NSERC
CRSNG

Project Summaries

2019-2024

NSERC PermafrostNet

www.permafrostnet.ca

Message from the Scientific Director

Permafrost underlies 35–50% of the Canadian land surface and is a defining characteristic of Canada's North. Most of the permafrost region will experience persistent loss of ground ice through the 21st century, leading to irreversible landscape transformations, profound challenges for infrastructure, and threats to the health and livelihoods of northerners.

NSERC PermafrostNet was created to help Canada prepare for permafrost change by transforming permafrost science, aligning it with decision-making, and developing solutions for adaptation. We achieve this through training the next generation of permafrost experts, building connections between researchers and stakeholders, and rapidly translating knowledge into action.

Over 40 students and postdoctoral fellows have been working across five research themes to quantify, understand and predict permafrost thaw and its consequences. As a result, the network has made significant advances in areas like data interoperability, numerical modelling, remote sensing, and designing practical solutions to adapt infrastructure and communities.

The network developed partnerships with over 40 organizations, including all levels of government, industry, Indigenous groups, and international collaborators. These connections ensure this research addresses real-world needs and that new knowledge can be rapidly implemented.

As we conclude the mandate of the network, I am confident NSERC PermafrostNet has delivered innovative science and the highly qualified personnel that Canada requires to tackle the impacts of thawing permafrost. We aim to leave a legacy where permafrost science has the resources, coordination, and partners needed to support adaptation and sustainable development across the North.

Dr. Stephan Gruber, Scientific Director

The network

NSERC PermafrostNet is a six-year strategic partnership network supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) that started in June 2019.

The network involves:

- 12 Canadian universities
- Over 40 partner organizations
- Over 40 students, Northern research assistants and postdoctoral fellows

The network takes a collaborative approach to permafrost research and training, bringing together expertise from multiple disciplines to work closely with stakeholders. This integration of research, training and partnerships has delivered knowledge, data, and tools to support adaptation to permafrost thaw across Northern Canada.

The network is hosted by Carleton University and is overseen, advised and managed by a number of governing bodies and individuals, including a Board of Directors, a Scientific committee, Knowledge Mobilization and Communication committee, and Equity, Diversity and Inclusion committee.

The network research focused on the big questions: Where and when is permafrost thaw occurring in Canada and what are the hazards arising from such change? To achieve this the research was organized into five interwoven themes requiring a critical mass and diversity of expertise that no single research group or government agency has. The network was a multidisciplinary arrangement of complementary expertise that works together with three aims; to quantify, understand and predict permafrost thaw and its consequences; to connect spatial scales from individual sites up to Earth-system modeling; and to prototype reliable and useful data and knowledge products for scientific research, engineering and application in government, communities, and industry. The research conducted by the network has been laying the foundation for advances in permafrost science and engineering practice across diverse topics such as data interoperability, numerical modelling and prediction, and practical applications of scientific theories for adaptation to permafrost thaw.

Over 40 partner organizations have supported this networked permafrost research with direct contributions of $X,XXX,XXX, and in-kind contributions to research activities totalling $X,XXX,XXX.

Partners include:

- Federal, provincial, and territorial agencies
- Standards organizations
- Industry
- Indigenous governments and organizations
- Research networks
- International collaborators

Building a permafrost knowledge partnership

It is clear that a single research group, government agency or industry cannot tackle the challenges presented by widespread and persistent thaw of permafrost alone. The establishment of a pan-Canadian network in 2019 has helped consolidate science, local knowledge and learning, and professional practice so that it provides relevant information at regional and national scales to wider audiences.

A number of workshops and projects led up to a seminal workshop in February 2017. This event looked at how the range of stakeholders concerned can work together to address the big challenges and opportunities in the permafrost community. The workshop was based on a preparation survey, cross-checked with previous permafrost workshops in Canada, that highlighted eight focus areas for discussion and action.

A diverse community of almost 60 individuals met at Carleton University, representing Federal, Yukon, Northwest Territories and Nunavut Governments, researchers from Canadian universities, and the private sector. The workshop objectives were to gain a shared understanding of what a Canadian permafrost network would work towards and to provide opportunities for people to network and build relationships. We wanted to find out what was needed to add value – rather than adding control. Through moderated discussions, the workshop provided concrete outcomes on the development of a permafrost network for Canada.

The network came up with an initial purpose, "*To advance knowledge about changing permafrost environments*". To address the broad membership and geographic distance, it was proposed that there should be a Secretariat in the Ottawa Region, likely at Carleton University, in addition to strong presence in the territories. At a minimum, the workshop participants felt that the network needed diverse membership, a director and/or paid coordinator, a website, a clear vision to help grow the network and to link with other organizations. Beyond these baseline activities, attendees envisioned the network having a multifaceted presence, including lobbying, providing education and outreach and data storage/sharing services.

Networked research

The network takes an integrated approach across five research themes:

- Theme 1: Characterization of permafrost
- Theme 2: Monitoring permafrost change
- Theme 3: Prediction of permafrost characteristics and change
- Theme 4: Hazards and impacts of permafrost thaw
- Theme 5: Adaptation to permafrost thaw

NSERC PermafrostNet's research themes collaboratively work to achieve three overarching objectives: i) quantify, understand, and predict permafrost thaw and its consequences; ii) connect spatial scales from individual sites to national-scale prediction and assessment and from field measurements to satellite-based remote sensing and Earth-system modeling; and iii) prototype reliable and useful data and knowledge products for stakeholders and develop relevant next practices with them. Research mobilization and training of students/postdocs is woven throughout these themes to maximize impact. Partnership is key to ensure outputs are useful and used.

The network intends to leave a legacy where permafrost research has the resources, coordination, and connections to support evidence-based decisions into the future.

Theme 1: Characterization of permafrost

Objective: Improve understanding of ground ice and properties to better represent thaw processes and provide inputs to predictive modelling.
Approach: Development of national ground ice and permafrost databases; novel geophysical techniques; analysis of permafrost cores.

Outcomes:
- Permafrost Information Network of Ground Observations (PINGO) collates borehole and related data to characterize permafrost and ground ice distribution. This enables better spatial analysis and model inputs.
- New databases compile information from electrical resistivity and permafrost core analysis. These datasets aid interpretation and tracking of permafrost change over time.
- Advanced core scanning provides improved quantification of ground ice content and properties.
- Studies of vulnerable landforms like peat plateaus and thaw slumps add to knowledge of how terrain responds to thawing.

Next challenges: Expand databases across Canada's diverse regions and permafrost types; integrate new characterization data to improve prediction of terrain sensitivity.

Theme 2: Monitoring of permafrost change

Objective: Detect and quantify changes occurring across the landscape by combining field measurements with remote sensing.
Approach: Borehole monitoring; novel remote sensing with satellite, drone, and airborne data; incorporation of Indigenous knowledge.

Outcomes:
- New methods developed to process and interpret remote sensing data over permafrost areas.
- Borehole databases integrated into online platforms for data analysis and model validation.
- Case studies reveal local impacts, like extensive ponding, and landscape-scale changes detectable from space.
- Outreach establishes community priorities to guide research.

Next challenges: Expanding monitoring networks to fill spatial gaps; regular acquisition and processing of remote sensing data; responding to community needs.

Theme 3: Prediction of permafrost change

Objective: Improve accuracy of models projecting future conditions and develop climate services to deliver predictions.
Approach: New model development and evaluation methods; large ensemble simulations; focus on translating outputs for decisions.

Outcomes:
- More comprehensive representation of key processes, like excess ground ice thaw and vegetation shifts.
- New testing approaches quantify model uncertainty and guide improvement.
- Climate services prototype provides information on future ground thermal regime tailored for infrastructure design.
- Software tools created to run large model ensembles on supercomputers and process results.

Next challenges: Incorporate expanded monitoring data into models; ensemble simulations across broader regions; co-development of climate services with users.

Theme 4: Hazards and impacts associated with permafrost thaw

Objective: Advance understanding of hazards arising from thaw to improve risk assessment and adaptation.
Approach: Field studies, remote sensing monitoring, modelling of vulnerable terrain; focus on implications for infrastructure and water quality.

Outcomes:
- New insights into erosion of riverbanks, coastlines, and other landscapes vulnerable to thawing.
- Better quantification of impacts on infrastructure like roads and rail embankments.
- Advances in remote sensing to monitor hazard evolution and model future risk areas.
- Initial assessments of thaw effects on mercury mobilization and hydrochemistry.

Next challenges: Incorporating findings into hazard maps/models; predicting interactions and cascading effects; monitoring change over larger regions.

Theme 5: Adaptation to permafrost thaw

Objective: Develop knowledge to support adaptation of infrastructure and communities affected by changing permafrost.

Approach: Site investigations of infrastructure performance; projections of maintenance costs; engagement with communities.

Outcomes:
- Evaluation of techniques like thermosyphons and snow compaction to stabilize infrastructure foundations.
- Regional analysis highlights increased maintenance costs associated with permafrost thaw.
- Implementation of solutions like geocells to reinforce rail embankments prone to thaw settlement.
- Community partnerships guide research priorities regarding landscape change and water quality.

Next challenges: Expanding analysis of adaptation options across infrastructure types and climates; cost-benefit analysis of solutions; responding to community adaptation needs.

Data for permafrost

Data is an important element in permafrost research. The network has prototyped reliable and useful data and knowledge products for stakeholders and integrate field data with simulation. This has been achieved through the shared use of network resources including a platform for permafrost data science and simulation.

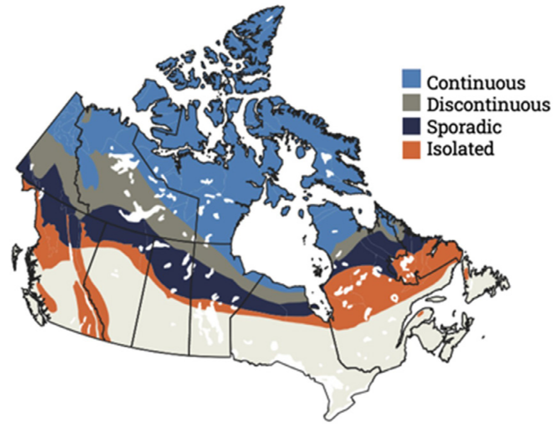
Data Interoperability

Using standards for your permafrost data when sharing or publishing it is one of the ways to make your data more discoverable and reusable by others.

Participants at the 2020 Permafrost Data Workshop identified access to standardized data and the discoverability of existing data as two of their main data-related challenges. NSERC PermafrostNet's subsequently created recommendations for sharing and publishing permafrost data.

Here we focus on ground temperature data and geotechnical measurements. These recommendations will promote data interoperability within the network and the broader community.

Establishing a Canadian database of geoelectrical surveys of permafrost.



Teddi Herring, Antoni G. Lewkowicz, University of Ottawa

Keywords: Geophysics, electrical resistivity tomography, database, monitoring, climate change.

Study locations: Canada-wide

The main outcome of this project is a database of electrical resistivity tomography (ERT) surveys of permafrost in Canada. These geophysical surveys are often used to characterize permafrost extent and conditions, but until now there has been no framework for data sharing. We created the Canadian Permafrost Electrical Resistivity (CPERS) database to archive surveys in a standardized way. The database enables researchers, practitioners, and community members to easily share and access data, improving our collective understanding of permafrost conditions and how they are changing over time.

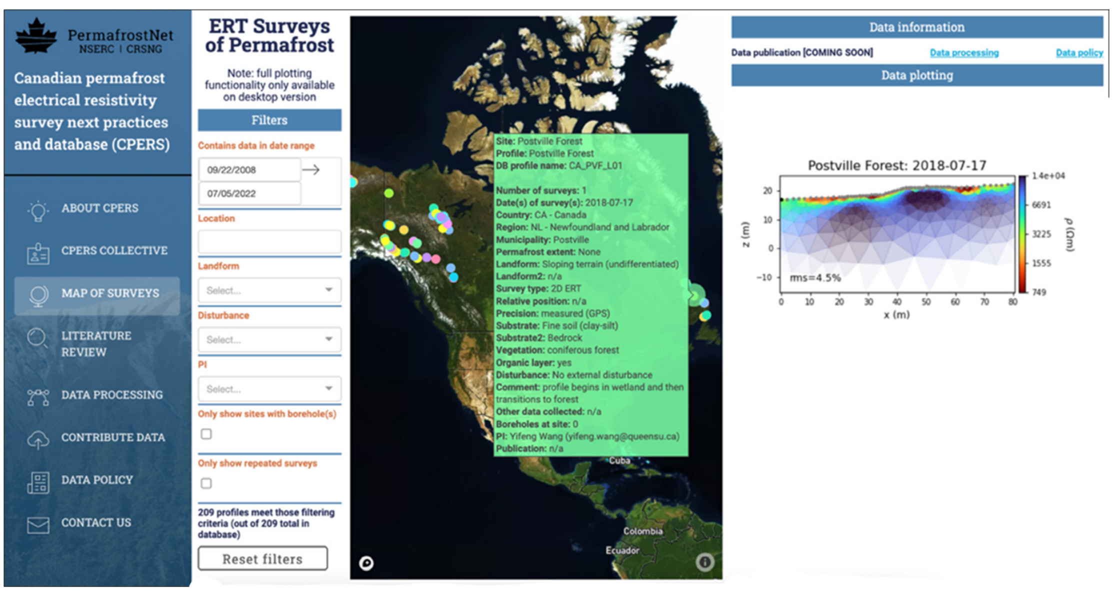


Figure 1. The CPERS website allows users to easily query and visualize ERT surveys of permafrost collected across Canada.

Research summary

Electrical resistivity tomography (ERT) surveys are commonly used to characterize permafrost, but historically, data sharing has been limited. We created and populated the Canadian Permafrost Electrical Resistivity (CPERS), published the data in an established repository to ensure long-term accessibility (CPERS Collective, 2023), and wrote a data paper to promote this resource (Herring et al., n.d.). We also created an interactive web map so data can easily be queried and plotted

PermafrostNet
NSERC | CRSNG

(https://data.permafrostnet.ca/cpers/). Researchers from the University of Ottawa, Queen's University, and the University of Alberta have already provided data for 280 ERT surveys collected between 2008 and 2022 in British Columbia, Labrador, Northwest Territories, Quebec, Yukon Territory, and Alaska. We used the initial data contributions to make large-scale interpretations of how permafrost conditions across Canada are influenced by mean annual air temperature, landform type, near-surface substrate, and surface disturbance (Herring et al., 2024). We also published a paper describing best practices for ERT surveying of permafrost (Herring et al., 2023) to provide guidance for ERT data acquisition, processing, and interpretation.

Taking action

Data is essential for characterizing permafrost environments and making informed decisions about mitigating and adapting to permafrost thaw. If you would like to contribute data to the CPERS database or learn more about the project, please visit https://data.permafrostnet.ca/cpers/.

Connections to other projects

1 2 This project is directly relevant to **Theme 1** (characterization of permafrost) and **Theme 2** (monitoring of permafrost change).

Partners, team members and support

We gratefully acknowledge Robert Way, Yifeng Wang, Alexandre Chiasson, Joseph Young, and Duane Froese for their data contributions, as well as the data collectors and field assistants, who are too numerous to list here. We thank Nick Brown for the IT support, Etienne Godin for assisting with the Nordicana D data publication, and the Digital Research Alliance of Canada for the digital resources. Greg Oldenborger, Fabrice Calmels, and Anne-Marie Leblanc provided guidance on this project. We thank members of the International Permafrost Association action group "Towards an International Database of Geoelectrical Surveys on Permafrost (IDGSP)" who collectively developed the metadata form and database structure used for this project.

Acknowledgment, thanks and funding

We gratefully acknowledge the Inuit of Nunatsiavut, Labrador, the Sahtu Dene and Métis of the central Mackenzie valley, Teslin Tlingit Council, Kluane First Nation, White River First Nation, Nacho Nyak Dun First Nation, Kaska Dena First Nation, Tr'ondek Hwëch'in First Nation, Vuntut Gwitchin First Nation, the Nunatsiavut Government, Nunatsiavut Research Centre, NunatuKavut Community Council, and communities of Fort Good Hope, Norman Wells, and Tulita. This work was supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) and NSERC PermafrostNet.

References

CPERS Collective. (2023). *The Canadian permafrost electrical resistivity survey database (CPERS) Version 1.0*. Nordicana D. https://doi.org/10.5885/45855XD-DC9883ABD609428B

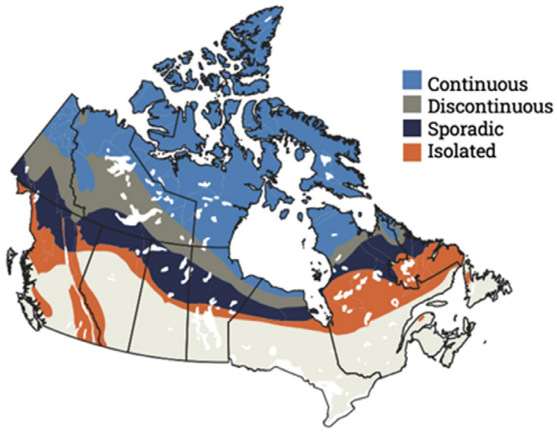
Herring, T., Lewkowicz, A. G., Chiasson, A., Wang, Y., Way, R. G., Young, J. M., Froese, D., Andersen, B., Bellehumeur-Génier, O., Bevington, A. R., Bonnaventure, P. P., Duguay, M. A., Etzelmüller, B., Gooseff, M. N., Godsey, S. E., Miceli, C. M., & Smith, S. L. (n.d.). The Canadian Permafrost Electrical Resistivity Survey Database (CPERS): 15 years of permafrost resistivity data [Manuscript in preparation]. *Arctic Science.*

Herring, T., Lewkowicz, A. G., Way, R. G., Wang, Y., Chiasson, A., & Froese, D. (2024). Large-scale assessment of permafrost conditions using the Canadian Permafrost Electrical Resistivity Survey (CPERS) database [Maniscript submitted to ICOP 2024]. *International Conference on Permafrost.*

Herring, T., Lewkowicz, A., Hauck, C., Hilbich, C., Mollaret, C., Oldenborger, G. A., Uhlemann, S., Farzamian, M., Calmels, F., & Scandroglio, R. (2023). Best practices for using electrical resistivity tomography to investigate permafrost [Manuscript accepted for publication]. *Permafrost and Periglacial Processes.*

PermafrostNet
NSERC | CRSNG

Mapping and understanding how ice conditions change in thermokarst lakes over multiple decades.



Maria Shaposhnikova1, Claude Duguay[1] and Pascale Roy-Léveillée[2].
1. University of Waterloo 2. Université Laval

Study locations: Old Crow Flats, northern Yukon.

Keywords: Lake ice, thermokarst lake, lake drainage, satellite, remote sensing, machine learning, neural network.

This research produces maps from a machine-learning algorithm that shows where the ice in shallow lakes is frozen to the bed (bedfast ice) and where it is not (floating ice). The differences in ice conditions impact the stability or thaw of permafrost. The maps can be generated going back 30 years and reveal how fast and where changes are happening. Having such maps helps us understand why changes in environments such as the Old Crow Flats occur and predict how they might continue in the future. The maps can inform local knowledge holders and scientists on how observations at differing locations may be related.

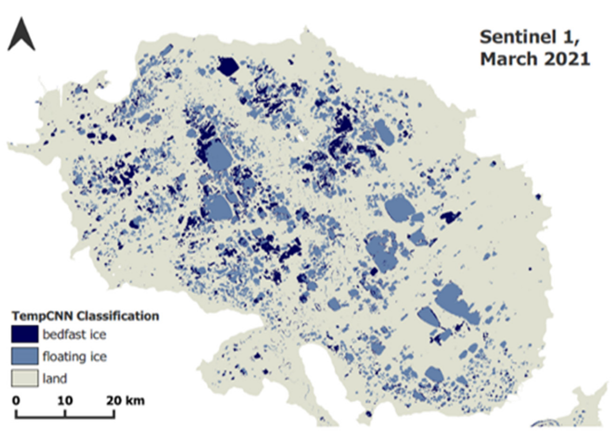


Figure 1 shows a map produced from a machine learning algorithm using a Synthetic Aperture Radar (SAR) image taken by the Sentinel 1 satellite in March 2021. The algorithm has classified the surface as either land, floating ice or bedfast ice. Maps have been produced from 1993 to 2021 and the machine learning algorithm can be applied in other permafrost regions.

Research summary

Lake ice changes in response to climate change. Many shallow Arctic lakes and ponds freeze to bed in the winter months, maintaining the underlying permafrost. As climate changes, fewer lakes are expected to develop bedfast ice, and this can accelerate permafrost thaw. To understand this, we need to know where the ice is bedfast, where it floats, and how these patterns change over time. This research has developed a method for making such maps based on satellite radar images. It produced maps for the Old Crow Flats from 1993 to 2021 that aligned well with field measurements and the Canadian Lake Ice Model. The maps show that the area covered by bedfast ice has increased over the 29 years, which is tentatively attributed to the catastrophic drainage of some lakes, lowered water levels, and a reduction in snowfall in the region.

PermafrostNet
NSERC | CRSNG

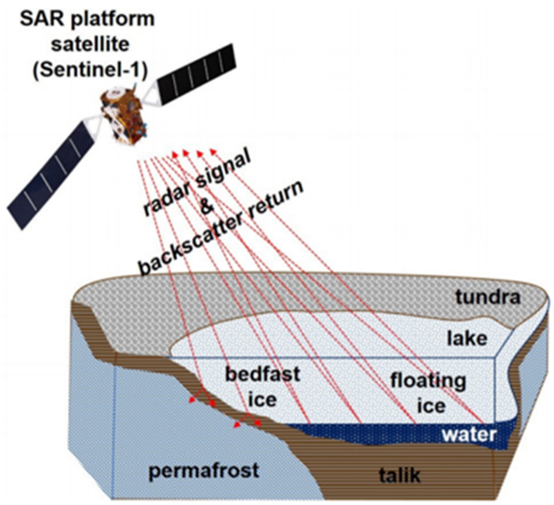


Figure 2 shows the components of tundra and lake landscapes and how a Synthetic Aperture Radar (SAR) satellite can detect the difference between land, floating ice and bedfast ice.

Taking action

he next step for these findings that researchers could follow up on is the simulation of the development of lowland thermokarst. Accurate maps of bedfast ice and lake extent allow for the tracking of lake drainages and early identification of catastrophic drainages and thermokarst events and processes, which scientists can use to predict future changes and also for the local community to employ mitigation and adaptation measures.

Connections to other projects

4 This project links to theme 4 projects also being conducted in Old Crow Flats by Danielle Chiasson, looking at permafrost recovery in drained lakes and ponds, and Nicole Corbiere, looking at mercury and methylmercury concentrations in drained basin complexes in Old Crow Flats, Yukon, Canada.

Regional synthesis

This work provides a strong baseline for future thermokarst lake ice dynamics analysis in the Old Crow Flats and beyond, as thermokarst lowlands cover approximately 20% of the northern permafrost regions and contain significant stores of soil organic carbon.

Documenting transitions between bedfast and floating ice is crucial to understanding permafrost dynamics beneath shallow lakes and drained lake basins, with potential impacts on methane ebullition and the regional carbon balance, in addition to affecting the livelihood of the local community (e.g. fishing, trapping, travelling).

Partners, team members and support

This research benefited from support from Nina Vogt, Louis-Philippe Roy, Caleb Charlie, and Cathy Koot (Yukon University), who collected field data in April 2021, Kevin Turner (Brock University), who provided a vegetation map of Old Crow Flats, and Nastaran Saberi (University of Waterloo) who provided technical support throughout the project.

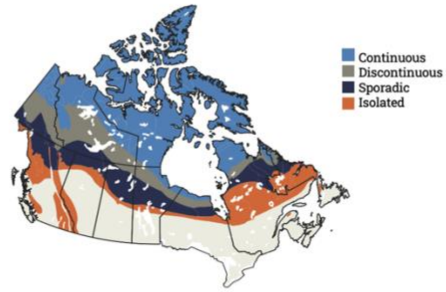
Acknowledgment, thanks and funding

This project recognizes Old Crow Flats as the traditional territory of the Vuntut Gwitchin First Nation and Aklavik First Nation and the Vuntut Gwitchin First Nation land claim agreement. The Old Crow Flats include Vuntut National Park, the Vuntut Gwitchin Category A Settlement Lands, and Special Management Area lands. Thanks go to the Vuntut Gwitchin First Nation and Yukon Government. This work was supported by the Natural Sciences and Engineering Research Council (NSERC) Alexander Graham Bell Canada Graduate Scholarship and NSERC PermafrostNet.

References

Shaposhnikova, M. (2021). Temporal Deep Learning Approach to Bedfast and Floating Thermokarst Lake Ice Mapping using SAR imagery: Old Crow Flats, Yukon, Canada. UWSpace. http://hdl.handle.net/10012/17414

Shaposhnikova, M., Duguay, C., and Roy-Léveillée, P. (2023). Bedfast and floating-ice dynamics of thermokarst lakes using a temporal deep-learning mapping approach: case study of the Old Crow Flats, Yukon, Canada. The Cryosphere, 17, 1697–1721, https://doi.org/10.5194/tc-17-1697-2023.



Fate of carbon in Canadian permafrost-affected soils

Charles Gauthier[1], Joe Melton[2], Oliver Sonnentag[1].
[1]*Université de Montréal,* [2]*Environment and Climate Change Canada*

Keywords: Carbon CLASSIC, permafrost, climate model

Study locations: Global, 20 sites

This research has shown us the importance of considering both the quantity of carbon in soils as well as the flux of carbon out of soils when modelling the response of soil carbon to climate change, especially in permafrost soils. This is important because many efforts made to improve models only consider the amount of carbon in soils while paying little attention to fluxes. For example, this research showed that considering fluxes when improving climate models can greatly help narrow down the errors.

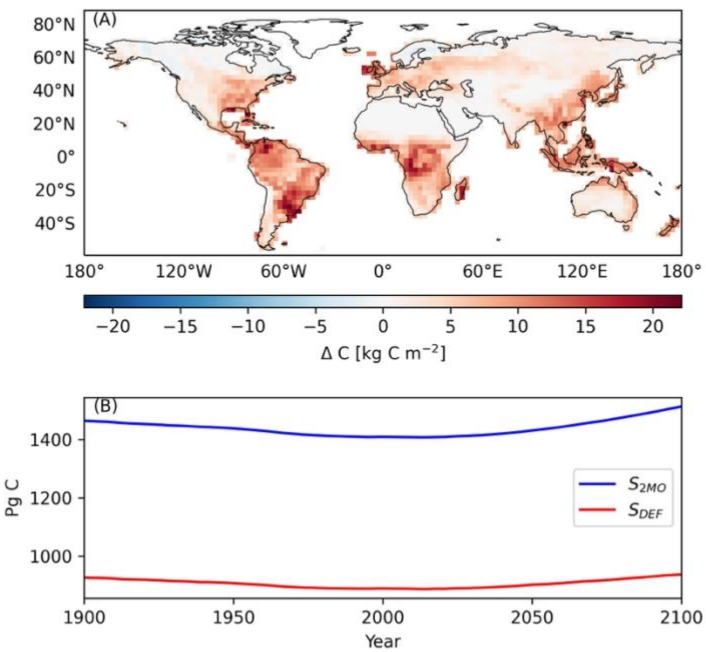


Figure 1. (A) Difference in simulated soil carbon at the end of the century (2100) between CLASSIC using its default parameter values (S_{DEF}) and our optimized parameters (S_{2MO}). (B) Historical and future simulation of global soil carbon stock using the S_{DEF} and S_{2MO} parameter sets. The figure indicates that with the new optimized parameters, CLASSIC predicts an increase of soil carbon globally, with less carbon in high latitude than the default parameterization predicts.

Research summary

Terrestrial biosphere models (TBMs) that are used to simulate the fate of soil organic carbon under climate change contain uncertainty due to poorly constrained parameters. Parameters related to soil carbon are impossible to measure in the field due to the scales at which they operate. Therefore, their value has to be assigned arbitrarily. In this research, we optimized the soil carbon parameters of CLASSIC. To do so, we used a global sensitivity analysis and a Bayesian optimisation framework that used bulk soil carbon data as well as soil respiration data. We were able to generate a parameter set that improved CLASSIC's simulation of high-latitude soil organic carbon and soil respiration. Our results provide the modeling community with an improved soil carbon scheme that can more adequately represent soil carbon dynamics. From those improved parameters, modelers will be able to make better predictions about the fate of soil carbon under climate change.

Taking action

Models such as CLASSIC are crucial tools to deepen our understanding of permafrost thaw and therefore have the potential to play a major role in addressing the issues caused by thawing permafrost. Firstly, permafrost related processes should be included in soil carbon schemes of terrestrial biosphere models. Then, to improve those processes, a wider variety of data should be collected to offer parameter optimization efforts more ways to constrain parameters. Data such as isotopic carbon concentration in soil which are poorly represented in permafrost soil could be part of next data collection campaigns.

Connections to other projects

3

This project received advice and feedback from all members of PermafrostNet theme 3. Additional discussions were held with members of other themes through joint meetings where we had the chance to present and discuss our projects.

Partners, team members and support

This project was supported by NSERC PermafrostNet and by Université de Montréal. Gesa Meyer from ECCC provided useful and critical help in performing the simulations with CLASSIC.

Acknowledgment, thanks and funding

The vast majority of this project was conceived and produced at Université de Montréal which is located on the traditional territory of the Kanien’kehà:ka in Tiohtiá:ke/Montreal. This territory as long been a place of exchange between several First Nations including the Kanien’kehá:ka of the Haudenosaunee Confederacy, Huron/Wendat, Abenaki, and Anishinaabeg. We recognize and respect the Kanien’kehà:ka as the traditional custodians of the lands and waters of this territory. This work was supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) and NSERC PermafrostNet.

References

Science Borealis Blog article, produced as part of pitch and polish:
https://blog.scienceborealis.ca/why-frozen-mud-is-a-technical-challenge-for-climate-scientists/

A scientific publication is currently in the works and should be submitted to the Journal of Advances in Modeling Earth Systems before the end of the year 2023 for publication in 2024.