG, SWITZERLAND)

Ritzichummu rock glacier, Swiss Alps.

The Action Group 'Rock glacier inventories and kinematics' launched in 2018. 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 kinematics (RGK) as an associated parameter of the Essential Climate Variable (ECV) permafrost, representative of the evolution of mountain permafrost.

The final version of the baseline concepts for inventorying rock glaciers was released for approval by Action Group members in early 2020. This document follows a 2019 workshop and builds up the basis on which practical inventorying guidelines can be developed. At the end of 2020, these guidelines were in the final stage of preparation before being submitted to the Action Group community for feedback in early 2021. A similar process has been undertaken for exploiting remote sensing data and SAR data to inventory rock glaciers from a kinematics base and assign a kinematic attribute to any recognized rock glacier landform. This second action began during a workshop in Fribourg, Switzerland on 11-13 February 2020. Both the actions and the workshops have been supported by the European Space Agency (ESA) project, CCI+ Permafrost. Partners from Argentina, France, Italy, Norway, UK, Switzerland, and USA have tested the approach in various mountain ranges over the globe.

The Fribourg workshop was attended by 25 scientists, mainly from Europe, but also from Hong Kong and China. A large part was dedicated to discussions on preliminary steps towards the development of climate-oriented products which could be derived from the monitoring of rock glacier kinematics and which could serve for its inclusion as an associated parameter of the ECV permafrost. The workshop resulted in a proposal to the Global Climate Observing System (GCOS), via the public review of its Implementation Plan 2022-2026, for the integration of RGK into ECV permafrost. Documents specifically dedicated to baseline concepts and guidelines are being prepared within the Action Group and will be submitted to its community for feedback in 2021.

Action Group participation is open to everyone via our mailing list, which had 130 subscribers in 2020 from more than 22 countries.

For more information and access to the released documents visit www.unifr.ch/geo/geomorphology/en/research/ipa-action-group-rock-glacier/.

Several participants from the Action Group workshop in Fribourg, Switzerland, 11-13 February 2020 (with the chimney of a former chocolate factory in the background).

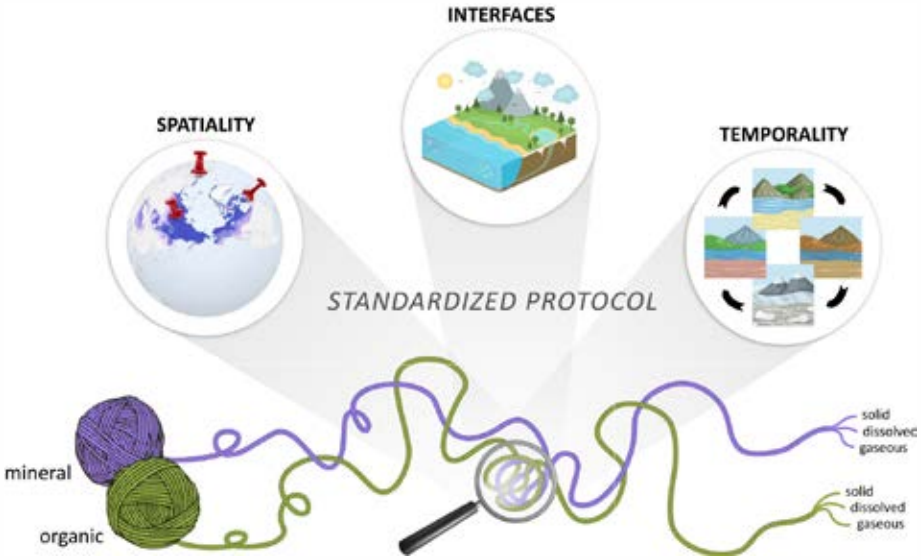
Standardized methods across Permafrost Landscapes: from Arctic Soils to Hydrosystems (SPLASH)

BY ACTION GROUP LEADER, FRÉDÉRIC BOUCHARD (UNIVERSITÉ PARIS-SACLAY, FRANCE)

Ongoing warming and thawing across the northern permafrost region are driving changes in Arctic hydrology and the mobilization of mineral and organic materials (i.e., nutrients, contaminants, and microorganisms) from formerly frozen soils to terrestrial ecosystems and surface water bodies, and ultimately to Arctic continental shelves and the atmosphere. Mineral and organic components interact along the 'lateral continuum' (from soils to aquatic systems), affecting biogeochemical cycles with strong spatial and temporal heterogeneities. There is an urgent need for a set of unified protocols to capture changes in the lateral transport of mineral and organic matter across Arctic permafrost landscapes.

The main objective of the 'SPLASH' Action Group is to provide the permafrost community with a suite of standardized field approaches for sampling soil, sediment, and water across different types of permafrost landscapes (e.g., palsa peatlands, shrub tundra, boreal forest), spanning disciplinary boundaries. SPLASH is a transdisciplinary initiative led by a Coordinating Committee composed of early-career researchers (ECRs), in collaboration with more than 30 other members from 11 countries (both ECRs and senior experts, referred to as the SPLASH team).

The idea is not to 'reinvent the wheel', but rather to coordinate with existing broad-scale research initiatives and networks, such as T-MOSAiC, Nunataryuk, IPaC, or the Permafrost Carbon Network. This will contribute to the ongoing effort on standardizing sampling strategies, improving data comparison, synthesis, and upscaling of results.



The mineral and organic permafrost pools, visualized as balls of wool with solid, dissolved and gaseous fractions represented as threads (Bouchard *et al.* 2020).

Of course, our Action Group's progress has been strongly impacted by the COVID-19 pandemic, given that no field sampling could be conducted across the Arctic. Nevertheless, we were able to submit and publish a presentation of the SPLASH project in the journal, *Advances in Polar Science*. We also prepared a brief online survey to collect basic input information from researchers who sample along the 'soil-to-hydrosystem continuum'. The survey asked about the 'WHAT, WHERE, and WHEN' of field sampling across permafrost landscapes, and answers are being currently compiled. Like everyone in the permafrost community and beyond, we cross our fingers to be able to conduct fieldwork in 2021.

For more information visit www.splash.biogeochimie.fr/.

For more information see:

Bouchard, F., Agnan, Y., Bröder, L., Fouché, J., Hirst, C., Sjöberg, Y., the SPLASH team (2020). The SPLASH Action Group - Towards standardized sampling strategies in permafrost science. *Advances in Polar Science*, 31(3), 153-155. DOI: 10.13679/j.advps.2020.0009.

Water sampling in a pool formed thawing of permafrost from a burst pipe, Yakutia, Republic of Sakha, Siberia, August 2019. IPA photo contest runner-up: *Ludwig Jardillier*.

NEW ACTION GROUP UPDATE

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

BY ACTION GROUP LEADERS CHRISTIAN HAUCK AND COLINE MOLLARET (UNIVERSITY OF FRIBOURG, SWITZERLAND)

The Action Group consists of more than 30 senior and early career permafrost scientists, geophysicists, and engineers from 10 IPA country members. Our main objective is to bring together the international community interested in geoelectrical measurements on permafrost and to lay the foundations for an operational database of geoelectrical surveys on permafrost, ideally in combination with GTN-P. Within regular meetings and activities, we aim to:

- Integrate historical and recent geoelectrical surveys within the IDGSP to serve as (a) permafrost evidence on a spatially denser grid than existing borehole temperatures, and (b) a baseline for permafrost and ground ice content monitoring in combination with GTN-P.
- Define a common strategy and standardized QA/QC criteria for repetition and inversion of geoelectric measurements
- Promote the repetition of geoelectrical measurements in a climate change context
- Develop permafrost resistivity data products (map of survey locations, typical values for different materials and landforms, standardised figures of mean resistivity change over time)

We will develop guidelines for measuring, processing and archiving geoelectrical data, organise standardised repetition protocols, initiate the IDGSP, increase the awareness of the value of geophysical data within the permafrost community, and coordinate first steps toward their potential integration into GTN-P.

STANDING COMMITTEE REPORTS

The Global Terrestrial Network for Permafrost (GTN-P)

BY CHAIR DMITRY STRELETSKIY (GEORGE WASHINGTON UNIVERSITY, USA) AND DIRECTOR OF THE SECRETARIAT, ANNA IRRGANG (AWI POTSDAM, GERMANY)

GTN-P
Global Terrestrial Network for Permafrost

USE OF GTN-P DATA

During 2020, members of the GTN-P network continued to contribute to the State of the Climate Report, and national and international assessments of climate change, including IPCC AR6. More than 40 publications used GTN-P data in 2020, including analysis of site-specific and regional trends in permafrost, and validations of modeling and remote sensing products.

GTN-P DATA SERVICE

GTN-P continued to provide users with up-to-date information on permafrost thermal state and active layer thickness. The GTN-P website had 2,200 individual visitors and 19,000 page views in 2020. The majority of the users came from the USA, Canada, Russia, Germany, China, France, UK, Switzerland, Sweden, and Italy. We thank all field investigators and national correspondents for their time and effort in collection and submission of observational data. We also thank the staff of Arctic Portal for their ongoing work on the GTN-P webpage and database. To access the latest data on permafrost temperature and active layer thickness visit gtnpdatabase.org/.

GTN-P & THE GLOBAL CLIMATE OBSERVING SYSTEM (GCOS)

The GTN-P Steering Committee continued to work towards defining products and requirements for the next GCOS implementation plan. This involved the revision and further definition of the three Essential Climate Variable (ECV) permafrost products: Thermal State of Permafrost (TSP), Active Layer Thickness (ALT) and the new Rock Glacier Kinematics (RGK).

GTN-P & THE GLOBAL CRYOSPHERE WATCH (GCW)

GTN-P Steering Committee members participate in the Permafrost Task Team, which was established to define permafrost best practices which will be included in the next World Meteorological Organization (WMO) Guide no. 8. The measure-

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ments best practice for permafrost aims to define reference methods for the configuration and operation of stations for in situ observations in high mountains and polar regions.

CONFERENCES & WORKSHOPS

GTN-P Steering Committee (SC) will hold a virtual National Correspondents Meeting and a corresponding session at RCOP in 2021. GTN-P will have a virtual National Correspondents Meeting on Sunday, October 24, 2021. The session *"The Global Terrestrial Network for Permafrost (GTN-P)"* is accepting abstracts.

The SC welcomes new members Hanne Christiansen (University Centre in Svalbard, UNIS) and Filip Hrbacek (Masaryk University, Czech Republic)! Filip Hrbacek was nominated by ANTPAS and is taking over representation of Antarctica since our former representative, Gonçalo Vieira, has taken over the role of Vice-President and GTN-P representative at the IPA. We would like to thank Sarah Strand, who left the SC in 2020 for her long-time engagement and representation of the IPA.

The SC is actively seeking nominations from all National Correspondents (NC) to take on leadership roles in advancing the GTN-P network to meet future challenges and goals. The formal election of new SC members will take place at the 2021 RCOP. More information on GTN-P governance is available in the Strategy and Implementation plan at library.arcticportal.org/1938/. All NCs are eligible to submit self-nominations or nominate a colleague by sending an e-mail to the GTN-P Secretariat prior to RCOP (ensure the person is aware and agrees to be nominated).

We thank all contributors for their engagement with the network and sincerely thank the IPA and AWI for their continuous support. For more information about the network, data access and news updates visit www.gtnp.org or contact GTNP-Secretariat@awi.de.

Deep boreholes (60 m), measurement stations and MeteoStation on top of the rock glacier Murtèl in the Swiss alps at 2670 m asl. TSP measurements ensured some GTN-P data entries in 2020. Photo: Jeannette Nötzli.

STANDING COMMITTEE REPORTS

Permafrost Young Researchers Network (PYRN)

BY ADAM KIRKWOOD (LAURENTIAN UNIVERSITY, CANADA) AND NIEK SPEETJENS (VRJE UNIVERSITEIT, NETHERLANDS), ON BEHALF OF THE PYRN EXCOM

Amongst the changes that 2020 brought, one thing that didn't change was the commitment of PYRN to foster collaboration and networking opportunities, and offer a support network for its members. PYRN is continuously expanding as new young researchers join, and if you haven't yet, you can too! Membership is free, and you can always engage with us on our social media, such as Twitter, Instagram (@pyrn_official), Facebook, and LinkedIn!

2020 was a challenging but exciting year for PYRN and its members. In a normal year, those involved in PYRN can meet each other and network at conferences, social nights, and seminars, but this year things went virtual. Despite this, PYRN had a very successful year, and looks forward to 2021.

IPCC GROUP REVIEW

Once again, PYRN worked together with the Association of Polar Early Career Scientists (APECS) to coordinate a group review of the draft reports from the Intergovernmental Panel on Climate Change (IPCC). This was a great opportunity for PYRN and APECS members to gain insight into the IPCC review process, connect with leading IPCC scientists, and learn about topics outside of their area of expertise!

CHANGES IN OUR BYLAWS

PYRN believes in the importance of

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Equity, Diversity, and Inclusion (EDI) practices within the network. In order to continuously work on being an equitable, diverse, and inclusive network, the PYRN Executive Committee and Council surveyed its members and created an addendum to the Discrimination and Harassment policies in the PYRN bylaws. EDI is something that PYRN will continue to work on, and if there are any concerns, issues, or suggestions for how PYRN can better adhere to new EDI policies, do not hesitate to reach out to any member of the PYRN Executive Committee or Council for support.

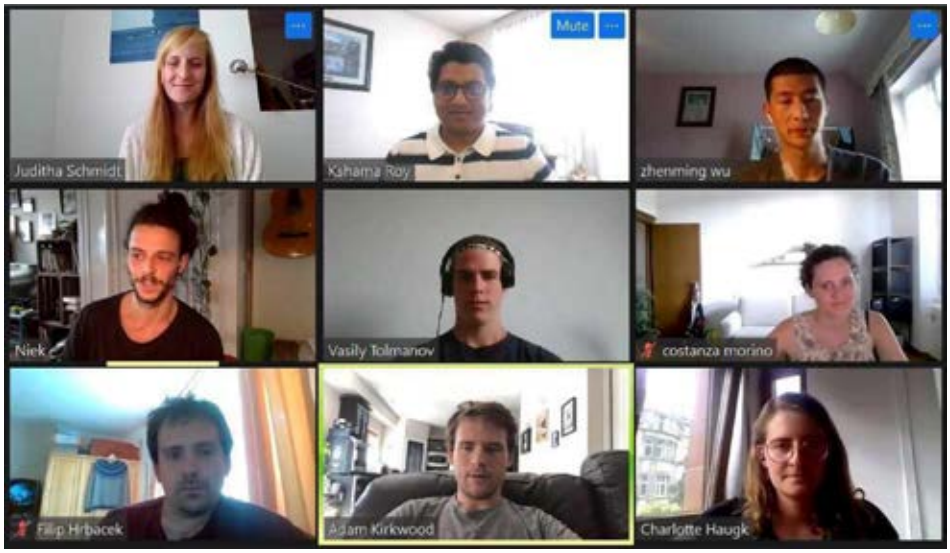
NEW EXECUTIVE COMMITTEE

In the middle of the eventful year that was 2020, PYRN elected its newest executive committee (ExCom) for 2020-2022. Though the new ExCom hasn't been able to meet in person yet, we have started off our term in good spirit, meeting digitally every month to continue the great work of the previous PYRN ExCom. We are planning some exciting virtual events! To get us started, we hosted a virtual holiday event, where the PYRN ExCom organized a virtual gift exchange and a 2020 bingo card.

UPCOMING EVENTS

The new PYRN ExCom is excited by the challenge of transitioning traditionally in-person events to more inclusive virtual events, and have plans for several events in queue. One such thing is continuing the webinar series offered by the previous ExCom that went digital in early 2020. We are also planning a virtual student day filled with interesting activities for the 2021 RCOP. This comes with the opportunity for PYRN members from across the globe to participate! We are looking forward to seeing you online!

That's all for now, so to all PYRN members and the permafrost community at large, happy 2021! For more information visit pyrn.arctic-portal.org/ or email contact@pyrn.org.



The first virtual meeting of the newly elected PYRN ExCom, with 11 members from 8 different countries. We continue to meet monthly and look forward to eventually meeting in person!

STANDING COMMITTEE REPORTS

Education & Outreach

BY CO-CHAIRS ANNA KLENE (UNIVERSITY OF MONTANA, USA) AND YLVA SJÖBERG (UNIVERSITY OF COPENHAGEN, DENMARK)

Our Standing Committee coordinates and promotes permafrost education and outreach to all generations across the globe. During a pandemic year, which cancelled almost all in-person activities for K-12 and higher education across the globe, educators continued physically-distance permafrost education and outreach activities.

While some of our committee members turned to web-based education platforms and activities (i.e., *Skype a Scientist*) to reach students attending virtual classrooms across broader geographic areas, some were able to continue established relationships with local K-12 and universities. We hope international field schools for students in higher education resume in 2022.

FROZEN-GROUND CARTOONS

The project began as an IPA Action Group (2016-2018) and has now evolved into 'Permafrost on All Channels'. Cartoons have been released in nine languages (Danish, French, German, English, Greenlandic (Kalaallisut), Inuktitut, Luxembourgish, Russian, and Swedish) with more languages coming soon. In spring 2020, an augmented reality app for cellphones was released. Videos on permafrost topics are now available in English and French. For more information contact frozengroundcartoon@gmail.com.

vEGU 2020

The virtual EGU (vEGU) session

CONTINUED FROM PAGE 10

Schoolchildren designing the ultimate permafrost-meter, inspired by frozen ground cartoons.

'Trans-disciplinary aspects of researching Arctic change: Science communication, outreach and education, integration, monitoring, modelling and risk perception' included 14 displays (several on permafrost) presented and discussed during an online chat session with more than 70 attendees.

The session resulted in a spinoff in the form of a special issue of Environmental Research Letters *'Focus on Arctic Change: Transdisciplinary Research and Communication'* with a submission deadline of 21 May 2021. At vEGU 2021 we will have a follow up session '*Effective communication of scientific & place-based knowledge of Arctic change*'.

GLOBE ACTIVITIES

If you live in an area with permafrost or frozen ground check out the Frost Tube Protocol designed to be implemented by students and teachers. This can be a physically-distanced hands-on learning activity. Additional data-collection and analysis activities for all climates are also available from the GLOBE program. This community has remained very active through the pandemic.

ONLINE TEXTBOOKS

There are two permafrost books written for high school and university students:

- *Permafrost in Our Time* by Kenji Yoshikawa (available in English and Russian)
- *Permafrost and Culture: Global Warming and Sakha Republic (Yakutia), Russian Federation* edited by Hiroki Takakura *et al.* (available in Russian)

UPCOMING OPPORTUNITIES

Educational sessions are planned for the 2021 RCOP. One education and outreach session has also been proposed for ICOP 2022 in Lanzhou, China, with additional session proposals accepted until May 2021. We look forward to seeing you all virtually until we can be in-person again.

WEB AND SOCIAL MEDIA

For more information about permafrost education and outreach activities, including links to a series of online resources, visit ipa.arctic-portal.org/activities/outreach/outreach-activities.

STANDING COMMITTEE REPORTS

Glacier and Permafrost Hazards in Mountains (GAPHAZ)

BY OUTGOING CHAIR DUNCAN QUINCEY (UNIVERSITY OF LEEDS, UK)

GAPHAZ continues to play an active role in advancing knowledge on mountain hazards and their impact on downstream communities. We now stand at more than 100 members, including business organisations, policy makers and practitioners. During the last year, our main activities have comprised online conference organisation and participation, lobbying and influencing on policy-related matters, particularly in the build-up to the 26th annual session of the Conference of the Parties (COP26), generating publications in mainstream and grey literature on mountain hazard themes, and signposting information to agencies in the face of emerging hazardous events.

Our members made major contributions to the virtual *'Risks from a Changing Cryosphere'* and *'Cryospheric Hazards'* sessions at the virtual EGU and AGU, respectively. There have also been online discussions about emerging events in Pakistan (outburst of Shisper ice-dammed lake), Peru (Salcantay landslide and resulting extreme debris-flow), Canada (landslide impacting the Taku River, British Columbia), and the USA (landslide at Haines, Alaska). Most recently, we have been actively involved in piecing together the events impacting the Chamoli district in Uttarakhand and providing information to relevant authorities who are leading the recovery mission.

The previously published Technical Guidance document on the 'Assessment of Glacier and Permafrost Hazards in Mountain Regions' is now available in French, Spanish and Russian. This document focusses on hazards that are directly conditioned or triggered by contemporary changes in mountain glaciers and permafrost, and is designed to be a key resource for international and national agencies, responsible authorities and private companies charged with assessing hazard development, mitigation and remediation.

Since 2019 our members have been involved in the development of Guidelines on the Management of Glacial Lake Outburst Floods (GLOFs) for India. This process was

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led by the National Disaster Management Authority (NDMA), within the framework of Swiss Agency for Collaboration and Development (SDC) to benefit from feedback by the international scientific community. In November 2020, these guidelines and a related summary for policymakers were published.

GAPHAZ has recently completed its bi-annual rotation of Officers and is pleased to welcome Holger Frey (University of Zurich) into the position of Secretary, with Michele Koppes (University of British Columbia) and Marta Chiarle (Italian National Research Council) moving to vice-Chair and Chair, respectively.

2021 promises to be another active year for GAPHAZ; we plan to co-organise and participate in major sessions at EGU and AGU, and organise a workshop in September to establish the state of science, share knowledge, and agree our future priority research agendas. We will continue to be a key source of information and data pertaining to the effects of climatic change on mountain regions and provide signposting and advice for the authorities and institutions dealing with the rapid changes that continue to impact the lives and livelihoods of the people living at high elevation.

For more information visit www.gaphaz.org/.

STANDING COMMITTEE REPORTS

Antarctic Permafrost, Periglacial Environments and Soils (ANTPAS)

BY CO-CHAIRS MARC OLIVA (UNIVERSITY OF BARCELONA, CATALONIA, SPAIN) AND MAURO GUGLIELMIN (UNIVERSITÀ DEGLI STUDI DELL'INSUBRIA, ITALY)

ANTPAS activities during 2020 were very restricted by the pandemic situation. Some members conducted research in Antarctica during the first months of the year, but since then field activities were cancelled in the frozen continent. The situation also led to the cancellation of the sessions that ANTPAS organized within the XXXVI SCAR conference scheduled to be held in Hobart, Tasmania, from 31 July to 11 August 2020. We expect the situation in 2021 will go back to normal and ANTPAS can continue to foster permafrost research in Antarctica promoting sessions and seminars in regional and international meetings.

For more information visit www.antpas.org/.

INTEREST GROUP UPDATE

Permafrost and Carbon Budgets (IPaC)

BY GUSTAF HUGELIUS (STOCKHOLM UNIVERSITY, SWEDEN) AND JUSTINE RAMAGE (NORDREGIO, SWEDEN)

The IPaC synthesis report on prioritized permafrost and carbon research topics was recently released. The first permafrost researcher survey solicited inputs and ideas on carbon (C) and nitrogen (N) related topics that could improve both estimations of permafrost carbon and the understanding of its contribution to the global carbon budget. The permafrost research community was asked: *"What are your ideas for prioritized permafrost and carbon (or nitrogen) research topics and how can IPaC facilitate progress?"*.

The survey aimed at identifying knowledge gaps in permafrost carbon (or nitrogen) cycling. Participants were asked to contribute ideas on processes important in global or regional carbon budgets and that might generate significant progress within one to two years.

In total, 25 IPaC members contributed to the survey, from which we identified 8 key topics:

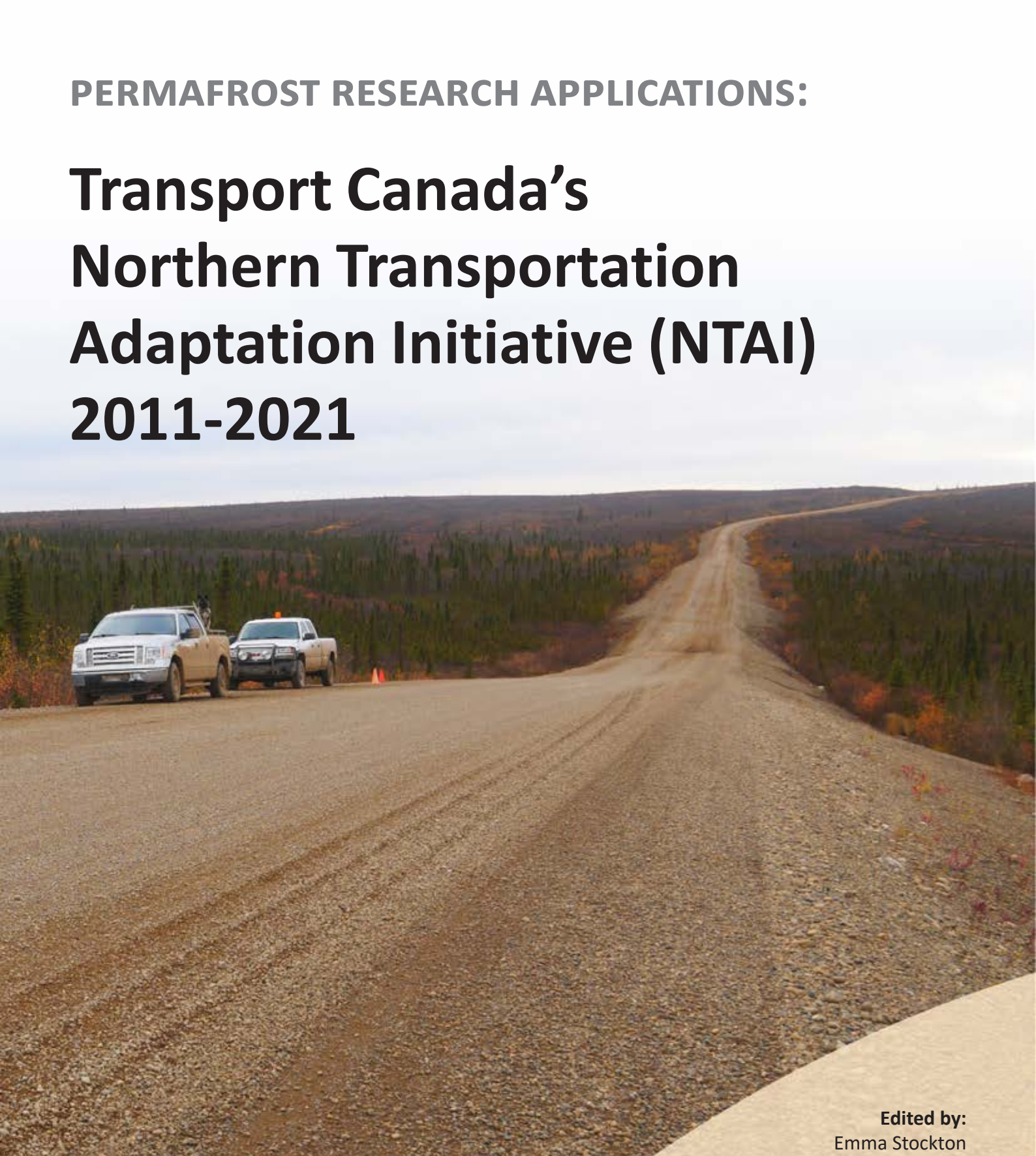
- Field sampling protocols
- Ecology of permafrost C & N
- Process-understanding for soil carbon mineralisation
- Mapping of ground ice and permafrost C
- Land-sea coast interactions
- Ecosystem recovery after disturbances
- Aquatic ecosystems
- Permafrost peatlands

Finally, researchers called for an updated review of permafrost carbon budgets. Through dissemination of this report, IPaC will help emphasize the need for further research relating to the prioritized permafrost and carbon research topics. IPaC will also facilitate collaboration between researchers working with the prioritized topics and support initiatives from the research community in this direction.

If you want to be involved or need help to strengthen your research collaboration, please contact ipa.permafrostcarbon@gmail.com. See our synthesis report for a list of contacts if you wish to initiate or be part in a specific working group.

PERMAFROST RESEARCH APPLICATIONS:

Transport Canada's Northern Transportation Adaptation Initiative (NTAI) 2011-2021



Peel Plateau
NT km 62, Dempster
Highway, September 2020

Edited by:
Emma Stockton
Christopher Burn
Jen Humphries

Special thanks to:
Astrid Schetselaar
Trevor Andersen
Pat Jardine

See also DOI: 10.52381/NTAI.2021

TRANSPORT CANADA'S

Northern Transportation Adaptation Initiative (NTAI)

BY CHRIS BURN (CARLETON UNIVERSITY)

From 2011 to 2021, Transport Canada's Northern Transportation Adaptation Initiative (NTAI) has helped northern agencies to prepare for challenges anticipated from climate change for transportation infrastructure built in the permafrost environment. The program has linked northerners with academic researchers and consulting engineers in southern Canada to conduct a series of projects aimed at providing innovative understanding and approaches to specific problems. The ethos of the program issued from experience with the Alaska Highway test section near Beaver Creek, Yukon, and work by the Québec Ministry of Transport on airstrips in Nunavik. Both initiatives were stimulated by infrastructure failing due to permafrost thaw and both were partnerships between transportation agencies and the university sector.

By 2010, the federal government was aware that risks would be posed by climate change to the transportation network in the North and knew that partnerships would be needed to stimulate innovation for infrastructure construction and maintenance practices. The NTAI also recognised the need for capacity development in permafrost engineering and northern applied science. Relatively few personnel qualified in these areas entered the workforce between 1980 and 2005 and by 2010 only two Canadian universities retained research interest in permafrost engineering. Part of the NTAI's mandate has been to train research students in permafrost issues relevant to transportation infrastructure and to provide short courses for professional development in this area.

When the NTAI was conceived, the primary risk to the transportation network was considered to be from thawing and loss of embankment integrity. The research conducted through the program identified a range of other geohazards, especially derived from a more active hydrologic regime and from thermokarst development close to infrastructure. These are perhaps more pressing and require immediate risk management. The program and its northern partners have also benefitted from opportunities to study infrastructure performance *ab initio* due to construction of the Inuvik-Tuktoyaktuk Highway.

The Dempster Highway, northern Yukon (August 2016).

CONTENTS

Maxine Bilodeau is the Director of Climate Change Adaptation & Planning for Transport Canada. She says that "the NTAI has played a unique role in Transport Canada's climate change agenda, influencing the way the department designs and implements programs, and helping to inform funding decisions. Northern jurisdictions own much of the transportation infrastructure in Arctic regions, and their active involvement in this program has helped target permafrost research to areas of most pressing need, ensuring the program's continued relevance. Overall, the NTAI is a great example of how research/industry/government collaboration can drive policy change and action to enhance the climate resilience of transportation systems in Canada's permafrost regions." The reports that follow outline some of the initiatives undertaken by the program. The projects have characteristically integrated permafrost science and engineering.

NTAI (2011-2021)

BY CHRIS BURN (CARLETON UNIVERSITY)

Fig. 1. Aufeis from subpermafrost groundwater discharge into Blackstone River, Yukon (2014).

During the last 10 years, permafrost has become a focus of international scientific attention. Amplification of climate change in the polar regions, regular transits of the Northwest Passage, awareness of climate risks posed by potential release of the 1600 billion tonnes of carbon stored in permafrost, and increased tourism in the Arctic have all raised public and scientific awareness of the North. The number of publications catalogued by the Web of Science with *permafrost* in the title has increased exponentially from approximately 10 per year in 1980, to 25 in 1990, 50 in 2000, 200 in 2010, 400 in 2015, and 700 in 2020. The vast majority of this published research concerns environmental aspects of the changing permafrost environment. Relatively little has addressed the challenges posed by climate change for northern infrastructure.

The NTAI is the first organized national program in Canada to address northern transportation infrastructure stability in anticipation of climate change. Several Canadian initiatives complemented the NTAI at its inception. First, the Transportation Association of Canada (TAC) sponsored development of *Guidelines for Development and Management of Transportation Infrastructure in Permafrost Regions* (2010). Second, the Canadian Standards Association released CSA PLUS 4011-10 *Infrastructure in permafrost: A guideline for climate change adaptation* (2010), now revised as PLUS 4011-19, and began a program of standards development for northern infrastructure construction. Third, the Beaver Creek test section at km 1865 of the Alaska Highway had been initiated as a full-scale experiment to examine the efficacy of several design approaches to address deteoriation of highway embankments above permafrost.

Fourth, the Government of Québec had begun geoscience and engineering programs to address similar aspects of its northern airports. Finally, by 2011 the Inuvik-Tuktoyaktuk Highway (ITH), the first major new infrastructure project in the North for 40 years was being designed. Most of these initiatives were primarily concerned with managing the disturbance to permafrost terrain brought about by construction and operation of infrastructure, rather than anticipating and preparing for the effects of climate change. The NTAI's focus on climate change was distinctive and forward looking at the time. Now it is recognised as integral to long-term management of transportation infrastructure.

During 2011-21, the NTAI contributed to several important developments in our understanding

Fig. 2. Left: new culvert installed at YT km 32, Dempster Highway in the North Klondike River Valley after failure of the infrastructure due to ice blockage in 2014. Photo taken in 2017. Right: failure of the culvert due to icing development two years later (2019).

CONTINUED FROM PAGE 16

of climate change impacts on infrastructure and potential strategies to manage these effects. First, the role of groundwater has been reassessed because increasing late summer and fall rainfall and longer freeze-up of northern streams has led to culvert blockage and failure due to icing, as, for example at YT km 32 of the Dempster Highway and at several points on the ITH (Figs 1, 2). The sinkhole at YT km 82 that develops perennially is also formed due to groundwater movement below the road (Fig. 3). Groundwater-induced thawing of permafrost led to closure of the east end of the runway at Inuvik in 2013 for six weeks of repairs.

Second, snow management techniques have been effective in arresting permafrost degradation either using snow sheds or by reducing embankment slopes. These techniques require capital investment; other maintenance approaches to snow management on slide slopes continue to be evaluated. Third, integrated tools for planning and risk assessment are now developed which take advantage of GIS platforms and data analytics. These allow hazard and risk assessments on a km-by-km basis or even over shorter spreads in advance of construction using available data. They

Fig. 3. A recurring sinkhole in the Dempster Highway embankment due to ground water flow at YT km 82 (2017).

are constrained by the quality of information and do not, of course, cover unanticipated events, such as icing development beneath bridges on the ITH (see p. 18).

Fourth, geohazards due to permafrost thaw outside the Right-of-Way, such as the retrogressive thaw slump at NT km 28.5 of the Dempster Highway are now recognised as presenting risk of highway failure. Fifth, catastrophic effects, such as the landslides and washouts in 2016 that closed the Dempster Highway for 2 weeks, while infrequent, are to be anticipated in sloping terrain, not just due to increases in precipitation but also forest fires that destabilize the active layer (Fig. 4).

Fig. 4. Landslide that blocked the Dempster Highway at YT km 243 following heavy rain (2018).

Finally, although the TAC guidelines promoted winter construction of new infrastructure, as employed on the ITH, the extent and rate of subsidence of the embankment is unpredictable if built with frozen and, perhaps, ice-rich fill. Progress has been made in characterizing the extent of embankment deformation and deformation progress over time to enable better assessment of the quantities of materials initially required by projects.

The importance of all these aspects will increase in the next decade as climate warming and increases in precipitation continue. New considerations will arise as the reality of the extent of anticipated climate change is incorporated in planning of new infrastructure, such as the Mackenzie Highway, and presents further challenges to maintenance crew and highway authorities. Hazard warning strategies operating at various time scales will be required and initiation of preventative maintenance works must be considered. This will require a significant adjustment in management strategies that are now characteristically reactive because of the high costs of a transportation network that serves part of Canada with a relatively low population density.

Assessment and monitoring of a new retrogressive thaw slump, km 1456 Alaska Highway

BY MUHAMMAD IDREES (TRANSPORTATION ENGINEERING BRANCH, GOVERNMENT OF YUKON), FABRICE CALMELS, LOUIS-PHILIPPE ROY, CYRIELLE LAURENT, FANNY AMYOT (YUKON UNIVERSITY), AND PANYA LIPOVSKY (YUKON GEOLOGICAL SURVEY)

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A retrogressive thaw slump (RTS), initiated by riverbank erosion was found close to the Alaska Highway at km 1456 in April 2019 (Figs 5, 6). Permafrost is discontinuous and ice-rich in places throughout the area. Satellite and aerial imagery show the RTS to have been active since 2014, with the headwall approaching the highway at an average rate of 8 m/yr.

A field program is in progress to assess development of the RTS and risk of highway failure. This includes drilling boreholes, now instrumented with ground temperature cables, humidity sensors, and inclinometer arrays to monitor ground conditions and RTS failure in real-time; monitoring of ground surface movement with differential GPS; aerial surveys by UAV; two- and tri-dimensional electrical resistivity tomography and electromagnetic surveys to map permafrost properties and groundwater movement.

Aerial surveys show the headwall to be approximately 80 m away from the road in May 2019 but with ablation of 12 m in summer 2019 and 14 m in summer 2020, the headwall is now 55 m from the road. Geophysical surveys suggest ice-rich permafrost under the road, indicating the risk posed by the RTS to the highway.

Real-time borehole monitoring through an array of sensors has shown initial stages of failure that could be used to trigger an alarm system. This information can be used to determine the relations between various measured parameters and the timing/rate of RTS failure. Ultimately, similar programs may be used to monitor other RTSs impacting transportation systems, and alert highway operators to anticipated road failure.

Fig. 5. Headwall of the Takhini RTS, Alaska Highway km 1456, July 2019.

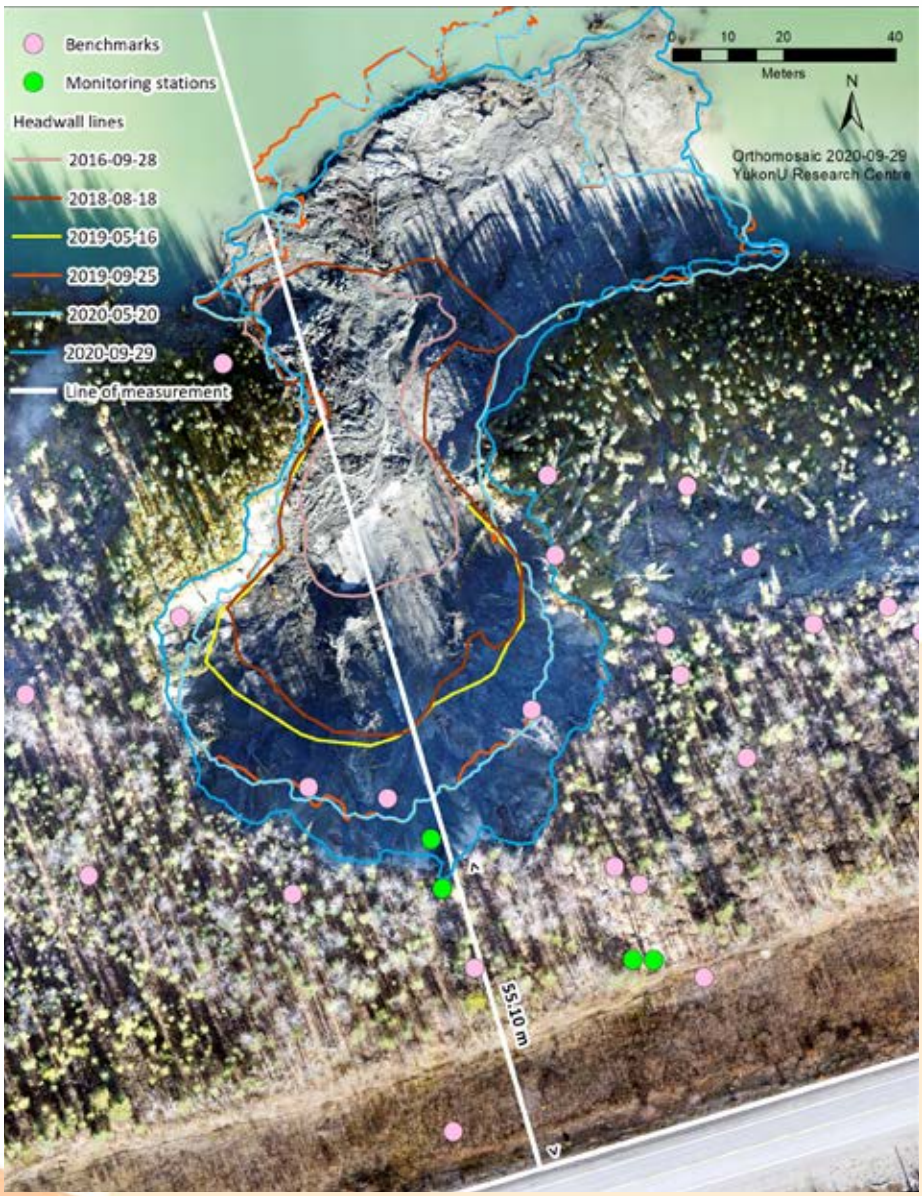

Fig. 6. Geospatial monitoring of Takhini RTS using drone imagery and benchmark surveys.

Aufeis on the Inuvik-Tuktoyaktuk Highway (ITH)

BY TIM ENSOM (WILFRID LAURIER UNIVERSITY), STEVEN KOKELJ (NORTHWEST TERRITORIES GEOLOGICAL SURVEY), AND PHILIP MARSH (WILFRID LAURIER UNIVERSITY)

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The distribution, growth mechanisms, and effects on infrastructure of aufeis (icings) along a transportation corridor in a permafrost environment are being investigated along the Inuvik-Tuktoyaktuk Highway (ITH), NT.

The ITH traverses sparse taiga forest and tundra over continuous permafrost and crosses hundreds of small streams, some of which have winter baseflow supplied by lakes. Under natural conditions the accumulation of snow in stream channels may provide adequate insulation to maintain winter water movement above the streambed or through a sub-channel talik.

The disturbance or elimination of snow in channels by infrastructure can promote channel refreezing (Fig. 7) and bed-fast ice, often initiating the icing process whereby pressurized water is forced to the surface and freezes in layers.

Aufeis may occur at several ITH stream crossings (Fig. 8) where topography, minimal vegetation, or highway structures limit snow accumulation. Ice can fill channels and adjacent riparian terrain well above peak flood levels, potentially resulting in hazardous road ice conditions or embankment scouring by spring runoff if rerouted by thick ice. The high water pressure that leads to icing during the refreezing of the active layer can also heave streambanks, lift culverts or other structures, and lead to streambank injection ice and subsequent summer subsidence and bank erosion.

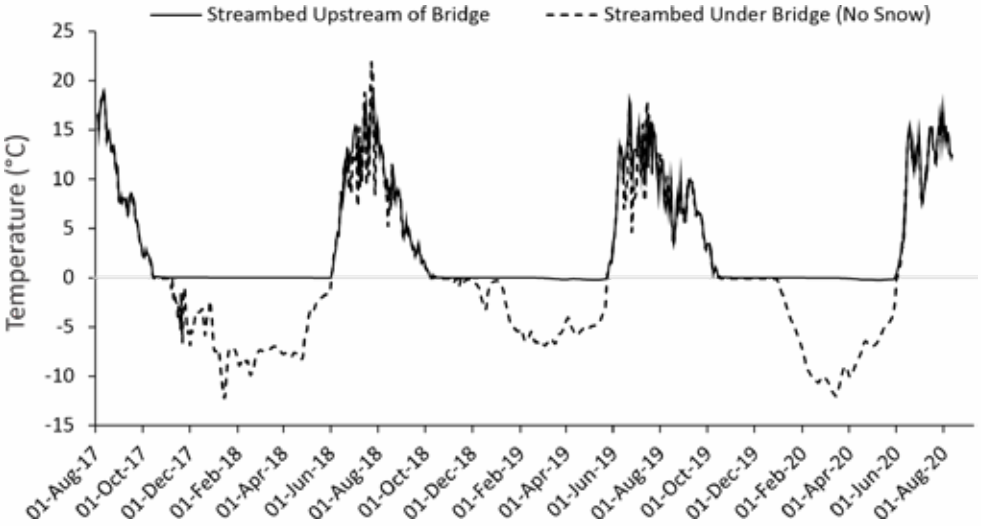

Fig. 7. Streambed temperatures under and upstream of an ITH bridge. Under the bridge the streambed refreezes during winter, likely due to an absence of snow.

Aufeis surveys and inventories have been conducted along the ITH to investigate relations between winter runoff in permafrost catchments, catchment terrain parameters, and antecedent weather conditions. This work is intended to aid the planning and management of linear infrastructure in continuous permafrost.

For more information see:

Ensom, T., *et al.* (2019). Thermal Regime of Stream Channels in Continuous Permafrost, Western Canadian Arctic. In *Cold Regions Engineering 2019, ASCE*. DOI: 10.1061/9780784482599.030.

Fig. 8. Large body of aufeis beneath the km 8 bridge on the ITH. Viewed from downstream, February 2017.

Surveying permafrost-thaw-induced landslides along linear infrastructure using RPAS

BY JURJEN VAN DER SLUIJS (GOVERNMENT OF THE NORTHWEST TERRITORIES), STEVEN KOKELJ, AND ASHLEY RUDY (NORTHWEST TERRITORIES GEOLOGICAL SURVEY)

NORTHWEST TERRITORIES GEOLOGICAL SURVEY

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Fig. 9. Debris tongue from RTS at NT km 28.5, Dempster Highway.

Permafrost thaw has increased risks to northern transportation corridors creating a growing need for innovative monitoring tools. This project demonstrated that Remotely Piloted Aircraft Systems (RPAS), or drones, can enable timely and detailed three-dimensional reconstructions of thawing slopes at scales that bridge the gap between conventional remote-sensing and field observations. RPAS surveys were implemented in order to monitor permafrost landslides, focussing on a rapidly evolving retrogressive thaw slump (RTS) at km 28.5 on the Dempster Highway, NT (Figs 9, 10).

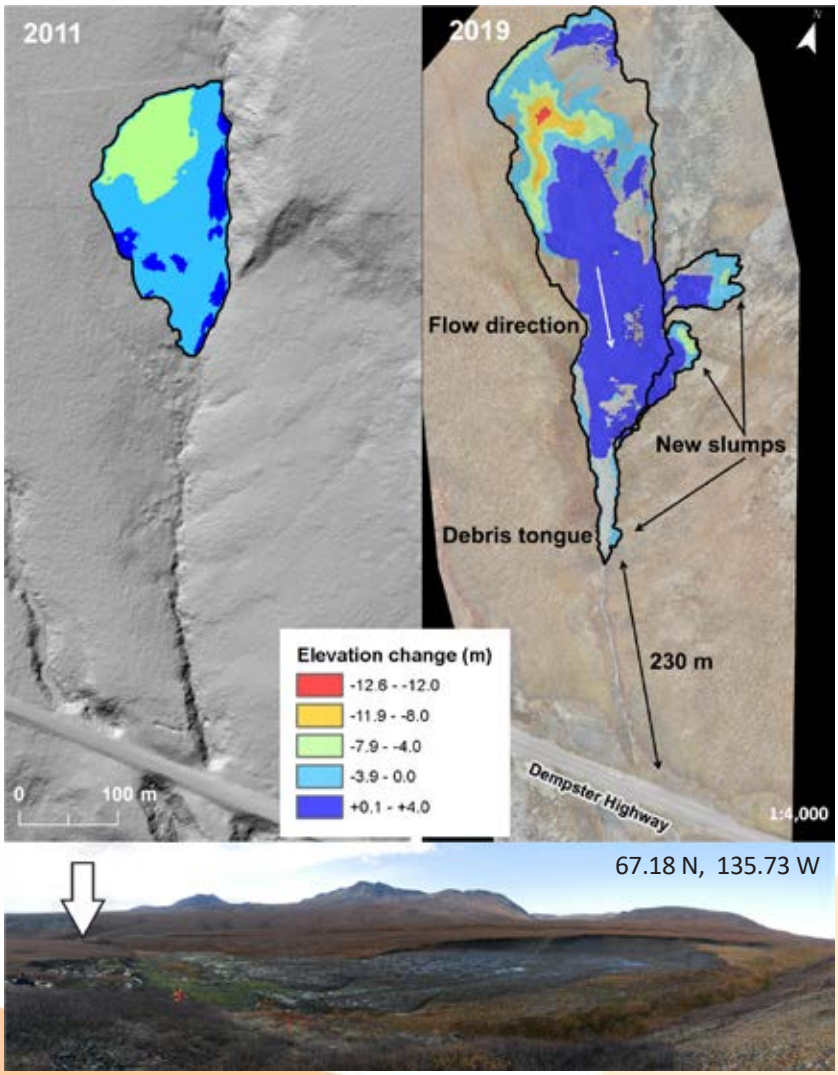

Fig. 10. Top: Images showing the growth and topographic difference in 2011 and 2019 of the RTS at NT km 28.5, Dempster Highway. Bottom: Looking west at the RTS (right) and new slumps (left) in September 2020, with arrow indicating the highway.

The RTS was monitored through repeat surveys and field observations, enabling processes of disturbance enlargement to be studied, and resulting in detection of a major thaw-driven landsliding event, where about 20,000 m³ of slumped materials flowed up to 450 m downslope, coming within 230 m of the highway. The acceleration of thaw slumping has created a spectacular exposure of icy permafrost 15-20 m in height, which has increased thaw season production of saturated slurry.

Monthly monitoring in summer 2019 indicated successive debris flow events reaching within about 300 m of the highway, indicating a sustained period of summer risk. Coupled with remote cameras, RPAS surveys have become an important tool to monitor growth of the disturbance and to inform the development of a real-time monitoring system that has been implemented by the Department of Infrastructure to minimize risk to the highway and ensure public safety.

For more information see:

Van der Sluijs, J., *et al.* (2018). Permafrost Terrain Dynamics and Infrastructure Impacts Revealed by UAV Photogrammetry and Thermal Imaging. *Remote Sensing*, 10, 1734. DOI: 10.3390/rs10111734.

Structural stability of highway embankments along the Inuvik-Tuktoyaktuk Highway (ITH)

BY MAROLO ALFARO (UNIVERSITY OF MANITOBA)

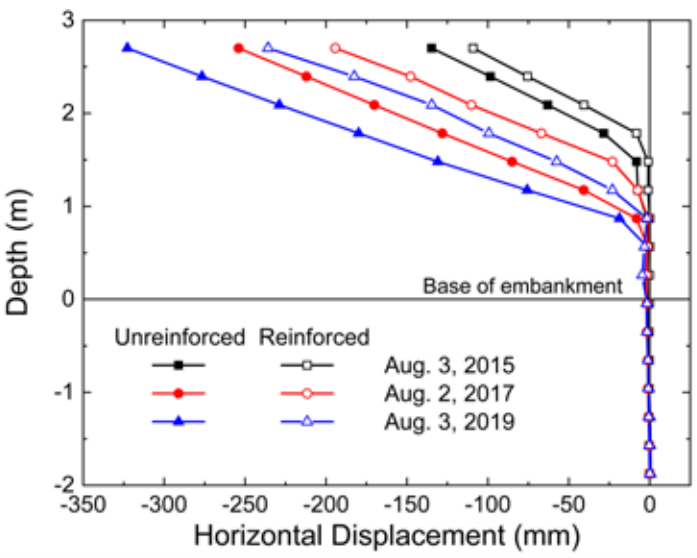

Fig. 12. Lateral movements at the mid-slope of the embankment. *Open symbols* = reinforced section; *Solid symbols* = unreinforced section.

Contact: marolo.alfaro@umanitoba.ca

This project is aimed at understanding the thermal and mechanical performance of highway embankments in the Arctic following winter construction. Two test sections were constructed in April 2015 as part of the Inuvik-Tuktoyaktuk Highway (ITH), NT. One section is reinforced with layers of wicking woven geotextiles at its side slopes (Fig. 11) to provide both reinforcement against lateral movements and drainage during the thawing season. The use of wicking geotextiles to reinforce fill slopes is a climate change adaptation measure to reduce the impact of thawing. The other test section is unreinforced and serves as the control section. Both test sections were instrumented with thermistor strings for temperature monitoring and ShapeAccelArrays to measure lateral movements and settlements. The geotextile reinforcement has been instrumented with strain gauges to measure tensile forces. The instrumentation has been monitored remotely using a satellite connection.

Fig. 11. Wicking geotextiles laid during construction of a reinforced section of the ITH.

Field data show warming of the embankment fill and foundation soil. The frozen core of the embankment has reduced in size since end-of-construction. Thaw depths at the embankment toes have increased.

Figure 12 shows recorded lateral movements in the mid-slope of the embankment over four years since construction. The lateral movements in the reinforced section (open symbols) are consistently less than the those of the unreinforced section (solid symbols). Seasonal thaw depths at the slopes have increased and led to additional lateral movements. Mobilization of tensile forces in the geotextile reinforcement reduced lateral slope movements.

For more information see:

De Guzman, E.M., *et al.* (2021). Performance of Highway Embankments in the Arctic Constructed under Winter Conditions. *Canadian Geotechnical Journal*. DOI: 10.1139/cgj-2019-0121.

Air-convection-reflective sheds to reduce permafrost warming, Alaska Highway, Yukon

BY SAMUEL GAGNON AND DANIEL FORTIER (UNIVERSITÉ DE MONTRÉAL)

Université de Montréal

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The 600 m long Beaver Creek experimental test site was established in 2008 at km 1865 on the Alaska Highway in Yukon to assess the performance of different mitigation techniques in reducing permafrost warming and subsidence of the highway embankment. The site is in the discontinuous permafrost zone and had an annual mean air temperature of -4.5 °C for the 1990-2019 period.

The mitigation techniques were designed to enhance heat extraction from the embankment or reduce absorption of solar radiation at the ground surface. One of the test sections included two air-convection-reflective sheds (ACRS) installed on each side of the road in fall 2009 to cover the shoulders and slopes of the embankment (Fig. 13). The ACRS were wooden structures, 30 m long by 15 m wide by 1 m high, with a roof made of white corrugated sheet metal, which reflected incoming solar radiation and shaded the ground. The ACRS prevented rainwater infiltration in summer and snow accumulation directly on the embankment sides in winter. Ground temperatures to 15.5 m depth were recorded hourly with instrumentation installed before the ARCS were erected under one of the sheds and in an unmitigated reference section.

From 2009 to 2016, mean annual soil surface temperatures under the two ACRS were on average 8 °C lower than at the reference section (Fig. 14). Calculation of seasonal heat exchanges shows that the ACRS allowed 311% more heat extraction in winter and 38% less heat influx in summer over the test period. The design of the ARCS promoted free air convection at the ground surface, which enhanced heat extraction from the embankment in winter when windspeeds in the area are very low (<5 km/h). Small-scale implementation of ACRS along vulnerable sections of highways or airstrips represent a viable approach for arresting permafrost thaw beneath side slopes of embankments.

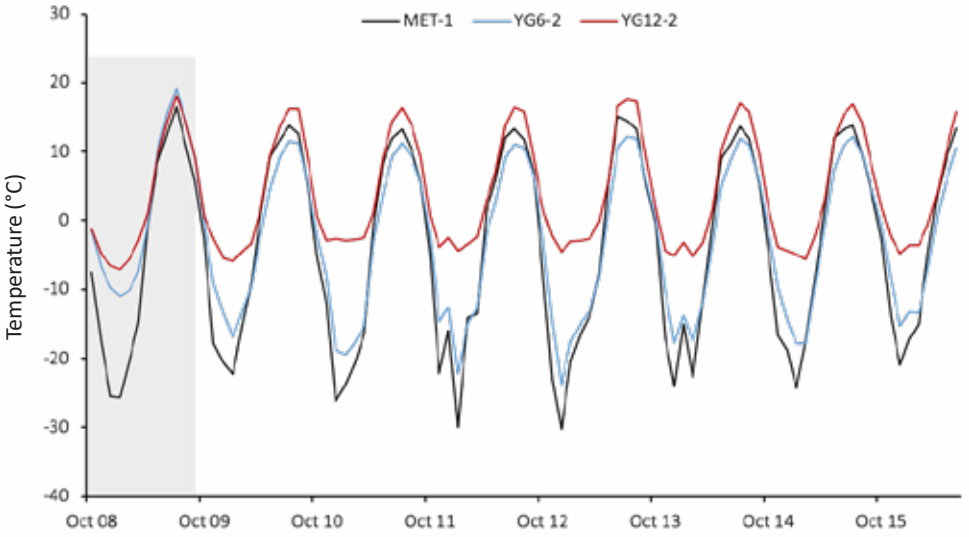

Fig. 14. Monthly air temperature (MET-1) and monthly soil surface temperatures under the southern ACRS (YG6-2) and the unmitigated reference section (YG12-2). The shaded area shows the period before the ACRS were installed.

Fig. 13 ACRS on the embankment slope of the Beaver Creek test site, Alaska Highway, Yukon.

For more information see:

Malenfant-Lepage, J., *et al.* (2012). Thermal effectiveness of the mitigation techniques tested at Beaver Creek experimental road site based on a heat balance analysis: Yukon, Canada. In *Cold Regions Engineering 2012, ASCE*. DOI: 10.1061/9780784412473.005.

Permafrost science for improvement and adaptation to climate change, Iqaluit International Airport, Nunavut

BY MICHEL ALLARD (UNIVERSITÉ LAVAL) AND VALÉRIE MATHON-DUFOUR (MINISTÈRE DE L'ENVIRONNEMENT ET DE LA LUTTE CONTRE LES CHANGEMENTS CLIMATIQUES, MELCC)

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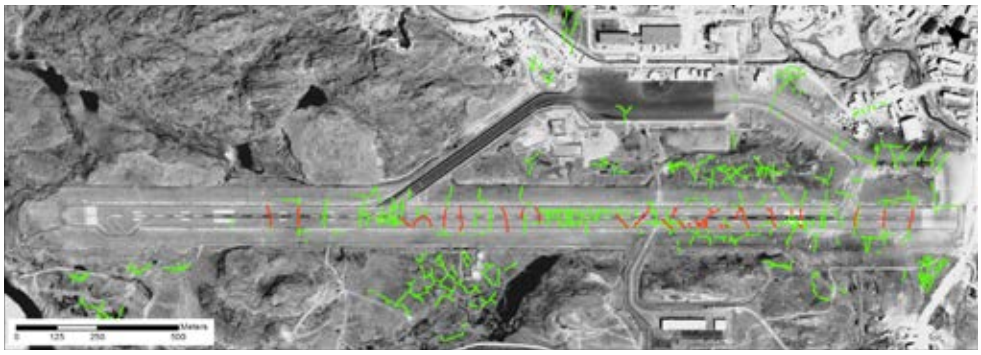


Fig. 16. Thermal contraction cracks mapped at Iqaluit Airport (green). Active cracks in the runway inherited from the original terrain conditions are shown in red (2010).

Iqaluit airport is a hub for air transportation in the eastern Canadian Arctic. It was built during World War II and since then has undergone repeated repairs and upgrades (Fig. 15). Repairs to the pavement during the last 70 years have been caused by structural failures from differential frost heave and thermal contraction cracking. Partial melting of ice wedges has also caused linear settlements in the runway surface.

As with most infrastructure in the Canadian Arctic, permafrost conditions were not investigated before construction. They were characterized in detail between 2010-18 in preparation for major renovations and upgrading in 2018-19 because the risks associated with thawing permafrost are now recognized. Data from air photo interpretation, archival research, geophysics, drilling and coring, ground temperature monitoring, and numerical modelling were integrated in a GIS application.

Mapping of surficial geology and terrain conditions indicative of the presence of ground ice was combined with analysis of 24 deep boreholes (~ 8 m) and 7 shallow boreholes (~ 3 m) drilled in natural terrain, embankment shoulders, and through paved surfaces. Ground Penetrating Radar was used to delimit cryostratigraphic units and locate features under the embankments, particularly cracks and ice wedges (Fig. 16).

Terrain conditions prevailing before airport construction still impact the stability and thermal regime of the infrastructure. Ice-rich near-surface permafrost and many ice wedges will continue to generate thaw settlement and loss of bearing capacity should climate warming continue.

Temperature profiles under asphalt pavement show warmer ground and faster, deeper, and longer thaw penetration than the shoulders and natural terrain, causing pooling of water under paved surfaces. The newly acquired geoscientific data on the airport's permafrost has oriented risk analyses and engineering design implemented during the recent improvements in order to make a modern infrastructure that is better adapted to the impacts of climate warming.

Fig. 15. Looking northwest over Iqaluit Airport, Nunavut (2012).

For more information see:

Mathon-Dufour, V., *et al.* (2015). Assessment of permafrost conditions in support of the rehabilitation and adaptation to climate change of the Iqaluit airport, Nunavut, Canada. *Proceedings, 68th CGC and 7th CPC*, Québec City, QC, Canadian Geotechnical Society, Richmond, BC. Paper 146.

Sinkholes related to permafrost thaw, Dempster Highway, Yukon

BY FABRICE CALMELS, LOUIS-PHILIPPE ROY, CYRIELLE LAURENT (YUKON UNIVERSITY), AND SANDRA MACDOUGALL (TRANSPORTATION ENGINEERING BRANCH, YUKON GOVERNMENT)

Contact: fcalmels@yukonu.ca

The Permafrost and Geoscience Research Group at Yukon University leads studies along the Dempster Highway investigating permafrost-related geohazards affecting the road and its surroundings. Sinkholes pose particular challenges for maintenance and safety as they may form almost instantly and be expensive to repair. A recurring sinkhole forms at km 82 on a west-facing hillslope at least annually and even several times per summer (see p. 17). A field study at the site including drilling, electrical resistivity tomography, and installation of ground temperature monitoring instruments started in 2016.

Results show snow accumulation on the embankment shoulder may have increased active layer thickness and opened new pathways through the soil for ground water flowing downslope. The repetitive sinkholes, first observed in 2011, indicate fine sediment in the roadbed is being removed by the flow. The loss of fine material creates a cavity that later collapses to form the sinkhole. Increasing precipitation in the area during the last two decades has likely contributed to the situation. Ground temperature records show infiltrated waters significantly affect the ground thermal regime at this site (Fig. 17).

Sinkholes result from various mechanisms. While intra- or supra-permafrost groundwater flow may induce some of them, in other cases icings impair drainage and channel water from the surface to the top of ice wedge troughs. Thermal erosion of ice wedges beneath the road leads to tunnels under the embankment, as at km 93 and 123 (Fig. 18). In some instances, the process begins in the field before reaching the road (km 123). Maintenance staff have noticed an increasing frequency of sinkhole development, possibly as an impact of climate change. Groundwater movement is a relatively new consideration for management of infrastructure above permafrost.

Fig. 18. Sinkhole forming due to thermal erosion at km 123, Dempster Highway.

For more information see:

Calmels, F., *et al.* (2018). Summary of climate- and geohazard-related vulnerabilities for the Dempster Highway corridor. Northern Climate ExChange, Yukon Research Centre, *Yukon College*, 204 p.

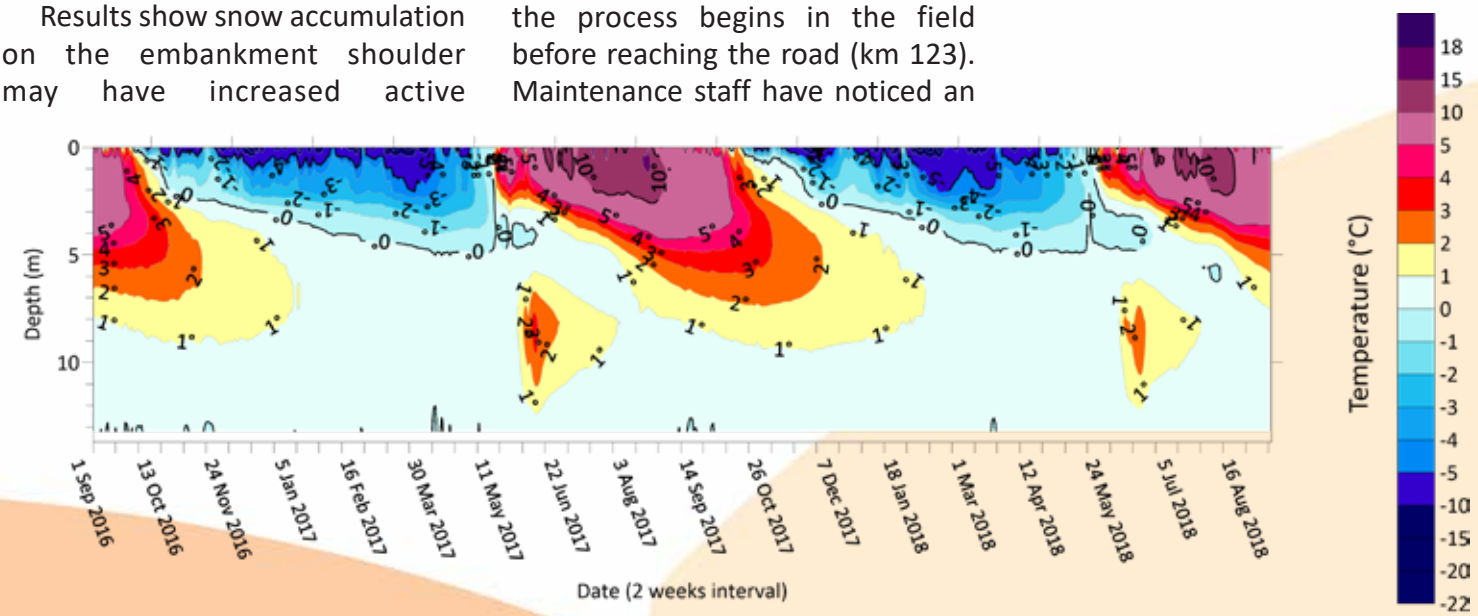


Fig. 17. Ground temperature record at km 82 over two years showing the impact of seasonal groundwater flow on thermal regime and flow in a conduit between 6 and 12 m depth for two months beginning in early June (see p. 17).

NTAI-supported students

BY CHRIS BURN (CARLETON UNIVERSITY)

An early priority of the NTAI was training of highly qualified personnel to become designers and managers of infrastructure in the permafrost regions of Canada.

Given that research programs in permafrost engineering were only active at Université Laval and the University of Manitoba in 2011, there were few students graduating who might have been able to assist with the challenges anticipated for infrastructure from climate change. Ironically, just at this time, international interest in permafrost science expanded, driven by biogeochemical considerations around the climatic risks from permafrost carbon, with little comparable interest in infrastructure.

In China, interest and experience developed regarding construction on the Qinghai Tibet Plateau, but language barriers precluded close cooperation, as with Russian engineers, regardless of motivation similar to the NTAI. Capacity development has therefore been an emphasis of the program for both advanced students and professionals in the private sector.

The NTAI encouraged student participation in projects and workshops. Thesis projects by several students were supported by the NTAI either directly or through a territorial agency. Below, we profile six students supported by the NTAI who have graduated and now assume positions in government and industry directly related to their training or who are engaged in further study. A preponderance of women in the group reflects the current Master student population in permafrost science and engineering and reflects the steps that are being made to develop a representative workforce in this area.

For professionals and students in related fields, the NTAI sponsored a series of short courses in Whitehorse and Inuvik that involved both classroom instruction and field visits to the north Alaska Highway and ITH. These courses have provided over a hundred people with a formal foundation in permafrost engineering and the scientific knowledge on which it is based. Professional participants at the courses have attended from engineering consultants and territorial transportation agencies. There have also been a few participants from Alaska, Scandinavia, and China.

The success of these courses is not simply reflected in their oversubscription, as at Inuvik in 2019 when enrollment doubled the anticipated numbers, but also in that they have formed the basis for the joint Canada-Norway project *Landscape & infrastructure dynamics of frozen environments undergoing climate change in Canada, Norway and Svalbard (NOK 6.57M)* funded by the Research Council of Norway. The courses stress to participants the importance of understanding the formation, occurrence, and properties of ground ice as a solid close to its melting point, because it may be thawed following a small change in the ground thermal regime. This is key background for successful engineering design.

PROJECT: The ground thermal regime of Peel Plateau, Northwest Territories, Canada

GRADUATED: 2016

NOW: Permafrost Research Scientist, Geological Survey of Canada (GSC)

Brendan O'Neill PhD, Carleton University

My PhD project at Carleton University investigated the ground thermal regime of continuous permafrost on Peel Plateau, NT. Extensive road maintenance has been necessary due to ground ice thaw near the Dempster Highway embankment. The research examined permafrost conditions in disturbed and undisturbed terrain near the road.NTAI supported my project and workshop attendance in Fairbanks, AK. Instruments from my PhD are still in operation and used by Government of the Northwest Territories and other students. A similar initiative would be useful for students because it provides 1) support for infrastructure-related research projects; 2) experience in formulating research questions relevant to applied infrastructure issues; 3) excellent networking opportunities that lead to connections with potential future employment; and 4) potential for collaborations with researchers outside immediate circles.

Snow accumulation and shrub growth, Dempster Highway, Peel Plateau, March 2014.

O'Neill, H.B., *et al.* (2016). Talik Formation at a Snow Fence in Continuous Permafrost, Western Arctic Canada. *Permafrost and Periglacial Processes*, 28, 558-565. DOI: 10.1002/ppp.1905.

PROJECT: Quantitative Risk Assessment of Embankment Infrastructure on Permafrost

GRADUATED: 2019

NOW: Geotechnical Engineer, BGC Engineering Inc.

Heather Brooks **PhD, Université Laval**

My PhD project at Université Laval developed a methodology and tool for the quantitative analysis of risk to embankment infrastructure due to the presence of permafrost. The methodology used Monte Carlo statistical analysis techniques which formed the basis of an Excel macro for calculating the risk associated with linear infrastructure on permafrost. As an early-career researcher, I really enjoyed the collaboration with other researchers working other aspects of transportation in northern regions. The NTAI program gave me the opportunity to connect with researchers in my field and broaden my professional connections. I now work at BGC Engineering Inc. as a practicing geotechnical engineer with some northern projects. A similar initiative would be useful to students in the future for developing collaborations that would not have been thought of or addressed if researchers were working independently.

Brooks, H., *et al.* (2019). Quantifying Hazard and Climate Change Fragility for the Airport Access Road in Salluit, Nunavik, Quebec. In *Cold Regions Engineering 2019, ASCE*. DOI: 10.1061/9780784482599.060.

PROJECT: Study of the influence of water flow and temperature on the thermal regime around culverts built on permafrost

GRADUATED: 2015

NOW: Transport Engineer, Stantec

Loriane Périer **MSc, Université Laval**

My masters project at Université Laval looked at the effects of water temperature and water flow on the thermal regime around culverts built on permafrost. Two culverts were monitored on the Alaska Highway near Beaver Creek, YT, to provide data used to develop and validate mathematical and thermal models. I attended a permafrost engineering course in Whitehorse, taught by professors Chris Burn and Guy Doré, which allowed me to learn about the challenges of building transportation infrastructure on permafrost. NTAI supported my attendance to the Permafrost Network of Expertise workshops as a speaker (Fairbanks, 2013) and participant (Nunavik, 2015). Most of all, I am proud to use the skills I have acquired for the analysis of permafrost in other complex and challenging environments.

Périer, L., *et al.* (2014). The effect of water flow and temperature on thermal regime around a culvert built on permafrost. *Science in Cold and Arid Regions*, 6. DOI: 10.3724/SP.J.1226.2014.00415.

PROJECT: Structural stability of highway embankments in the Arctic corridor

GRADUATED: 2020

NOW: Geotechnical Engineer, Peter Kiewit Sons ULC

Earl Marvin de Guzman **PhD, University of Manitoba**

My PhD project at the University of Manitoba looked at the structural stability of highway embankments in the Arctic, such as the Inuvik-Tuktoyaktuk Highway (ITH). The research focused on field monitoring of temperature and displacements of geotextile reinforced and unreinforced embankments, laboratory testing of thawing fill material, and numerical modelling for near- and long-term climate change conditions with the aim of improving existing design guidelines for Arctic highway embankments. NTAI supported my participation in workshops. The program allows students to communicate their research progress to an audience with special interest in permafrost, learn about on-going research and develop connections. NTAI allowed students to be part of, and learn from, the larger network of experts in Canada's north.

De Guzman, E.M., *et al.* (2021). Performance of Highway Embankments in the Arctic Corridor Constructed under Winter Conditions. *Canadian Geotechnical Journal*, 58. DOI: 10.1139/cgj-2019-0121.

Inuvik-Tuktoyaktuk Highway (ITH)

PROJECT: Development of a methodology for the design of low-impact drainage systems along transportation infrastructure in permafrost environments

Julie Malenfant-Lepage **PhD Candidate, Université Laval**

I am in the final writing stage of my PhD project on developing a methodology for the design of low-impact drainage systems along transportation infrastructure in permafrost environments at Université Laval. Water flow along embankments increases permafrost thaw and soil erosion resulting in settlement, loss of functional capacity and potential failure. The project focusses on validating the design method implemented along the airport access road in Salluit (Nunavik, QC) where drainage system has been adapted to climate change. The research will promote and identify adaptation strategies to counteract environmental changes caused by infrastructure in a changing climate. NTAI allowed me to conduct fieldwork which is essential in understanding basic concepts and assimilating theories related to permafrost science and engineering.

Malenfant-Lepage, J., *et al.* (2018). Critical shear stress of frozen and thawing soils. 5th European Conference on Permafrost, Chamonix, France, *EUCOP5 Book of Abstracts*, 182.

PROJECT: Retrogressive thaw slump self-stabilization

Eva Stephani **PhD Candidate, University of Alaska Fairbanks**

My current NTAI-funded PhD project at the University of Alaska Fairbanks aims to advance our understanding of retrogressive thaw slump (RTS) self-stabilization to support the development of effective adaptation strategies for infrastructure at risk. I am evaluating the climate, terrain, subsurface, and infrastructure conditions at various sites in the Northwest Territories and northern Alaska in order to assess the vulnerability and resilience of terrain to RTS, and interactions with infrastructure in sensitive permafrost. NTAI fulfilled and further motivated my desire to integrate permafrost science and engineering, and bridge gaps between industry, academia, and government. This perspective, supported by my experience at NTAI workshops, was highly valued by prospective employers.

Stephani, E., *et al.* (2014). A geosystems approach to permafrost investigations for engineering applications, an example from a road stabilization experiment, Beaver Creek, Yukon, Canada. *Cold Regions Science and Technology*, 100, 20-35. DOI: 10.1016/j.coldregions.2013.12.006.

CAPACITY BUILDING

Permafrost Engineering Courses

BY EMMA STOCKTON AND JEN HUMPHRIES (CARLETON UNIVERSITY)

Since 2011, professors Guy Doré (Université Laval) and Chris Burn (Carleton University) have run a one-week course on *"Permafrost engineering applied to transportation infrastructure"* for researchers and professionals. The course combines classroom lectures with field excursions and has been held six times at two northern research institutions. Most recently at Aurora College in Inuvik (2019), and at Yukon University in Whitehorse (2011-2016). One-day summary versions were also developed for the 2015 and 2019 Canadian Permafrost Conferences in Québec City.

The course was created because many geotechnical engineers with experience in permafrost terrain are no longer practicing or are expecting to retire, and environmental considerations are assuming an increasing role in project development and design. Transport Canada recognized and addressed these factors as part of the NTAI program. The course objectives were to:

- Understand the context and challenges of building linear infrastructure in permafrost environments
- Provide the basic principles for effective site investigation, design and management of linear infrastructure
- Apply principles of risk analysis to the development of linear infrastructure
- Analyze complex situations and propose solutions to unstable infrastructure
- Develop transversal skills, and international and multidisciplinary collaborations.

Local field trip to a long-term monitoring site near Inuvik. Photo: Weronika Murray.

Classroom lectures have been divided into two themes: the *permafrost environment* and *permafrost engineering*. Chris introduced

CONTINUED FROM PAGE 26

topics on transportation infrastructure in northern Canada, permafrost characteristics, heat transfer, ground ice, climate change, and thermokarst terrain. Guy then discussed infrastructure design and considerations, freezing and thawing soil mechanics, slope stability, drainage, site investigations, and management strategies. Overall, the material applied theoretically based knowledge to practical situations.

Participants have also completed a practical exercise using TEMP/W, a 2D thermal modelling software, to examine the sensitivity of permafrost terrain to changes in temperature over time caused by surface disturbances and climate change.

Field excursions have typically included short local trips and day-long trips along the Alaska Highway or ITH where participants visited existing research sites and observed permafrost conditions and construction methods discussed in class.

The six courses have been attended by 111 participants including, students (44%), professionals (28%), government employees (15%), academics (7%), and others (5%) (Fig. 19). Women accounted for a third of total participants, and almost 60% of students. NTAI has also helped defray travel and accomodation costs for students who attended the courses. The courses have provided researchers and professionals from a variety of backgrounds the opportunity to network and collaborate, promote mutual learning, and initiate a multidisciplinary dialogue on potential environmental and socio-economic impacts of permafrost thaw.

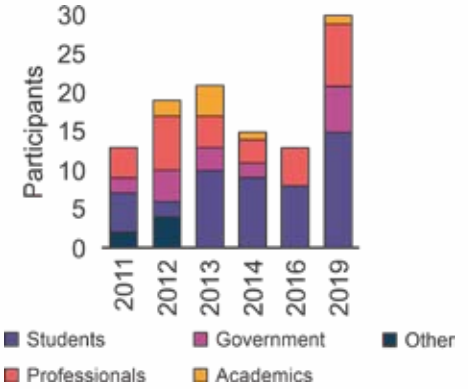


Fig. 19. Number of participants to NTAI-supported permafrost engineering courses from 2011-2019.

For more information on the 2019 course visit sentinelnorth.ulaval.ca/en/permafrostengineering2019.

CAPACITY BUILDING

Permafrost Workshops

BY EMMA STOCKTON AND JEN HUMPHRIES (CARLETON UNIVERSITY)

Annual permafrost workshops on NTAI projects began in 2010 with the inaugural 'Workshop of the Network of Expertise on Permafrost' in Haines Junction, YT. The workshop outlined existing highway research projects such as the Beaver Creek Test Section (Alaska Highway), Front Street (Dawson City), and Highway 3 (Yellowknife). Followed by a discussion on how the program will address knowledge gaps, capacity issues, and the practical problems of operating highways in the north.

Workshops have been held in Alaska and Canada in all three territories and two provinces. The 2021 meeting was held virtually, due to the COVID-19 pandemic. Workshops typically comprise technical and student presentations on proposed or existing projects, review of the program's objectives, and field trips. In 2017, discussions focussed on federal coordination, territorial adaptation needs and priorities, and capacity development. The intention was to determine how to better coordinate and collaborate with federal partners, disseminate information to support a common understanding of priority areas of action for northern partners, and build a community of practice.

Participants at the NTAI Workshop for Canadian Highways Built on Permafrost, held in Whitehorse, YT, February 2019. Photo: Tim Ensom.

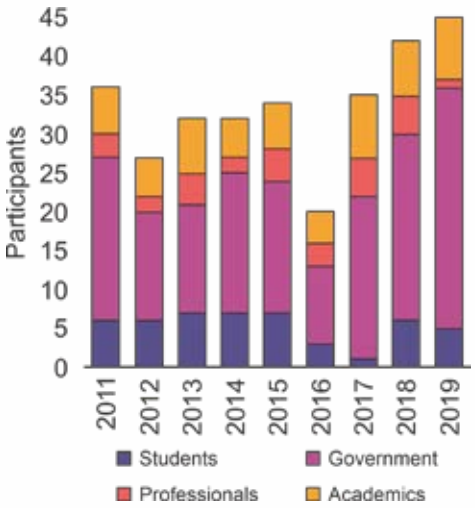


Fig. 20. Number of participants to NTAI-supported permafrost workshops from 2011-2019.

Over 300 participants have attended the meetings including, government employees (56%), academics (18%), students (16%), and professionals (10%) (Fig. 20). Women accounted for a quarter of total participants, and 28% of students. NTAI has helped defray travel and accomodation costs for students who attended these workshops.

Conclusion

BY CHRIS BURN (CARLETON UNIVERSITY)

The projects presented in this report indicate the first steps taken to develop resilience for northern transportation infrastructure in anticipation of the growing impacts of climate change in Canada's North. Over the next few decades, transportation agencies will need to watch closely the emissions trajectory of greenhouse gases to determine the conditions at which the climate may settle and a new ground thermal environment will reach equilibrium.

Projected warming in fall and winter will be the principal driver of climate change and a critical long-term challenge for effective operation of current technology, such as thermosyphons and air convection embankments (ACE), which relies on a significant differential between air and ground temperatures in winter to cool the ground. In the short term, however, we may expect rehabilitation and maintenance to continue as in the past with some adjustments to designs for new infrastructure components.

Maintenance activities may soon have to include off Right-of-Way conditions as part of their mandate, such as for control of icings to protect embankments and culverts. Maintenance may also require systems for predicting embankment failure with sufficient time for remedial action, perhaps based upon antecedent conditions (e.g., precipitation intensity and amount). Rehabilitation of highways will be required where permafrost thaw leads to instability or failure of infrastructure is anticipated. Cost management may require planning over several years to prepare stockpiles of ACE rock, for example. Re-routing of highways in response to permafrost thaw may be necessary in places and require significant planning and negotiation, such as Chapman Lake, Dempster Highway. Negotiation of new Rights-of-Way will need to recognize that Land Claims Agreements now affect most areas in the North.

Finally, ground ice and permafrost thaw sensitivity must be considered in the design of new northern infrastructure and the selection of routes and sites, as well as the associated increase in costs. Innovation in airborne geophysics for detection of ground ice will be required, especially south of treeline where on-ground access is difficult.

Other Publications

Brooks, H., *et al.* (2018). Permafrost geotechnical index property variation and its effect on thermal conductivity calculations. *Cold Regions Science and Technology*, 148, 63-76. DOI: 10.1016/j.coldregions.2018.01.004.

Brooks, H., *et al.* (2020). Soil Bridging Effects within Permafrost-Supported Embankment Infrastructure. *Cold Regions Engineering*, 35. DOI: 10.1061/(ASCE)CR.1943-5495.0000232.

Burn, C.R., *et al.* (2015). Permafrost characterization of the Dempster Highway, Yukon and Northwest Territories. *Proceedings, Proceedings, 68th CGC and 7th CPC*, Québec City, QC, Canadian Geotechnical Society, Richmond, BC. Paper 705.

Chen, L., *et al.* (2019). Impact of heat advection on the thermal regime of roads built on permafrost. *Hydrological Processes*, 34, 1647-1664. DOI: 10.1002/hyp.13688.

Coulombe, S., *et al.* (2012). Using air convection ducts to control permafrost degradation under road infrastructure: Beaver Creek Experimental Site, Yukon, Canada. In *Cold Regions Engineering 2012, ASCE*. DOI: 10.1061/9780784412473.003.

De Guzman, E.M., *et al.* (2018). Large-scale direct shear testing of compacted frozen soil under freezing and thawing conditions. *Cold Regions Science and Technology*, 151, 138-147. DOI: 10.1016/j.coldregions.2018.03.011.

De Guzman, E.M., *et al.* (2019). Monitored thermal performance of varying embankment thickness on permafrost foundations. In *Cold Regions Engineering 2019, ASCE*. DOI: 10.1061/9780784482599.015.

Doré, G., *et al.* (2016). Adaptation methods for transportation infrastructure built on degrading permafrost. *Permafrost and Periglacial Processes*, 27, 352-264. DOI: 10.1002/ppp.1919.

Ensom, T., *et al.* (2020). The distribution and dynamics of aufeis in permafrost regions. *Permafrost and Periglacial Processes*, 31, 383-395. DOI: 10.1002/ppp.2051.

Flynn, D., *et al.* (2016). Forecasting ground temperatures under a highway embankment on degrading permafrost. *Journal of Cold Regions Engineering*, 30(4). DOI: 10.1061/(ASCE)CR.1943-5495.0000106.

Humphries, J., *et al.* (2019). Storm wind frequency and direction, Dempster Highway, Richardson Mountains, Yukon and Northwest Territories. In *Cold Regions Engineering 2019, ASCE*. DOI: 10.1061/9780784482599.016.

Idrees, M., *et al.* (2015). Monitoring permafrost conditions along the Dempster Highway. *Proceedings, 68th CGC and 7th CPC*, Québec City, QC, Canadian Geotechnical Society, Richmond, BC. Paper 703.

Kurz, D., *et al.* (2020). Seasonal deformations under a road embankment on degrading permafrost in Northern Canada. *Environmental Geotechnics*, 7, 163-174. DOI: 10.1680/jenge.17.00036.

Malenfant-Lepage, J., *et al.* (2018). Critical shear stress of frozen and thawing soils. 5th European Conference on Permafrost, Chamonix, France, *EUCOP5 Book of Abstracts*, 182.

O'Neill, H.B., *et al.* (2015). Field measurements of permafrost conditions beside the Dempster Highway embankment, Peel Plateau, NWT. *Proceedings, 68th CGC and 7th CPC*, Québec City, QC, Canadian Geotechnical Society, Richmond, BC. Paper 380.

O'Neill, H.B., *et al.* (2015). 'Warm' Tundra: Atmospheric and Near-Surface Ground Temperature Inversions Across an Alpine Treeline in Continuous Permafrost, Western Arctic, Canada. *Permafrost and Periglacial Processes*, 26, 103-118. DOI: 10.1002/ppp.1838.

O'Neill, H.B., *et al.* (2017). Impacts of variations in snow cover on permafrost stability, including simulated snow management, Dempster Highway, Peel Plateau, Northwest Territories. *Arctic Science*, 3, 150-178. DOI: 10.1139/as-2016-0036.

O'Neill, H.B., *et al.* (2019). New ground ice maps for Canada using a paleogeographic modelling approach. *The Cryosphere*, 13, 753-773. DOI: 10.5194/tc-13-753-2019.

Périer, L., *et al.* (2015). Influence of water temperature and flow on thermal regime around culverts built on permafrost. *Proceedings, 68th CGC and 7th CPC*, Québec City, QC, Canadian Geotechnical Society, Richmond, BC. Paper 089.

Short, N., *et al.* (2014). RADARSAT-2 D-INSAR for ground displacement in permafrost terrain, validation from Iqaluit Airport, Baffin Island, Canada. *Remote Sensing of Environment*, 141, 40-51. DOI: 10.1016/j.rse.2013.10.016.

Stephani, E., *et al.* (2020). Taliks, cryopegs, and permafrost dynamics related to channel migration, Colville River Delta, Alaska. *Permafrost and Periglacial Processes*, 31, 239-254. DOI: 10.1002/ppp.2046.

Thiam, P.-M., *et al.* (2018). Mitigating pavement shoulder cracking in northern, low volume highways by incorporating Tencate Mirafi® H_2Ri wicking geotextile. *71st CGC and 13th Joint CGS/IAH-CNC Groundwater Conference*, Edmonton, AB. Paper 329.

Veuille, S., *et al.* (2015). Heat advection in the active layer of permafrost: physical modelling to quantify the impact of subsurface flow on soil thawing. *Proceedings, 68th CGC and 7th CPC*, Québec City, QC, Canadian Geotechnical Society, Richmond, BC. Paper 722.

NSERC PermafrostNet

BY TRISTAN MACLEAN (CARLETON UNIVERSITY, CANADA)

NSERC PermafrostNet is adjusting to the unprecedented and challenging year of 2020 by focusing on member needs and pivoting to new and safer ways of operating. Our work and events have been moved online and to address the cancelled fieldwork of the 2020 season we have doubled the available funding for Northern Research Assistantships for the upcoming season. Theme 2 Co-Lead, Trevor Lantz, has stepped forward to lead a new action group dedicated to connecting with people in Northern communities and regions to establish how best to serve their needs for research in permafrost thaw. Subgroups from the five themes are now meeting online regularly to discuss specific research topics and how they relate with others.

SCIENCE COMMUNICATION

Since January 13, 2021, the network has been running the *Science Communication Toolbox for Researchers* in a series of seven workshops over 3 months. This NSERC funded program will provide network members the opportunity to hone their skills for carrying out a wide range of communications for a variety of audiences.

CLIMATE DATA SCIENCE

A new tool for performing quality control on ground temperature data is now available from NSERC PermafrostNet. This small program makes it easy to view ground temperature files, flag suspicious data and remove any bad sensor observations. The program can currently read files matching the NTGS ground temperature template, and Geoprecision datalogger outputs. You can download the latest version from the PermafrostNet GitLab page.

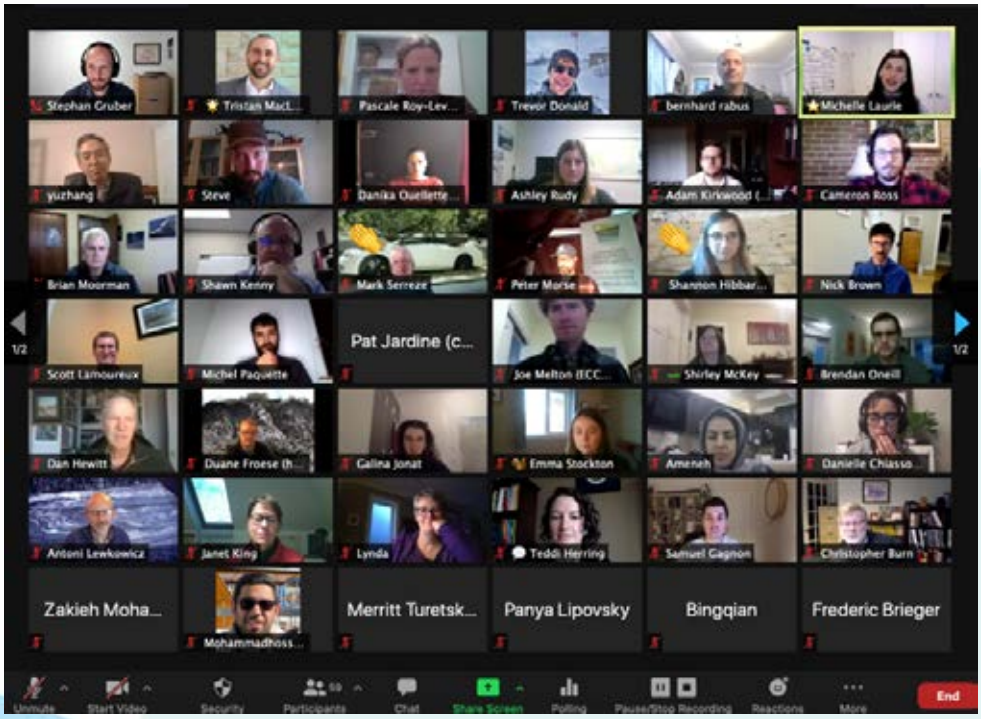
ANNUAL GENERAL MEETING

The 2nd AGM was held on November 16-18, 2020 in partnership with the Canadian Permafrost Association (CPA). During the virtual event, over 200 participants united to share progress, build connections and welcome our graduate students and postdoctoral fellows.

On Monday, CPA members hosted a keynote presentation by Ryley Beddoe (RMC), followed by seven presentations covering everything from coastal erosion to laboratory characterization of permafrost. Tuesday featured Duane Froese (University of Alberta) presenting a second keynote, with 12 concurrent presentations immediately after. The afternoon transitioned to the NSERC PermafrostNet sessions featuring the equity, diversity and inclusion committee (EDIC) delivering an interactive session, followed by a policy panel and a presentation by the network's data scientist Nick Brown. Wednesday was kicked-off by AGM Chair, Brian Moorman (University of Calgary) who moderated a keynote panel on the future of permafrost science, followed by a second session by the EDIC, Flash presentations by the students and post-doctoral researcher, presentations by international partners and a panel discussion on "Northern Infrastructure: needs and directions". Further details, videos and resources are posted on our website, in our attendee area and on our new YouTube channel.

NETWORK COMMITTEES

We are delighted to announce that Kathryn Elliot has taken over as the new Chair of the Knowledge Mobilization and Communication Committee (KMCC). The KMCC and EDIC would welcome expressions of interest to join from network members. The KMCC is looking for members to represent Indigenous and Government stakeholders specifically. Please email tristan.maclean@carleton.ca to express interest in joining.



2020 Virtual joint NSERC PermafrostNet/Canadian Permafrost Association AGM.

Permafrost Carbon Network

BY CHRISTINA SCHÄDEL (NORTHERN ARIZONA UNIVERSITY, USA)

Major activities of the Permafrost Carbon Network in 2020 include four newly published science syntheses and the 10th Annual Meeting of the network (held virtually). The science highlights include a synthesis with a first estimate of thermokarst (abrupt thaw) carbon emissions using numerical models. Abrupt thaw occurs in <20% of the permafrost zone but could double permafrost carbon emissions.

Another synthesis showed that widely used land models project near-surface drying of the terrestrial Arctic despite increases in the net water balance driven by climate change. Drying was generally associated with increasing active layer depth and permafrost thaw in a warming climate. A third synthesis assessed the potential for mobilization of old soil carbon after permafrost thaw. This synthesis suggests widespread but not universal release of permafrost soil organic carbon following thaw. Finally, an expert assessment, provided the first circumarctic assessment of the quantity and climate sensitivity of organic matter and methane hydrates on continental shelves of the Arctic Ocean. The assessment suggests slow but substantial greenhouse gas release from submarine permafrost.

We welcomed more than 200 participants to the 10th Annual Meeting held virtually. Four panels discussed *"What is the current, bottom line provided by science synthesis on topics central to the permafrost carbon-climate feedback?"* The panels were structured around:

- How much carbon is stored in the permafrost region and how vulnerable is it?
- How much carbon will be released through gradual climate warming and abrupt permafrost thaw?
- Are increases in Arctic carbon emissions already occurring?
- Integrating permafrost science into climate policy

For more information visit www.permafrostcarbon.org/news.html.

For more information see:

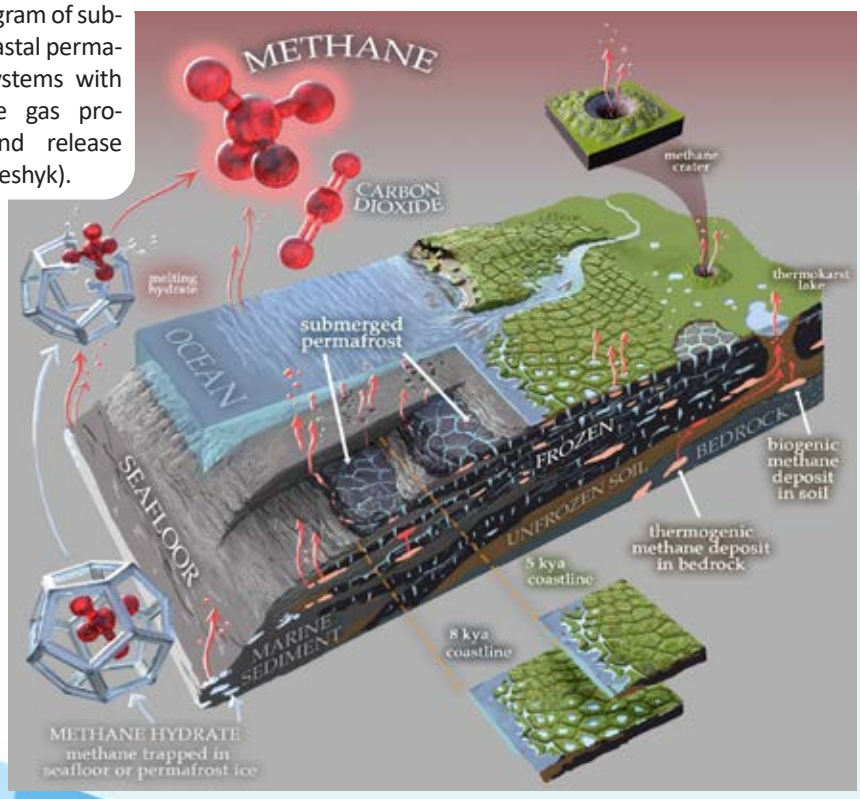
Turetsky, M.R., *et al.* (2020). Carbon release through abrupt permafrost thaw. *Nature Geoscience*, 13(2), 138–143. DOI: 10.1038/41561-019-0526-0.

Andresen, C.G., *et al.* (2020). Soil moisture and hydrology projections of the permafrost region – a model intercomparison. *The Cryosphere*, 14(2), 445–459. DOI: 10.5194/tc-14-445-2020.

Estop-Aragonés, C., *et al.* (2020). Assessing the Potential for Mobilization of Old Soil Carbon after Permafrost Thaw: A Synthesis of 14C Measurements from the Northern Permafrost Region. *Global Biogeochemical Cycles*, DOI: 10.1029/2020GB006672.

Sayedi, S.S., *et al.* (2020). Subsea permafrost carbon stocks and climate change sensitivity estimated by expert assessment. *Environmental Research Letters*, 15, DOI: 10.1088/1748-9326/abcc29.

Thermokarst wetlands, Wrigley, NWT, Canada. IPA photo contest runner-up: *David Olefeldt*.



Artistic diagram of subsea and coastal permafrost ecosystems with greenhouse gas production and release (Victor O. Leshyk).

ESA CCI+ Permafrost

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

The second version of the climate records of Mean Annual Ground Temperature as well as Active Layer Thickness for the northern hemisphere (1997-2018) was released in November 2020. An additional dataset for permafrost extent following the IPA class descriptions has been derived from 2 m ground temperatures. This dataset is currently the most popular and the new version has been downloaded more than 50 times as of 2020.

Participants at the 5th progress meeting held on 14 January, 2021.

Existing databases (GTN-P, CALM, PERMOS, ROSHYDROMET, records stored on PANGAEA, Nordicana D & the Arctic Data Centre) as well as direct provisions by colleagues maintaining some of the boreholes have been used for validation of the permafrost modelling results. The datasets have been harmonized to facilitate the assessment. The validation report is accessible on the project webpage. The time series reveal insight into spatial patterns of ground temperature change at different depths. An increase of more than 1 °C per decade can be observed specifically in Arctic coastal settings.

The processing system is currently adapted to ingest further satellite products, specifically new dataset on land surface temperature and snow from other ESA CCI+ projects. The release of a new version is planned for 2021.

Extensive work has been carried out within the CCI+ Permafrost project extension 'Rock glacier kinematics as a new associated parameter of the ECV permafrost' in 2020. The close cooperation with the IPA Action Group 'Rock glacier inventories and kinematics' enabled the definition of requirements and mapping strategies.

Discussion of the rock glacier mapping strategy with hands on exercise in collaboration with the IPA action group, University of Fribourg, Switzerland, 11 February 2020.

Eventually, RGK inventories were generated according to the standards defined by the IPA Action Group in different climatic regions. This included: the western Alps (Switzerland), Ultental (Italy), Vanoise Massif (France), Troms (Northern Norway), Finnmark (northern Norway), Nordenskiöld Land (Svalbard), Disko Island (Greenland), Tien Shan (Kazakhstan-Kyrgyzstan), Brookes Range (Alaska), Central Andes (Argentina), and Retezat mountains (Romania).

We would like to thank all collaborating researchers for their support for validation data provision, specifically Alexander Kholodov (Univ. of Alaska, USA), Alexander N. Fedorov (Melnikov Permafrost Institute, Yakutsk, Russia) & Mathias Ulrich (University of Leipzig, Germany), as well as for contributions to the rock glacier inventories: Xavier Bodin (EDYTEM – CNRS, France), Tobias Bolch (Univ. of St Andrews, UK), Francesco Brardinoni and Gabriel Pellegrinon (Univ. of Bologna, Italy), Margaret Darrow (Univ. of Alaska, USA), Christophe Lambiel (Univ. of Lausanne, Switzerland), Lucas Ruiz (IANIGLA, Argentina).

For more information visit climate.esa.int/en/projects/permafrost/.

Projets d'adaptation aux changements climatiques en région de pergélisol au Nunavik du ministère des Transports du Québec

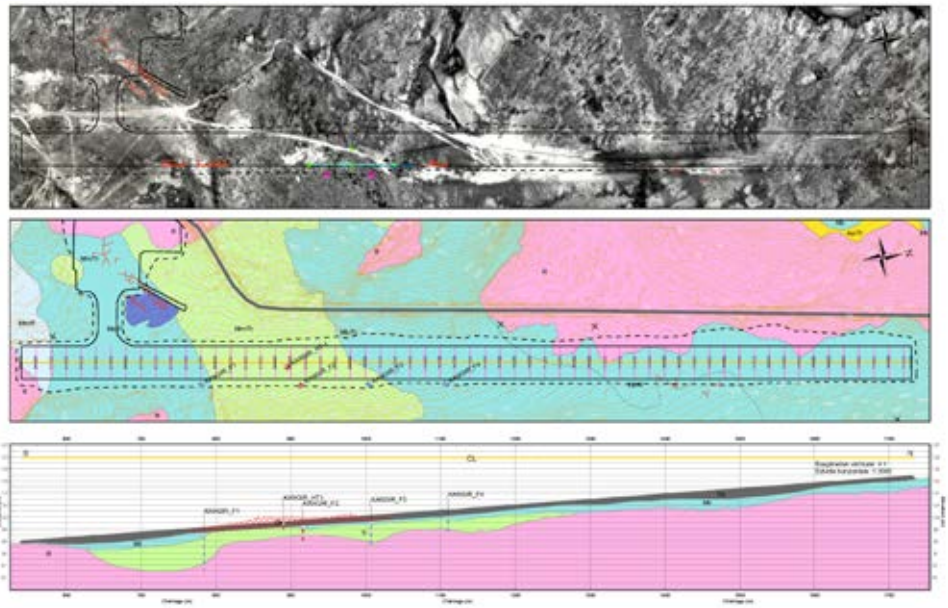
BY ANICK GUIMOND (MINISTÈRE DES TRANSPORTS DU QUÉBEC)

Transports Québec

Le réchauffement climatique qui se produit depuis le début des années 1990 dans le nord du Québec, engendre des vulnérabilités pour plusieurs infrastructures aéroportuaires du ministère des Transports du Québec (Ministère) au Nunavik. Depuis le début des années 2000, un endommagement prématuré de certaines infrastructures, notamment causé par le dégel du pergélisol, a été observé. L'évolution anticipée des dégradations peut diminuer la durée de vie utile de certains ouvrages en l'absence d'interventions adaptées qui prennent en compte les impacts liés aux changements climatiques (CC).

Depuis 2003, pour assurer la résilience de ses ouvrages, le Ministère réalise plusieurs actions concrètes et projets de recherche innovateurs en adaptation aux CC visant à:

- Caractériser de façon approfondie le pergélisol (teneur en glace des sols à partir d'échantillons intacts, stratigraphie des dépôts avec des relevés géophysique, essai de consolidation au dégel)
- Développer un réseau de suivi pour documenter l'évolution du régime thermique du pergélisol (thermistances, fibre optique).
- Documenter l'impact des CC sur l'évolution des conditions thermique et mécanique du pergélisol ainsi que sur le comportement des infrastructures.
- Expérimenter des techniques d'adaptation (remblai en pente douce, remblai à convection d'air, surface à albédo élevé).
- Favoriser l'innovation technologique (DTS, drain thermique, systèmes d'acquisition de données compacts).
- Développer des stratégies d'adaptation et réaliser des travaux d'adaptation à grande échelle.
- Suivre et analyser la performance (technologique et coûts-bénéfices-efficacité) des interventions en adaptation (expérimentales et à grande échelle).
- Soutenir la révision des critères de conception.
- Quantifier et améliorer la gestion des risques en lien avec les impacts du dégel du pergélisol sur la fonctionnalité des ouvrages pour cibler les interventions optimales en adaptation.
- Développer des outils d'aide à la décision et de gestion pour faciliter l'intégration des nouvelles connaissances en CC dans



Carte synthèse des dépôts de surface de l'aéroport à Kangirsuk, Nunavik, 2007 (*Surficial geology, Kangirsuk Airport, Nunavik, 2007*).

Expérimentation de techniques d'adaptation sur la piste d'atterrissage à Tasiujaq, Nunavik, 2005 (*Tasiujaq Airstrip Test Sections, Nunavik, 2005*).

CONTINUED FROM PAGE 39

la planification des interventions (conception, construction, entretien) et permettre le suivi de la performance des travaux d'adaptation.

Le développement du savoir doit se poursuivre notamment pour permettre : la validation des hypothèses sur l'interaction entre certains phénomènes naturels et climatiques, l'identification des techniques d'adaptation les plus performantes à grande échelle et une gestion intégrée des risques à long terme. Pour contribuer à assurer la résilience des infrastructures de transport en région de pergélisol, les intervenants en transport doivent poursuivre le développement de cette nouvelle expertise et intégrer davantage les connaissances de la recherche en adaptation aux CC dans la pratique. Pour répondre à ce besoin et favoriser la prise en compte des CC, la diffusion des connaissances, la formation ainsi que le développement d'outils d'aide à la décision et de normes doivent être accentués.

Travaux d'adaptation à grande échelle (contrepoids en remblai à convection d'air) sur la piste d'atterrissage à Puvirnituq, Nunavik, 2010 (*Air convection embankment, Puvirnituq airstrip, Nunavik, 2010*).

Pour plus d'informations, contactez Anick.Guimond@transports.gouv.qc.ca

ENGLISH TRANSLATION

Climate change adaptation projects in the permafrost regions of Nunavik by the Quebec Ministry of Transport (MTQ)

Climate warming in Arctic Quebec that began in the early 1990s has affected infrastructure at several airports operated by the Quebec Ministry of Transport (MTQ). Premature damage to various facilities has been caused by thawing permafrost. The service life of airport structures can be reduced by permafrost degradation without preventative engineering interventions that consider the effects of climate change.

Since 2003, MTQ has carried out several activities and research projects to ensure that its infrastructure is adapted to anticipated climate change. These have been aimed at:

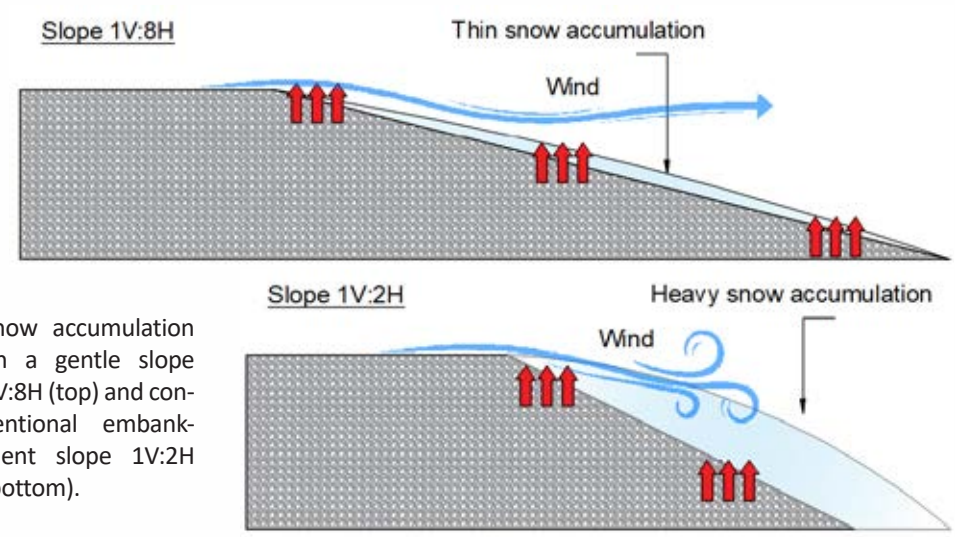
- Thoroughly characterizing permafrost conditions in the vicinity of infrastructure, for example, examining the ice content of intact soil samples, using geophysics for surveys of cryostratigraphy, and testing soils to obtain thaw consolidation characteristics.
- Developing monitoring networks to document the evolution of the permafrost thermal regime, in some cases with fibre-optic technology.
- Documenting climate change effects on the thermal and mechanical states of permafrost and on the behavior of infrastructure.
- Experimenting at field scale with adaptation techniques such as gentle side slope and/or air convection embankments, and high albedo surfaces and subsequently implementing these adaptations.
- Promoting technological innovation with fibre optic thermal sensing, heat drains, and compact data recording systems.
- Monitoring and analyzing the technical performance and cost-benefit effectiveness of adaptation interventions.
- Supporting review of design criteria.
- Quantifying and improving risk management related to thawing permafrost to target optimal adaptation interventions.
- Developing decision support and management tools to integrate new climate change knowledge in the planning of interventions.

Further research is needed to validate hypotheses on the interaction between earth processes and climatic phenomena, to identify the most effective adaptation techniques for large scale application, and to develop integrated long-term risk management strategies. Transport stakeholders must continue to develop this new expertise and further integrate climate change adaptation research into practice. This will help ensure the resilience of transport infrastructure in permafrost regions. Dissemination of research findings, training, and development of decision support tools and standards are priorities.

For more information contact Anick.Guimond@transports.gouv.qc.ca.

Design and integrated management tools for adaptation of MTQ's transportation infrastructure in Nunavik

BY EMMANUEL L'HERAULT, GUY DORÉ, MARÍA FERNANDA BARÓN HERNÁNDEZ, MICHEL ALLARD, CHANTAL LEMIEUX (UNIVERSITÉ LAVAL), AND ANICK GUIMOND (MINISTÈRE DES TRANSPORTS DU QUÉBEC)



Snow accumulation on a gentle slope 1V:8H (top) and conventional embankment slope 1V:2H (bottom).

Airstrips and access roads owned by the provincial Ministry of Transport (MTQ) play a vital role for the well-being of remote communities in northern Quebec. Several research projects have been initiated by MTQ at specific facilities and undertaken by Université Laval since 2000 in response to concerns regarding climate change and permafrost stability. Large-scale adaptation strategies for permafrost-supported linear infrastructure have been developed and implemented over the past decade across northern Quebec.

Assessment of the thermal and mechanical performance of eight adapted runways or access roads began in 2018. The adaptation techniques to limit permafrost degradation include air convection embankments (ACE), heat drains, and gentle slopes used alone or in combination. The performance assessment includes collection of long-term monitoring data, field observations, and lessons learned from past practice to redefine the best practices for the design, implementation and maintenance of transportation infrastructure in the permafrost zones.

At the Tasiujaq airstrip, gentle side slopes, heat drains, and an ACE were installed over 50 m lengths of the runway embankment. Ten years of thermal monitoring suggest all methods contribute to thermal stability, but the gentle slope (1V:8H) appears to be the most effective at cooling the ground and reducing active-layer thickness. Crosswinds during winter favour snow accumulation along conventional embankments, but deposition is minimized on the gentle slope due to snow drifting. Minimal snow accumulation limits insulation of the ground. Air convection and heat drain techniques are more effective for thicker embankments, and where the difference between air and ground temperatures is greater.

For more information contact emmanuel.lherault@cen.ulaval.ca.

For more information see:

Barón Hernández, M.F., *et al.* (2019). Long-term monitoring of mitigation techniques of permafrost thaw effects at Tasiujaq Airport in Nunavik, Canada. In *Cold Regions Engineering 2019, ASCE*. DOI: 10.1061/9780784482599.058.

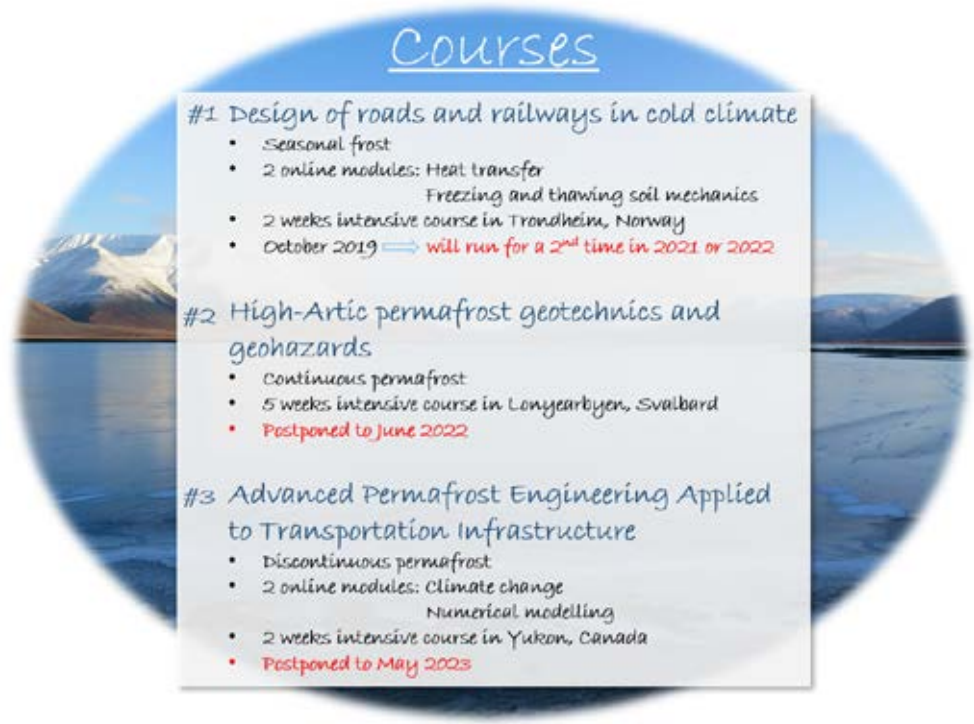
Tasiujaq Airstrip, Nunavik, northern Quebec.

PROJECT UPDATES

Frozen Canoes

BY HANNE CHRISTIANSEN (UNIVERSITY CENTRE IN SVALBARD, UNIS)

FROZEN CANOES (*Landscape & infrastructure dynamics of frozen environments undergoing climate change in Canada, Norway, and Svalbard*) started in 2018 and was planned to end in 2021. It is funded by the INTPART program of the Norwegian Research Council. FROZEN CANOES was hit hard by the COVID-19 pandemic in 2020, restricting any of the planned exchange, meeting or teaching activities. The second master course 'Geohazards and geotechnics in high Arctic permafrost environments', developed by the FROZEN CANOES project and scheduled for 5 weeks in June-July 2020, was cancelled with other courses in the academic program at UNIS. The course was postponed to 2021 but all intensive master courses at UNIS have now been suspended until midsummer 2021.



However, the planned session 'Integrating Science and Engineering, Education for Challenges to Northern Infrastructure Under a Changing Climate' at Arctic Change 2020 was delivered online in December, with presentations from FROZEN CANOES project members and others working on applied permafrost challenges in the Arctic. A good discussion ended the session. The project period has been extended to 2022 so that the master course at UNIS is now planned after a delay of two years, and we hope that it will be possible to expand the project period into 2023 for major educational and research collaboration activities in Yukon.

For more information visit www.ntnu.edu/ibm/frozen-canoes.

PROJECT UPDATES

Permafrost & Periglacial Processes (PPP)

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

Despite the COVID-19 pandemic, PPP has made several changes to widen its scope and better serve the permafrost community, including two new types of papers:

- *Technical notes* present results from analysis of observational data, simulations, or a combination of both. Contributions will have a maximum length of 10 double-spaced, word-processed A4 pages.
- *Data papers* alert the scientific community to data sets. Contributions will have a maximum length of 10 double-spaced, word-processed A4 pages. Only data sets of continuous measurements containing at least 5 years of continuous data or noncontinuous data sets covering a period of at least 10 years will be considered.

For more information visit onlinelibrary.wiley.com/page/journal/10991530/homepage/forauthors.html.

The Editor-in-Chief, Professor Mauro Guglielmin, thanks the outgoing Associate Editors, Professor Denis Lacelle and Professor Emeritus Doug Goering, for their work over the past two years. The journal welcomes the new Associate Editor, Professor Seth Campbell (University of Maine). PPP has issued a call for nominations (including self-nominations) of a second Associate Editor. Some initial contacts with potential candidates for the position are in progress.

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A new submission system has recently been developed on the Research Exchange platform. This system will permit submission of papers in free-format mode. Authors will henceforth be able to upload manuscripts as single files that include text, figures, and tables.

Beginning in March 2021, a selection of papers of especially wide interest will be designated by the Editor-in-Chief to be publicized on Wiley Earth and Space Science social media channels, and a new service, "Transfer Desk Assistant" will be available. This service will facilitate the transfer of some submitted manuscripts to other Wiley journals deemed to be more appropriate.

The third special Issue in the series "Transactions of the IPA", edited by Professor Chris Burn, was published in 2020. The issue contains nine papers covering some of the hottest topics in permafrost and periglacial research.

In 2021, a new special issue containing seven papers to commemorate the journal's founder, Professor Hugh M. French, will be edited by the Editor-in-Chief and previous Editors, Professor Julian Murton and Professor Antoni Lewkowicz.

PROJECT UPDATES

Nunataryuk

BY HUGUES LANTUIT (ALFRED WEGNER INSTITUTE, AWI, GERMANY)

Since November 2017, AWI in Potsdam has coordinated the Horizon2020 EU-project *"NUNATARYUK: Permafrost thaw and the changing Arctic coast; science for socioeconomic adaptation"*. The five-year project (2017-2022) has a budget of €11.5 million and unites 26 partners from 11 countries.

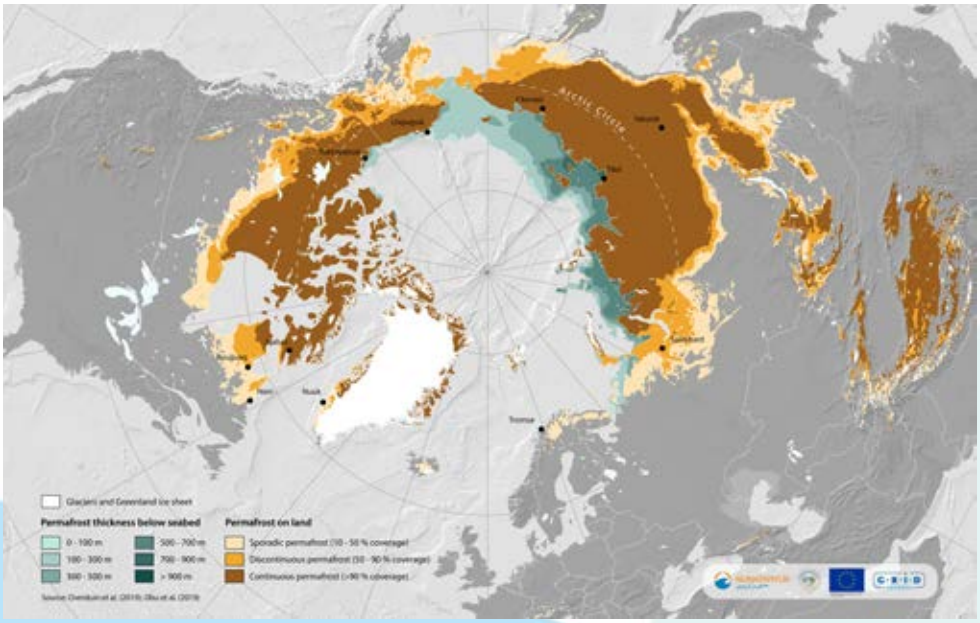
We bring together world-leading specialists across disciplines in natural science and socioeconomics to:

- Develop quantitative understanding of the fluxes and fates of organic matter released from thawing coastal and subsea permafrost
- Assess risks posed by thawing coastal permafrost to infrastructure, indigenous and local communities, and people's health from pollution
- Estimate the long-term impacts of permafrost thaw on global climate and economy.

In 2020, a demographic study of the population on permafrost presented first estimates of the number of inhabitants on permafrost in the Arctic and projected changes due to permafrost thaw. As well as new estimates on source and fate of organic carbon from eroding permafrost coasts, and social representations of permafrost thaw among people from the Sakha Republic, Russia.

We also produced a new Northern Hemisphere permafrost map which reflects an improved understanding of land-based permafrost and includes the latest understanding of submarine permafrost extent.

For more information visit nunataryuk.org/.



New Northern Hemisphere permafrost map, including the offshore (Overduin *et al.*, 2020).

For more information see:

Ramage, J., Jungsberg, L., Wang, S., Westermann, S., Lantuit, H., and Heleniak, T. (2021). Population living on permafrost in the Arctic. *Population and Environment*, DOI: 10.1007/s11111-020-00370-6.

Jong, D., Bröder, L., Tanski, G., Fritz, M., Lantuit, H., Tesi, T., Haghipour, N., Eglinton, T.I., and Vonk, J.E. (2020). Nearshore zone dynamics determine pathway of organic carbon from eroding permafrost coasts. *Geophysical Research Letters*, 47(15), DOI: 10.1029/2020GL088561.

Doloisio, N., and Vanderlinden, J.-P. (2020). The perception of permafrost thaw in the Sakha Republic (Russia): narratives, culture and risk in the face of climate change. *Polar Science*, 26, DOI: 10.1016/j.polar.2020.100589.

PROJECT UPDATES

Coastal and Offshore Permafrost in a Changing Arctic

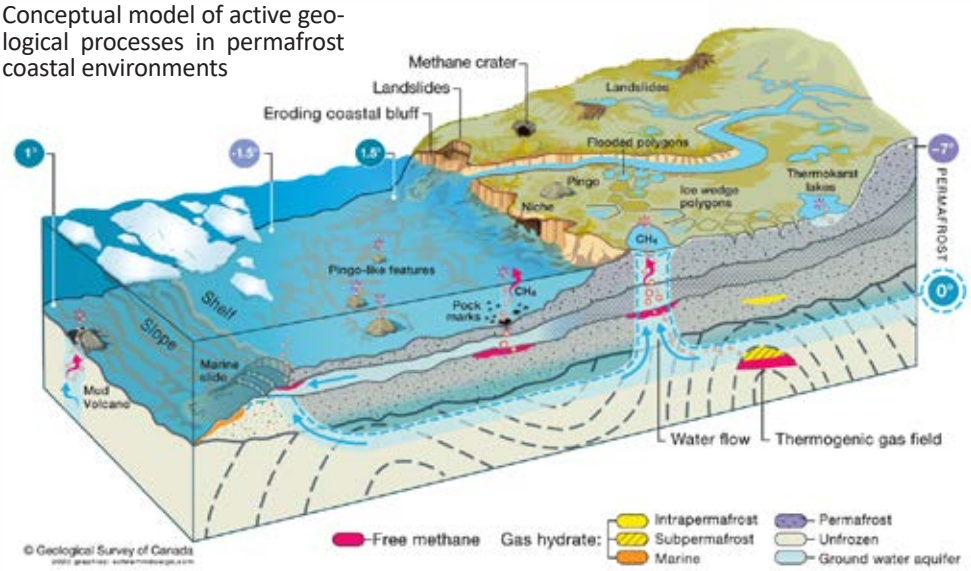
BY CHRIS BURN (CARLETON UNIVERSITY)

Scott Dalllimore of the Geological Survey of Canada has led an international team supported primarily by Tiina Kurvits (GRID Arendal, Norway), Ben Jones (UAF, USA), and Young Jin (Polar Research Institute, South Korea) to produce a Rapid Response Assessment on Coastal and Offshore Permafrost. The principal team members also included Christopher Burn (Carleton), Michelle Côté (GSC), Peter Morse (GSC), and Stephen Wolfe (GSC) from Canada, and Charles Paull (MBARI, CA) from the United States. The four-part Story Map was published in October and is available at: www.grida.no/publications/512.

It is a spectacularly illustrated compilation of interactive maps, diagrams, photographs, videos, and text resources on science and engineering in erodible coastal permafrost settings. It draws on examples from the western Arctic coast of North America and is unique in presenting holistically the terrestrial-coastal-offshore environment. The coverage is comprehensive, considering earth surface processes, biogeochemistry, and submarine geosystems on the coastal shelf. Interactive and animated maps display climate, sea ice, sea level, biochemical, and socio-economic data from the circumpolar region.

The Story Map is presented in two parts: one summarizes scientific knowledge and the other examines issues raised by northern communities and identifies gaps that scientists need to address. There is also an executive summary and crowd source map for the public to document coastal permafrost observations.

Conceptual model of active geological processes in permafrost coastal environments



PROJECT UPDATES

PRISMARCTYC

BY ANTOINE SÉJOURNÉ (UNIVERSITÉ PARIS-SACLAY, FRANCE)

The Belmont Forum organization is funding a new international project called *"Permafrost degradation impacts on soils, human societies, water resources and carbon cycle"*. The PRISMARCTYC project (2021-2024), led by Antoine Séjourné, aims to understand the hydrogeomorphological, geochemical, microbiological, and socio-economic impacts of current permafrost thaw dynamics to soils and surface/groundwater in the Arctic and Sub-Arctic. The study will focus on the near-surface permafrost-hydrosystem continuum in small Arctic watersheds where localized and rapid thermokarst occurrences remain under-studied. This will be achieved by comparing different sites in Siberia and Alaska with different permafrost settings, climate-sensitivity, vegetation, and permafrost degradation types along a latitudinal and longitudinal gradient. A set of quantitative indicators of the vulnerability of soils and surface/groundwater will be used to understand and cross-compare the impacts of permafrost degradation between sites.

Our team includes scientists from France (Université Paris-Saclay, Université de Toulouse, Institut de Recherche pour le Développement), Russia (Melnikov Permafrost Institute, University of Moscow, Institute of Physico-Chemical and Biological Problems in Soil Science), USA (University of Alaska Fairbanks) and Japan (University of Hokkaido).

The Paris Agreement emphasizes the value of education, training, and public awareness of climate change. Teachers are pivotal for climate education and must therefore receive sufficient support to implement effective lessons on climate change. This project emphasizes the teaching of climate change and outreach activities in local communities by involving four primary schools in Yakutia and France, an association for Sakha ecological education, and the Office for Climate Education.

ASSOCIATED ORGANIZATIONS

Canadian Permafrost Association (CPA)

BY LUKAS ARENSON (BGC ENGINEERING INC., CANADA), CPA PRESIDENT

Like everyone else, the Canadian Permafrost Association (CPA) was challenged by the pandemic that did not allow for any in-person meetings. As a quick response and to stay connected, the CPA initiated a Speakers Series in July with monthly talks. This series was well attended by our members and provided an excellent opportunity to share their research during a time where such exchanges are limited. In November the CPA held their first virtual Annual General Meeting, which consisted of three technical sessions and the annual business meeting. It was held in partnership with NSERC PermafrostNet, who added an additional 1.5 day of activities, turning this three day Zoom meeting into a successful and diverse event.

For more information visit canadianpermafrostassociation.ca/.

2020 Virtual joint NSERC PermafrostNet/Canadian Permafrost Association AGM.

For more information see:

Arenson, L., Rudy, A., and Morse, P. (2020). CPA Virtual Annual General Meeting, 16-17 November 2020, Book of Abstracts. *Canadian Permafrost Association (CPA)*.

ASSOCIATED ORGANIZATIONS

Chinese Academy of Sciences (CAS)

BY NIU FUJUN (CAS, CHINA)

Since the World Health Organization (WHO) declared a "global health emergency of international concern" on January 30, 2020, the pandemic has gradually brought negative impact on scientific research in China and around the world. The Chinese Academy of Sciences is concerned with the prevention and control of the pandemic. Most planned scientific research activities and academic conferences have been cancelled or postponed, such as the 12th ICOP now scheduled for 20-24 June 2022. Some in-person conferences, discussions and field investigations have been carried out where participants numbers are not more than 50. We hope the pandemic will be precisely controlled with global cooperation.

For more information visit english.cas.cn/.

An in-person meeting between the Northwest Institute of Eco-Environment and Resources (NIEER) and the Chinese Academy of Sciences (CAS).

ASSOCIATED ORGANIZATIONS

Melnikov Permafrost Institute (MPI)

BY OLGA ALEKSEEVA (MPI, RUSSIA)

Despite the challenging circumstances brought about by the COVID-19 pandemic, the MPI (Yakutsk, Russia) continued extensive field studies in Siberian permafrost regions. The final stage of a major three-year project to assess risk to the Power of Siberia Pipeline system from permafrost degradation and a changing climate was successfully completed. Detailed surveys to characterise permafrost and terrain conditions in problem areas along the pipeline corridor were undertaken throughout 2020. A report was prepared and submitted to the pipeline design contractor, VNIPIgasdobycha, providing preventive and mitigative measures for changing permafrost conditions during the pipeline construction and operation.

Water sampling at an icing-prone site in the pipeline corridor, Lukoyava River valley, Amur Region, June 2020.

For more information visit mpi.ysn.ru/en/.

ASSOCIATED ORGANIZATIONS

Swiss Permafrost Monitoring Network (PERMOS)

BY JEANNETTE NÖTZLI (WSL INSTITUTE FOR SNOW AND AVALANCHE RESEARCH)

PERMOS began in 2000 as an unconsolidated network of sites from research projects, and became the first national long-term observation network for permafrost and an early component of GTN-P. After 20 years of operation, PERMOS holds the largest and most diverse collection of mountain permafrost data worldwide and can be considered a role model for structure and organization. The monitoring strategy is based on ground and subsurface temperatures, changes in ground ice, and permafrost creep velocities. All observation elements indicate significant changes to mountain permafrost in the Swiss Alps over 20 years. A clear warming trend is underlined by decreasing ground ice and increasing rock glacier velocities. Due to COVID-19 restrictions, meetings and excursions were postponed, held virtually, or cancelled. Fortunately, fieldwork could take place as usual by respecting additional safety regulations. An exceptionally early snowfall in October 2020, caused some data acquisition problems to terrestrial geodetic surveys on rock glaciers and burial of temperature loggers. However, continuous measurements from borehole stations were not affected.

For more information visit www.permos.ch/.

ASSOCIATED ORGANIZATIONS

United States Permafrost Association (USPA)

BY JERRY BROWN AND FRITZ NELSON (MICHIGAN STATE UNIVERSITY, USA)

The pandemic has affected the U.S. permafrost community in myriad ways. Fieldwork during 2020 was severely curtailed in much of northern Alaska, and strict quarantine protocols have been in effect. However, workers at the Toolik Lake Field Station and staff at the Ukpeaġvik Inupiat Corporation maintained critical measurements for many groups unable to get to the field. Travel restrictions prevented normal in-person conferences. As

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a result, virtual meetings, including those of the American Geophysical Union and the U.S. Permafrost Association, have been held online. Many universities have adopted distance learning, and online classes, seminars, colloquia.

The 2021 RCOP is now scheduled for October 24-29. The current status of the conference and results of the 28 individual organizational annual reports can be found on the USPA website. The Annual Meeting of the USPA was held virtually during the AGU with 50 members in attendance and 300 permafrost-related abstracts and virtual presentations. Results from the annual election of the 13-member Board of Directors were announced and include President Cathy Wilson, President-Elect John Thornley, Past President John Zarling, and four new board members.

For more information visit usermafrost.org/.

Dr Cathy Wilson, 2021 USPA President.

ASSOCIATED ORGANIZATIONS

University Centre in Svalbard (UNIS)

BY HANNE CHRISTIANSEN (UNIVERSITY CENTRE IN SVALBARD, UNIS)

Research and educational field activities have been reduced at UNIS during 2020 due to COVID-19. During the start of the pandemic all winter field activities were stopped. In late spring, some key activities were resumed, and by summer most basic research fieldwork was running, but with strict infection control measures. All course activities remain cancelled at UNIS, including fieldwork components. However, individual bachelor, master and PhD thesis fieldwork studies have been carried out. Many research collaborators were unable to visit Svalbard in 2020 due to a mandatory 10-day isolation in Norway before flying to Svalbard, or travel restrictions at their home institutions. The permafrost group at UNIS lost a major winter drilling season to establish new boreholes but have replanned for winter 2021. During 2020, the IPA Secretariat moved from UNIS to Carleton University, Canada.

ASSOCIATED ORGANIZATIONS

Aurora Research Institute (ARI)

BY ALICE WILSON AND JOEL MCALISTER (ARI, CANADA)

At the onset of the global COVID-19 pandemic, the ARI temporarily closed, and suspended field activities. Staff responded to challenges with innovative approaches. In early spring 2020, ARI modified fieldwork protocols to be compliant with the territorial Chief Public Health Officer (CPHO) guidelines. ARI strived to meet commitments while also mitigating the risks and spread of COVID-19 in an effort to protect our staff and communities across the Northwest Territories.

Left: Alice Wilson and Mary Cockney (ILA, Environmental Monitor) collecting snow depths and densities. Right: Snow cat at a compaction site near the ITH (both January 2021).

With CPHO-approved protocols, ARI was able to implement and support permafrost research and monitoring programs in the western Arctic, and continued to train community members in permafrost data collection and research. ARI led research includes a snow manipulation project, the effects of retrogressive thaw slumping on water quality, and the feasibility of using local vegetation to revegetate and stabilize coastline affected by thaw slumping. Routine ground temperature monitoring occurs along the Dempster and Inuvik to Tuktoyaktuk Highways (ITH). Territorial CPHO guidelines have

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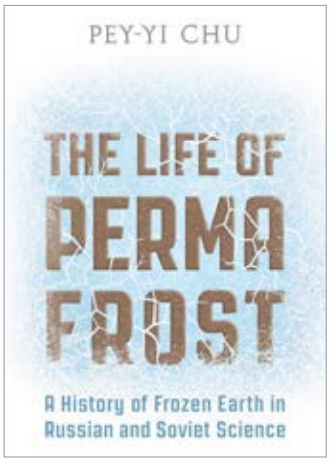
prevented external partners from travelling to the western Arctic for fieldwork. ARI continues to support partners by deploying and retrieving equipment, downloading data, assisting with fieldwork, and collecting and shipping samples to southern academic institutions, Parks Canada, the Geological Survey of Canada, the Northwest Territories Geological Survey, Northwest Territories Dept. of Lands, Department of Fisheries and Oceans, and the Joint Secretariat.

For more information visit nwtresearch.com/.

NEW BOOK

The Life of Permafrost: A History of Frozen Earth in Russian and Soviet Science

BY PEY-YI CHU (POMONA COLLEGE, USA), *UNIVERSITY OF TORONTO PRESS*



The Life of Permafrost provides an intellectual history of permafrost, placing the phenomenon squarely in the political, social, and material context of Russian and Soviet science. The understandings of frozen earth were shaped by two key experiences in the Russian Empire and the Soviet Union. On one hand, the colonization and industrialization of Siberia nourished an engineering perspective on frozen earth that viewed the phenomenon as an aggregate physical structure: ground. On the other, a Russian and Soviet tradition of systems thinking encouraged approaching frozen earth as a process, condition, and space tied to planetary exchanges of energy and matter. Aided by the US militarization of the Arctic during the Cold War, the engineering view of frozen earth as an obstacle to construction became dominant. This fascinating story of how permafrost came to acquire life as Russian and Soviet scientists studied, named, and defined it.

IN MEMORIAM

Vyacheslav Nikolaevich Konishchev (1938-2020)

BY VICTOR VASIL'EVICH ROGOV AND TRANSLATED BY VASYA TOLMANOV (MOSCOW STATE UNIVERSITY, RUSSIA)

Professor V.N. Konishchev passed away on July 21, 2020. He was a Doctor of Geography, Honoured Scientist of the Russian Federation, Honoured Professor of Lomonosov Moscow State University and Head of the Department of Cryolithology and Glaciology (1993-2017).

His internationally renowned research focussed on the significance and place of cryogenesis in the system of natural processes on Earth, the dynamics of mineral matter in the permafrost zone, and the geoecological role of the Earth's cryosphere and its evolution. He discovered the cryogenic nature of mineral matter in loess deposits, showed the leading role of cryogenesis in deposit formation, and proved the polygenetic nature of the ice complex in Siberia.

He was active in teaching for more than half a century, supervising one DSc and nine PhD theses. Vyacheslav Nikolayevich was given an *Honoured Scientist of the Russian Federation* award in 1998 and was named *Honoured Professor of Moscow State University* in 2004.

He conducted scientific and organizational work in international organizations for permafrost scientists and geographers for many years. He was the Secretary of the Terminology Committee of the International Permafrost Association (IPA) and editorial board member of major scientific journals such as *Vestnik MGU, Earth Cryosphere, Engineering Geology,* and *Permafrost and Periglacial Processes*. He published more than 250 scientific and educational-methodical works. The bright memory of Dr Konishchev will remain in the hearts of relatives, friends, and colleagues.

Konishchev, V.N. (1998). Relationship between the lithology of active-layer materials and mean annual ground temperatures in the former USSR. *Proceedings, 7th International Conference on Permafrost*. Centre d'études Nordiques, Université Laval: Québec; 591-594.

IN MEMORIAM

Matti Seppälä

(1941-2020)

BY JAN HJORT (UNIVERSITY OF OULU, FINLAND) AND MISKA LUOTO (UNIVERSITY OF HELSINKI, FINLAND)

Professor Emeritus Matti Seppälä (University of Helsinki) passed away unexpectedly on November 24, 2020. He was a renowned researcher and teacher of periglacial geomorphology. Internationally, he will be remembered as 'Professor Palsa' because of his seminal palsa studies in Northern Fennoscandia. Aeolian processes were also close to his heart. He studied Geography at the University of Turku, earning his PhD in 1971. He had a long, colourful and productive academic career at several Finnish research institutes. He was Finland's long-standing national representative for the IPA. Matti felt at home outdoors, acquiring field experience through numerous activities in Europe, North and South America, and Antarctica.

In his own words, he 'swam in a thaw lake of a pingo', and 'slept in a snow pit under the stars in the Antarctic'. He enjoyed nature with every fibre of his being, especially in Finnish Lapland. He often took students into the field in remote regions and visiting scholars were inevitably taken on a field excursion to Lapland from which co-operative research projects often followed. Matti was a true conversationalist and took part in debates in the media and in peer-reviewed journals. In addition to his opinion pieces, many of his students and Finnish colleagues will remember his loud singing.

Undoubtedly, Matti's achievements in periglacial geomorphology will echo long into the future. Matti Seppälä was a man of integrity. For us, friends and colleagues of Matti, the world is now more monotonous and mundane than before.

Seppälä, M. (2003). An experimental climate change study of the effect of increasing snow cover on active layer formation of a palsa, Finnish Lapland. *Proceedings, 8th International Conference on Permafrost*, Zurich, Switzerland. Balkema: Lisse; Vol. 2, 1013-1016.

IN MEMORIAM

Alan E. Taylor

(1941-2020)

BY SCOTT DALLIMORE (GEOLOGICAL SURVEY OF CANADA)

With sadness we record the passing of our friend and colleague Alan Taylor on July 30th, 2020. Al had a long career in both Ottawa and Sidney, BC, with the Earth Physics Branch of Energy, Mines and Resources, Canada and the Permafrost Section of the Geological Survey of Canada. Al's training was in physics, but he worked as a geoscientist and became a registered professional engineer late in his career. His speciality was geothermics as applied to many aspects of permafrost science.

He was involved in developing new techniques to measure ground temperatures in abandoned exploration wells and determined the geothermal and geophysical properties of permafrost throughout the Canadian Arctic. He recognised that records of environmental change could be interpreted from analysis of in situ ground temperatures, particularly on the response of permafrost to past sea level change and ice cover.

He played critical roles in the GSC's gas hydrate research program contributing substantially to complex field programs in 1998, 2002, 2007 and 2008, and was the lead engineer for Aurora Research Institute (ARI) when they acted as the designated operator for a successful gas hydrate testing program in 2008. After retirement he continued to work as a contractor for major Arctic projects. Al was a gentleman, always optimistic, generous, kind, and thoughtful. He encouraged many young students and stood out as a role model to many of us. He was an avid cyclist, be it a trip down the Galloping Goose trail to Victoria or following along the Rhine. Al was one of our best colleagues and we will miss him.

Taylor, A.E., Dallimore, S.R., Wright, J.F. (2008). Thermal impact of Holocene lakes on a permafrost landscape, Mackenzie Delta, Canada. Proceedings, *9th International Conference on Permafrost*. University of Alaska Fairbanks: Fairbanks, AK; Vol. 2: 1757-1762.

NEW IPA WEBSITE

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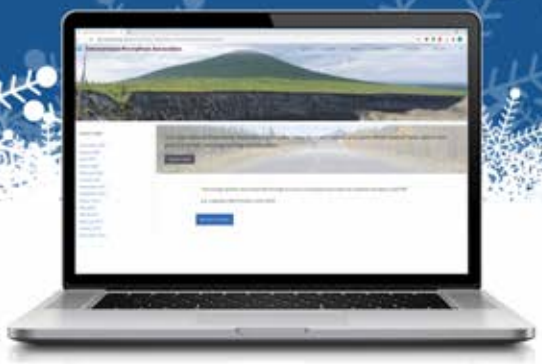

- Updated content
- Access to IPA publications
- Easier navigation
- News & event updates

www.permafrost.org

Congratulations!

PHOTO CONTEST WINNERS

In January 2021 the IPA launched a photo contest for the best shots of permafrost landscapes and research activities to be included on the new website. Following tremendous participation we are pleased to announce the winners:

1st Place (€100): *Francesco Malfasi* (frost hummocks along the south coast of Saunders Island, Falkland Islands, February 2017).

Runners-up (€50 ea): *David Olefeldt* (rapidly expanding thermokarst wetlands within a peatland complex, near Wrigley, NWT, Canada, May 2019) and *Ludwig Jardillier* (thawing of permafrost from a burst pipe, Yakutia, Republic of Sakha, Siberia, August 2019).

David Olefeldt - RUNNER-UP

Francesco Malfasi - WINNER

Ludwig Jardillier - RUNNER-UP

IN APPRECIATION

Hanne Christiansen & Sarah Strand

IPA President & Executive Director (2016-2020)

BY CHRIS BURN (CARLETON UNIVERSITY, CANADA)

In June 2020, Prof. Dr. Hanne Christiansen completed her term as president of the IPA (2016-20), concluding a remarkable period of continuous service to the association over 22 years. Hanne was appointed as Executive Director in 1998, serving under presidents Hugh French and Jerry Brown, was elected to the executive committee at NICOP in Fairbanks (2008) and was simultaneously appointed Vice-President. She remained in post until she assumed the Presidency. Hanne's presidency was marked by expansion of IPA's conference activity with RCOPs in Japan, France, and New Zealand, and would, of course, have culminated at the ICOP in China except for the COVID-19 pandemic.

In association with her IPA responsibilities, Hanne has developed permafrost research and education at UNIS, so that her 6-week graduate course in late winter is heavily oversubscribed each year. Her research program in permafrost and periglacial geomorphology has included investigations in northeast Greenland, the Faroe Islands, and Svalbard. Her dedication to permafrost science will be especially remembered for her organization of the EUCOP in 2010 in Svalbard, with its very interesting and enjoyable field excursions.

Hanne has been ably and kindly assisted by Sarah Strand as Executive Director. Sarah has been particularly influential in facilitating financial arrangements and organization for the Association. The IPA is grateful to them both for their dedication and service to our Association and we wish them the very best for the future.

Former IPA President, Hanne Christiansen (left), and Executive Director, Sarah Strand (right), both from UNIS.

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