REPORTS FROM THE ADHERING BODIES OF THE INTERNATIONAL PERMAFROST ASSOCIATION

Country Reports

2022-2023

secretariat@permafrost.org
www.permafrost.org

To cite this report:

Stockton, E.J., and Burn, C.R. (eds.) 2024. *Country Reports 2022-2023: Reports from the Adhering Bodies of the International Permafrost Association*. International Permafrost Association (IPA). DOI: 10.52381/CR.2022-2023.1

TABLE OF CONTENTS

Note:

In 2023, the IPA Council voted to pause membership of Russia in the International Permafrost Association. This decision was taken following the invasion of Ukraine by forces of the Russian Federation. The decision will be examined regularly until such time as it is possible for a majority of adhering bodies to conduct activities with agencies of the Russian state. Hence, there is no report from Russia in this issue of *Country Reports*.

ARGENTINA and Chile

BY DARIO TROMBOTTO LIAUDAT (IANIGLA-CRICYT-CONICET) AND SEBASTIÁN RUIZ (PONTIFICIA UNIVERSIDAD CATÓLICA DE CHILE)

In March 2022, the Geocryology group of Mendoza organized a Special Session on Cryosphere Sciences at the XXI Argentine Geological Congress, Puerto Madryn, Patagonia.

In 2022-2023, Dario Trombotto Liaudat taught courses on South American Gecryology at the Faculty of Mathematics, Astronomy and Physics (FAMAF), National University of Córdoba. It was possible to achieve two credits for doctoral students in Physics and Geosciences. In 2023, a link with a Mini Ulpan course on Geocryology, a plenary session, *"Cryosphere in Crisis: The Fragile Balance of Our Planet"* was organized at the National University of Córdoba. Dario Trombotto Liaudat was appointed Guest Professor. At FAMAF, periglacial ice studies of the Andes Mountains are carried out with the research group of Dr. Carlos Di Prinzio.

In 2023, Dario Trombotto Liaudat and Prof. Lothar Schrott (University of Bonn, Germany) led an excursion to the rock glaciers in Cordón del Plata, Mendoza. It is part of a collaboration between Argentina and Germany within the framework of the international project, *Spatial occurrence and hydrological significance of Andean permafrost, Agua Negra, Argentina (HyPerm)*. Professors and 26 students from Germany, France, Brazil, Czech Republic, Luxembourg, and Argentina participated (Fig. 1).

In 2023, the Geocryology unit (Carla Tapia Baldis, Dario Trombotto Liaudat) joined the international *PERMOLARDS* project with Prof. Susan Conway (University of Nantes, France) and Dr. Costanza Morino (Laboratoire EDYTEM, Université Savoie Mont Blanc, Le Bourget du Lac cedex , France). Field work in the

Fig. 1. Excursion to the rock glaciers in Cordón del Plata.

Fig. 2. Pachón Valley, San Juan, Argentina. Photo: Silvio Pastore.

Andes of San Juan was conducted on degraded permafrost (molards) and catastrophic phenomena.

Detailed geophysical studies on a rock glacier in the valley of Pachón, San Juan, Argentina were carried out. This fieldwork is part of the *Proposal for comprehensive management of the water resource in the arid region applying new technologies: pilot experiences in the San Juan river basin* project led by Silvio Pastore (Universidad Nacional of San Juan, Argentina) (Fig. 2).

At the 2022 Chilean Cryosphere Society meeting (SOCHICRI), BGC engineering presented permafrost distribution maps. The University of Atacama and GEOESTUDIOS presented work on rock weathering implications on the Antarctic Peninsula, and planetary analogs in the Puna de Atacama (27°S).

- Ruiz-Pereira, S., *et al.* (2022). Assessment of physical weathering in bedrock areas at the Trinity Peninsula, Antarctica: Towards a classification of the current weathering grade in polar areas. *Journal of South American Earth Sciences*, 118. DOI: 10.1016/j.jsames.2022.103913.
- Schlarmann, L., *et al.* (2022). High altitude campaign in the Puna de Atacama: a Mars analogue environment. *44th COSPAR Scientific Assembly*, 16-24 July 2022 (Online). B4.2-0044-22.

The Hydrogeology and Glaciology groups of El Centro de Estudios Avanzados en Zonas Áridas (CEAZA) (La Serena, Chile) analyzed the geophysical signatures of rock glaciers in the Chilean Andes located at the headwaters of the Elqui River.

In December 2022, CEAZA (Shelley MacDonell) and University of Bergen held the *Summer school on*

cryospheric monitoring and water resources in the Chilean Andes in La Serena. It was supported by the Norwegian research school on changing climates in the coupled earth system (CHESS). The summer school focused on integrating close-range remote sensing techniques with Earth Observation Data for the study of glacial and periglacial environments, by collecting UAV-data and analysing new and old data on the Tapado Glacier (Fig. 3). The 11-day course included a poster session on previous studies, theoretical lectures, fieldwork on La Laguna catchment, post-processing analysis, and final presentations.

PermaChile+ network's expeditions throughout the Ojos del Salado massif retrieved over a decade of thermal datasets from sites 4,400-6,800 m asl, and collected preliminary data on permafrost thicknesses through geophysical surveys (Fig. 4). In 2022-2023, CEAZA (Nicole Schaffer and Shelley MacDonell) completed a glacier inventory for the La Laguna Basin (Elqui Province, Chile) using guidelines by IPA Action Group, *Rock Glaciers Inventories and Kinematics (RGIK)*. The inventory is being updated to align with the consensus version for the Central Andes of Argentina and will be reviewed by RGIK prior to publication. Nicole Schaffer took part in two exercises by RGIK to apply the developed guidelines for inventorying rock glaciers, including defining the activity status (movement) in the Brooks Range, AK, and Central Andes of Argentina.

At the 2023 SOCHICRI, a preliminary permafrost distribution map by order of the General Water Directory of Chile was presented. The map accounts for several borehole monitoring sites across different latitudes (24-52°S) in continental Chile.

At CEAZA and Universidad de La Serena, doctoral student Gonzalo Navarro continued to understand how the water transfer by glacier ice-debris assemblages relates to their internal structure. The study investigated the internal structure of the Tapado glacier complex, at northern Chilean Andes (30°S) by employing a combined approach using geophysics and UAV-based remote sensing. Fieldwork was conducted in ice-debris units (debris-covered glacier, rock glacier, and a moraine) using Electrical Resistivity Tomography, Ground Penetrating Radar, Refraction Seismic Tomography, and Uncrewed Aerial Vehicles. Overall, internal structural arrangement and composition was observed to affect water routing and storage on the explored ice-debris landforms and a potentially relevant hydrological role of the rock glacier is described based on its observed heterogeneous internal structure associated with enhanced vertical infiltration compared to the debris-covered glacier.

Fig. 3. Collecting geophysical data on the Tapado glacier complex. Photo: Gonzalo Navarro (February 2022).

Fig. 4. Retrieval of ground surface temperature data from the summit of Ojos del Salado (6,800 m asl).

- Navarro, G., *et al.* (2023). Internal structure and water routing of an ice-debris landform assemblage using multiple geophysical methods in the semiarid Andes. *Frontiers in Earth Science*, 11. DOI: 10.3389/feart.2023.1102620.

In the central Andes of Chile, research continued on hydrological connections of proglacial areas under favorable conditions for permafrost occurrence, with evidence showing sub-decadal dampening timeframes and insight on thawing origins of groundwater springs by means of metagenomic proxies.

- Pereira, S.R., *et al.* (2023). Hydrological connections in a glaciated Andean catchment under permafrost conditions (33°S). *Journal of Hydrology: Regional Studies*, 45. DOI: 10.1016/j.ejrh.2022.101311.

Chile is also involved in *PermaIntern* (see p.46). In 2023-2024, Sebastian Ruiz Pereira will supervise interns in glacier-permafrost environments, including PhD student, Viviána Jó, and MSc student, Levente Iván (Eötvös Loránd University, Hungary).

For more information contact Dario Trombotto Liaudat (dtrombot@mendoza-conicet.gob.ar).

AUSTRIA

BY ANDREAS KELLERER-PIRKLBAUER (UNIVERSITÄT GRAZ)

25-YEARS IPA-AUSTRIA (1998-2023)

2023 was a special anniversary year for Austrian permafrost research. During the 7th ICOP in Yellownife, NT, Canada in June 1998, Austria officially applied to become an IPA adhering body at the initiative of Gerhard Karl Lieb and Viktor Kaufmann (University of Graz). Daniel Vonder Mühll (Switzerland) made a motion nominating Austria for membership and Francesco Dramis (Italy) seconded the nomination (Fig. 5). The inclusion of Austria in the IPA was confirmed unanimously. In September 2023, a celebratory 25th anniversary symposium took place in Mallnitz, organised by Universität Graz and Hohe Tauern National Park. The aim was to honour the historic event and promote the exchange of expertise between colleagues in Austria currently working on geomorphological issues with a focus on permafrost or periglacial topics. About 35 participants from Austria, Italy, and Germany took part in the symposium, which consisted of lectures, posters, and an excursion to the Dösen valley with the famous Dösener rock glacier (Fig. 6). The program and the contributions are published in an anthology.

- Kellerer-Pirklbauer, A. (ed.) (2023). 25 Jahre International Permafrost Association (IPA)-Austria: 1998-2023. Book of Abstracts. Symposium; 27-29 September 2023, Mallnitz, National Park Hohe Tauern Kärnten.

NEW BOOK: PERIGLACIAL LANDSCAPES OF EUROPE

In 2022, a new book overviewing periglacial forms and processes in Europe was published. One chapter focuses on the European Alps. Around 20,000 years ago, 55% of the European Alps were glaciated, while the remaining area was covered by periglacial processes that led to the formation of remarkable landforms. In the course of the late glacial glacier ice vanishing, previously glaciated areas were changed by periglacial remodelling, resulting in the formation of rock glaciers or solifluction landscapes. Together with colleagues from France, Italy, and Switzerland, Andreas Kellerer-Pirklbauer authored a chapter on the periglacial landscapes of the Alps.

- Kellerer-Pirklbauer A., *et al.* (2022). European Alps. In: M., Oliva, D., Nývlt, J.M., Fernández-Fernández (eds). *Periglacial landscapes of Europe*. Springer. DOI: 10.1007/978-3-031-14895-8_9.

Fig. 5. Council Meeting at 7th ICOP in Yellowknife, NT, Canada in 1998. Daniel Vonder Mühll (Switzerland) made a motion nominating Austria for membership. Photo: Viktor Kaufmann.

Fig. 6. Celebrating 25 years of IPA Austria (1998-2023) in the Dösen valley. Photo: Andreas Kellerer-Pirklbauer.

2022 AK-PERMAFROST & PYRN DA-CH MEETING

From 24-26 November 2022, the Arbeitskreis Permafrost (AKPF) and Permafrost Young Researchers Network for Germany, Austria, and Switzerland (PYRN DA-CH) meeting took place in Kaprun, Austria. About 45 colleagues met at Kaprun castle, with views of the Hohe Tauern Mountain Range. The conference began with a PYRN networking meeting for early career scientists to discuss *"how to start a career in science during a pandemic"*. 17 talks and 10 posters from all career levels covered a range of locations across the globe and various methods and approaches (Fig. 7).

KRYOSPHERE MONITORING AUSTRIA

In 2022-2023, Kryosphären Monitoring Österreich (KryoMon.AT), funded by the Federal Ministry of Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK), was launched. The initiative aimed to (i) systematically present and make

Fig. 7. AKPF and PYRN DA-CH meeting at Kaprun castle, Austria, in November 2022. Photo: Georesearch, Austria.

accessible all long-term measurements related to changes in the Austrian cryosphere for stakeholders and, above all, the public, and (ii) foster closer collaboration within the research community, deliver a coordinated future presentation on monitoring results, and develop a strategy paper for long-term provision of periodic reports on the state of the Austrian cryosphere. An important component of KryoMon.AT was the Austrian permafrost monitoring network. A chapter in the first report examined temperature trends at Sonnblick and Kitzsteinhorn, and changes in movement rates of three rock glaciers (Äußeres Hochebenkar, Hinteres Langtalkar, Dösen) since the beginning of the measurements. The project involved numerous institutions, including the Universities of Graz, Innsbruck, Salzburg, and Krems, Graz University of Technology, the Austrian and Bavarian Academies of Sciences, GeoSphere Austria, Bluesky Wetteranalysen, GEORESEARCH, the Biologische Station Neusiedl and Hydrography Austria.

- Hansche, I., *et al.* (2023). KryoMon.AT - Kryosphären Monitoring Österreich 2021/22. Kryosphärenbericht Nr. 1, 204 S. DOI: 10.25364/402.2023.1.

GRAZ

In 2022-2023, Viktor Kaufmann (Graz University of Technology), supported by students and staff members continued to monitor four rock glaciers in the Hohe Tauern Range (Dösen, Hinteres Langtalkar, Leibnitzkopf and Tschadinhorn rock glaciers) using geodetic measurements. In 2022, UAV-based aerial surveys at the sites Leibnitzkopf and Tschadinhorn were carried out by masters student, S. Niksic. In 2023, the aerial surveys were repeated in close cooperation with the Institute of Geography and Regional Science, University of Graz. Results of the annual geodetic measurements can be found in:

- Kellerer-Pirklbauer, A., *et al.* (2024). Acceleration and interannual variability of creep rates in mountain permafrost landforms (Rock glacier velocities) in the European Alps over the time period 1995-2022 based on geodetic surveys: Climate factors versus site-specific effects. *Environmental Research Letters*, 19. DOI: 10.1088/1748-9326/ad25a4.
- Pellet, C., *et al.* (2022). Cryosphere - Rock glacier velocity. In: J., Blunden, T., Boyer (eds). *State of the Climate in 2021*. Bulletin of the American Meteorological Society, 103(8). DOI: 10.1175/2022BAMSStateoftheClimate.1.
- Pellet, C., *et al.* (2023). Cryosphere - Rock glacier velocity. In: J., Blunden, T., Boyer, E., Bartow-Gillies (eds). *State of the Climate in 2022*. *Bulletin of the American Meteorological Society*, 104(9). DOI: 10.1175/2023BAMSStateoftheClimate.1.

A general overview of rock glaciers in Austria with a focus on the Dösen rock glacier can be found in:

- Kellerer-Pirklbauer, A., Lieb, G.K., and Kaufmann, V. (2022). Rock Glaciers in the Austrian Alps – a general overview with a special focus on Dösen Rock Glacier, Hohe Tauern Range. In: C., Embleton-Hamann (ed.). *Landscapes and Landforms of Austria, World Geomorphological Landscapes*. Springer Nature. DOI: 10.1007/978-3-030-92815-5.

Permafrost-related research by the two working groups Cascade and GST at the Institute of Geography and Regional Science, University of Graz was carried out at eleven mountain regions in the Central Alps of Austria. In some study areas, research activities were accomplished in close collaboration with the Institute of Geodesy, Graz University of Technology, and Geosphere Austria (formerly Zentralanstalt für Meteorologie und Geodynamik, ZAMG).

In 2022-2023, permafrost monitoring in the Hohe Tauern Range was carried out within the framework of two long-term project initiatives (Permafrost monitoring in the Hohe Tauern National Park Carinthia, 2022-2024; and long-term monitoring of ecosystem processes in the Hohe Tauern National Park – Modul 07) coordinated by Andreas Kellerer-Pirklbauer with support from the Hohe Tauern National Park authorities in Carinthia and Tyrol. Both projects aim to gather long-term data on permafrost (temperature data series) and periglacial processes (rock glacier velocitiy data series, rockfall activities). About 100 ground temperature data loggers measuring surface and subsurface ground temperatures are operating in the eleven working areas.

Fieldwork and maintenance of the monitoring devices was accomplished at five active rock glacier sites (Dösen, Hinteres Langtalkar/Kögelekar, Leibnitzkopf, Weissenkar, and Tschadinhorn), one active rockfall site (Mittlerer and Hoher Burgstall, near Pasterze Glacier), four marginally permafrost sites (Hochtor area, Fallbichl area, Hintereggen valley, Hochreichart area), and one bedrock permafrost site (Innerer Knorrkogel). The effect of recent warming on permafrost and periglacial conditions was studied at one of these study sites (Hochtor) using ground temperature data (2010-2022), repeated electrical resistivity tomography measurements (2019, 2022) and auxiliary data dating back even to Roman times. A background for this study was that air temperatures in Europe in 2022 had been the highest on record for the meteorological summer season, at 1.3°C above the 1991-2020 average. Results of the study indicate the Hochtor site changed from an active to inactive permafrost site with a supra-permafrost talik.

- Kellerer-Pirklbauer, A. and Eulenstein, J. (2023). The summer heatwave in 2022 and its role in changing permafrost and periglacial conditions at a historic mountain pass in the Eastern Alps (Hochtor, Hohe Tauern Range, Austria). *Permafrost and Periglacial Processes*, 34(4). DOI: 10.1002/ppp.2205.

Long-term rock glacier velocity data were used for European-focused and globally-relevant publications. The seasonal behaviour of the rock glacier kinematics of the Dösen rock glacier were studied and numerically modelled in addition to the annual geodetic and photogrammetric rock glacier monitoring. First results were presented at the European Geosciences Union (EGU) General Assembly in 2023.

- Pfeffer, H., *et al.* (2023). Movement pattern analysis of the Dösen Rock Glacier (Hohe Tauern Range, Austria) using a multi-method approach. *EGU General Assembly 2023,* Vienna, Austria, 23-28 April 2023, EGU23-12685. DOI: 10.5194/egusphere-egu23-12685.

The Alpine Hydrogeology Group at the Institute of Earth Sciences, University of Graz, carried out research on hydraulics of thermokarst channel networks, their impact on permafrost degradation, heat transfer and solute transport in active rock glaciers, remote sensing techniques and physical process understanding of thermokarst lake development on rock glaciers. The *RG-AlpCatch* project, which focuses on rock glaciers as groundwater storages in alpine catchments and their impact on downstream river systems with regard to climate change, is in its final stages. At five high-alpine test sites along the main drainage divide of the Austrian Alps, the catchment responses of rock-glacier influenced springs and mountain streams were analysed through (semi-distributed) rainfall-runoff models. In addition, the future response of these alpine catchments was evaluated based on a set of climate projections for three representative concentration pathways (RCP2.6, RCP4.5, RCP8.5). The results quantify the elevation-dependent shifts in recharge and discharge dynamics, predominantly responding to the changing snow cover dynamics inferred from future climate scenarios. The modeling results were compared to a set of 722 stable isotope samples (snow, ice, rainfall, spring flow, and river flow) collected monthly during a two-year period, that complements the Austria-wide compilation of rock glacier spring isotope and water chemistry data compiled since 2016 through a series of high-alpine research projects.

The process of understanding water flow through active rock glaciers and its interaction with thermokarst channel development was improved. A case study in Hüttekar, Ötztal Alps, revealed that the evolution of these channel networks triggered the outburst of a 166,000 m³ thermokarst lake that subsequently initiated a 50,000 m³ debris flow at the rock glacier front.

- Seelig, S., *et al.* (2023). The role of thermokarst evolution in debris flow initiation (Hüttekar Rock Glacier, Austrian Alps). *Natural Hazards and Earth System Sciences*, 23. DOI: 10.5194/nhess-23-2547-2023.

INNSBRUCK

The Institute for Interdisciplinary Mountain Research (Austrian Academy of Sciences), and the Verein Gletscher und Klima continued and expanded their rock glacier monitoring programs. The long-term monitoring of surface displacement at Äußeres Hochebenkar rock glacier showed that the lower section of the rock glacier has accelerated again in 2022-2023 (up to 27 m per year) and continues to endanger the road below. Additionally, geological mapping and analyses of rock glacier runoff are being carried out in the Futschöl valley, Silvretta, and at the Lazaun rock glacier, Senales Valley, Italy in collaboration with the Universities of Bolzano and the University of Graz to determine how temperature, conductivity and chemical components differ between active, inactive, and relict rock glaciers. A publication about the hydrogeology of the Lazaun rock glacier is in review.

SALZBURG

In 2022-2023, borehole-based permafrost monitoring at the long-term research site, Open-Air-Lab Kitzsteinhorn (OpAL), Hohe Tauern Range, was expanded. Monitoring is operated by GEORESEARCH. In 2022, three deep boreholes (20-40 m) were drilled and equipped with inclinometers and thermistors to measure deformation and temperature in the permafrost-affected bedrock (Fig. 8). In 2023, five deep boreholes (15-30 m) were instrumented with piezometers and thermistors to monitor pore-water pressure. Temperature measurements show a continued warming trend in 2016-2023 that is more pronounced in near-surface regions (+0.1 °C per year) than at depth (+0.04 °C per year).

VIENNA & KORNEUBURG

Permafrost research activities by GeoSphere Austria are concentrated in the central Hohe Tauern Range with the Hoher Sonnblick area (summit area and adjacent slopes), the Pasterze Glacier area (rockfall monitoring), and the northern Schober Mountains (rock glacier monitoring).

Long-term permafrost monitoring at Hoher Sonnblick region investigates the spatial distribution of permafrost (*GCW-Permafrost 1*, funded by the Austrian Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology). Measurements include, basal temperature of the snow cover (BTS, since 2012) and rock temperature of the Sonnblick north face (since 2016) with one deep (20 m) and six shallow (1 m) boreholes. Due to lightning strikes the borehole equipment was changed several times. At least two geophysical measurements per year are carried out using electrical and seismic imaging methods. These activities are accompanied by the development of a new algorithm for the joint inversion of geophysical data that directly solves for petrophysical parameters (air, ice and water content in the subsurface). In 2022-2023, repeated UAV-based surface measurements of the Sonnblick North-face were conducted to get a picture of rock fall activity. 21 locations with significant surface changes indicating rock falls were identified.

In 2022-2023, UAV surveys were conducted to monitor rock falls at the Burgstall area near Pasterze Glacier (Großglockner Mountains) and the rock glacier Hinteres Langtalkar 4. At Mittlerer Burgstall, rock fall events and sliding processes still continue in the detachment zone of a extensive rock slide. The movement of the lower part of Hinteres Langtalkar has generally decreased compared to earlier years. Both these activities, at Burgstall and Hinteres Langtalkar, are funded by the National Park Hohe Tauern Carinthia and are accomplished with the University of Graz and the Graz University of Technology.

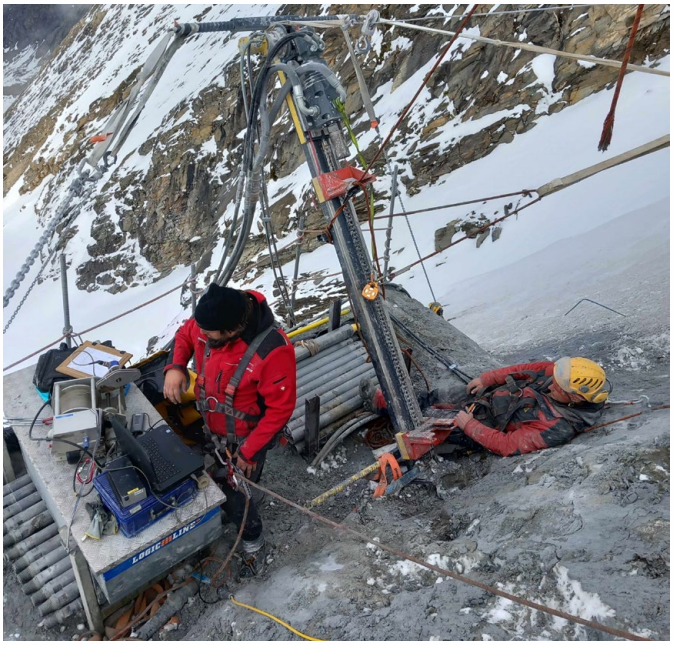


Fig. 8. Deep boreholes (20-40 m) being drilled and equipped with inclinometers and thermistors at the OpAL site, Kitzsteinhorn, Hohe Tauern Range. Photo: Ingo Hartmeyer.

b.geos has been developing several datasets in support of permafrost change impact studies across the Arctic. This includes an inventory of infrastructure in proximity to coasts, land-water change, general landcover and rain-on-snow occurrence. Activities have been funded through ERC, ESA and H2020. A review on the potential of satellite remote sensing for permafrost research has been published:

- Bartsch, A., Strozzi, T., and Nitze, I. (2023). Permafrost Monitoring from Space. *Surveys in Geophysics*, 44. DOI: 10.1007/s10712-023-09770-3.

The Austrian Polar Research Institute (APRI) organized the Arctic Science Summit Week 2023 with the University of Vienna. APRI has also contributed to a special exhibition on polar studies in the Natural History Museum of Vienna through several of its member institutions. It opened in autumn 2023 and includes exhibits on permafrost.

For more information contact Andreas Kellerer-Pirklbauer (andreas.kellerer@uni-graz.at).

BELGIUM

BY SOPHIE OPFERGELT (UCLOUVAIN), ELIE VERLEYEN (UNIVERSITEIT GHENT), AND SANDRA ARNDT (UNIVERSITÉ LIBRE DE BRUXELLES)

GHENT UNIVERSITY: PROTISTOLOGY & AQUATIC ECOLOGY

As part of *Climate change Experiments in Arctic and Antarctic Polar desert Soils (ExPoSoils)*, funded by BelSPO IMPULS (2023-2026), a field campaign to Ny-Ålesund, Svalbard, took place in June-July 2023 (Fig. 9). Another campaign to Sør Rondane Mountains, Antarctica (BELARE 23-24) took place in January-February 2024. A third campaign is planned to Ny-Ålesund, Svalbard, in August-September 2024, to sample a snow fence and Open Top Chamber plots.

In 2022-2023, Ghent University published:

- Almela, P., *et al.* (2023). Soil moisture drives differences in the diversity and trophic complexity of high Arctic tundra soils. *FEMS Microbiology Ecology*, 9(6). DOI: 10.1093/femsec/fiad050.
- Frankl, A., *et al.* (2022). Tracing hotspots of soil erosion in high mountain environments : how forensic science based on plant eDNA can lead the way : an opinion. *Plant and Soil*, 476(1-2). DOI:10.1007/s11104-021-05261-9.
- Frey, B., *et al.* (2023). Long-term N-addition alters the community structure of functionally important N-cycling soil microorganisms across global grasslands. *Soil Biology and Biochemistry*, 176. DOI: 10.1016/j.soilbio.2022.108887.
- Pedersen, A.O., *et al.* (2022). Five decades of terrestrial and freshwater research at Ny-Ålesund, Svalbard. *Polar Research*, 41. DOI: 10.33265/polar.v41.6310.
- Pessi, I.S., *et al.* (2023). Novel diversity of polar Cyanobacteria revealed by genome-resolved metagenomics. *Microbial Genomics*, 9(7). DOI: 10.1099/mgen.0.001056.

Fig. 9. Sampling at Knudsenheia, Ny-Ålesund. Photo: Iain Rudkin.

- Tytgat, B., *et al.* (2023) Polar lake microbiomes have distinct evolutionary histories. *Science Advances*, 9(46). DOI: 10.1126/sciadv.ade7130.

BGEOSYS, UNIVERSITÉ LIBRE DE BRUXELLES: SUBSEA PERMAFROST

The team has contributed to novel model tools:

- A pan-arctic model for carbon and biogeochemical cycling in subsea-permafrost bearing sediments as part of the EU H2020 project Nunataryuk (2017-2023).
- A microbial-explicit model of methanogenic activity in thawing subsea permafrost as part of the FNRS funded project UNCORK (2022-2026).
- A fully coupled thermo-hydraulic-(micro) biogeochemical model for methane hydrate-bearing sediments as part of the FNRS funded project FIESTA (2019-2024).

In 2022-2023, Université Libre de Bruxelles published:

- De La Fuente, M., *et al.* (2022). Assessing the benthic response to climate-driven methane hydrate destabilisation: state of the art and future modelling perspectives. *Energies*, 15(9). DOI: 10.3390/en15093307.
- Freitas, F.S., *et al.* (2022). Benthic organic matter transformation drives pH and carbonate chemistry in Arctic marine sediments. *Global Biogeochemical Cycles*, 36(7). DOI: 10.1029/2021GB007187.
- Miesner, F., *et al.* (2023). Subsea permafrost stocks are large and of dominantely low reactivity. *Scientific Reports*, 13. DOI: 10.1038/s41598-023-36471-z.
- Westerveld, L., *et al.* (2023). *Arctic Permafrost Atlas*. GRID-Arendal, Arendal.
- Winkelmann, R., *et al.* (2023). Tipping points in the cryosphere. In: T.M. Lenton, *et al.* (eds). *Global Tipping Points Report 2023*, University of Exeter, Exeter, UK.

Future research plans include (i) subsea permafrost incubations at the Alfred Wegener Institute (AWI) with gas, enzyme, and microbial community analyses in thawing subsea permafrost, (ii) pan-Arctic assessment of subsea permafrost thaw impacts on Arctic Ocean carbon cycling, and (iii) assessment of the efficiency of benthic methane sinks and its

impact on seafloor emissions over a wide range of environmental conditions. The team will attend ICOP2024 in Whitehorse, Canada.

UCLOUVAIN: PERMAFROST GEOCHEMISTRY

The group is working on the Earth's surface processes controlling chemical weathering and element export from continents to the hydrosphere, with a specific focus on the enhanced thawing of the permafrost in response to warming of the Earth's high latitude regions. To tackle the complexity of interacting processes in the rock-soil-plant-water system, they use a novative approach crossing geochemistry with collaborations in geophysics, geomatics and climatology to target changes in (i) biogeochemical processes, (ii) mineral-organic carbon interactions, (iii) ecosystem functioning, (iv) atmospheric conditions across season, anchored in long-term field-based studies. The team is working on the following permafrost projects:

- *WeThaw*: Mineral weathering in thawing permafrost: causes and consequences (ERC Starting Grant 2017-2022).
- *LIFTHAW*: Nutrient lift upon permafrost thaw: sources and controlling processes (BELSPO 2023-2025).
- *LandSense*: Pushing the boundaries of Critical Zone research: Unravelling hydrological controls on carbon and nutrient fluxes by integrating proximal sensing, field measurements and smart modelling (ARC 2021-2026).
- *RESIST*: Recent Arctic and Antarctic sea ice lows: same causes, same impacts?
- *BetuLeaf*: with Sorbonne Université.

In June 2022 and September-November 2023, UClovain led two field campaigns to Eight Mile Lake, AK, USA in collaboration with Northern Arizona University (Fig. 10). Articles on the campaigns can be found at Daily Science and La Libre Belgique.

Fig. 10. Eight Mile Lake, AK, USA in September (top) and November (bottom) 2023. Photo: Maëlle Villani.

In 2022-2023, UCLouvain published:

- Bröder, L., *et al.* (2022). Contrasting export of particulate organic carbon from Greenlandic glacial and nonglacial streams. *Geophysical Research Letters*, 49(21). DOI: 10.1029/2022GL101210.
- Hirst, C., *et al.* (2023). Evidence for late winter biogeochemical connectivity in permafrost soils. *Communications Earth & Environment*, 4(85). DOI: 10.1038/s43247-023-00740-6.
- Hirst, C., *et al.* (2022). Seasonal changes in hydrology and permafrost degradation control mineral element-bound DOC transport from permafrost soils to streams. *Global Biogeochemical Cycles*, 36(2). DOI: 10.1029/2021GB007105.
- Mauclet, E., *et al.* (2023). Quantifying exchangeable base cations in permafrost: a reserve of nutrients about to thaw. *Earth System Science Data*, 15(9). DOI: 10.5194/essd-15-3891-2023.
- Mauclet, E., *et al.* (2023). Tracing changes in base cation sources for Arctic tundra vegetation upon permafrost thaw. *Geoderma*, 429. DOI: 10.1016/j.geoderma.2022.116277.
- Mauclet, E., *et al.* (2022). Changing sub-Arctic tundra vegetation upon permafrost degradation: impact on foliar mineral element cycling, *Biogeosciences*, 19(9). DOI: 10.5194/bg-19-2333-2022.
- Monhonval, A., *et al.* (2023). Strontium isotopes trace the dissolution and precipitation of mineral organic carbon interactions in thawing permafrost. *Geoderma*, 433. DOI: 10.1016/j.geoderma.2023.116456.
- Monhonval, A., *et al.* (2022). Thermokarst processes increase the supply of stabilizing surfaces and elements (Fe, Mn, Al, and Ca) for mineral–organic carbon interactions. *Permafrost and Periglacial Processes*, 33(4). DOI: 10.1002/ppp.2162.
- Monhonval, A., *et al.* (2023). Mineral organic carbon interactions in dry versus wet tundra soils. *Geoderma*, 436. DOI: 10.1016/j.geoderma.2023.116552.
- Thomas, M., *et al.* (2023). Evidence for pres-

ervation of organic carbon interacting with iron in material displaced from retrogressive thaw slumps: case study in Peel Plateau, western Canadian Arctic. *Geoderma*, 433. DOI: 10.1016/j.geoderma.2023.116443.

- Villani, M., *et al.* (2022). Mineral element recycling in topsoil following permafrost degradation and a vegetation shift in sub-Arctic tundra. *Geoderma*, 421. DOI: 10.1016/j.geoderma.2022.115915.

In 2022-2023, UCLouvain communicated their research at several conferences, including:

- Goldschmidt, 9-14 July 2023.
  - Denis, G., *et al.* Nanok Expedition: an ice triathlon in Greenland partnering with scientists for climate research.
  - Opfergelt, S., *et al.* Evidence from silicon isotopes for pulses of sub-ice microbial activity during winter in the Lena River.
  - Thomas, M., *et al.* Evolution of Fe oxides crystallinity in permafrost deposits from mid-Pleistocene to Holocene: implications for mineral organic carbon interactions.
  - Villani, M., *et al.* Silicon isotopes as a tool to capture biogeochemical connectivity in permafrost soils: implications on Fe-organic carbon interactions.
- 6th European Conference on Permafrost (EUCOP6), 18-22 June 2023.
  - du Bois d'Aische, E., *et al*. Iron, manganese and aluminum solubility with permafrost thaw in an Arctic peatland: coupled geochemical and geophysical measurements. Book of Abstracts, p. 338.
  - Opfergelt, S., *et al.* Pulses of sub-ice microbial activity during winter: evidence from nitrate concentrations and silicon isotopes in the Lena River. Book of Abstracts, p. 69.
  - Osy, C., *et al.* Influence of rapid sea ice loss events on permafrost. Book of Abstracts, p. 159.
  - Thomas, M., *et al.* Combining geophysical data, microtopography, and very-high resolution UAV imagery to map lowland permafrost degradation in the Stordalen mire, Abisko, Sweden. Book of Abstracts, p. 213.
  - Thomas, M., *et al.* More than one third of the organic carbon exposed by the world's largest thaw slump (Batagay, Siberia) is not directly available for mineralization but geochemically stabilized. Book of Abstracts, p. 400.
  - Villani, M., *et al.* Flow-path changes in permafrost soils affect Fe-organic carbon interactions: evidence from silicon Isotopes. Book of Abstracts, p. 343.
- AGU Fall Meeting, 12-16 December 2022.
  - Villani, M., *et al.* Silicon Isotopes: A Tool to Capture Winter Biogeochemical Connectivity in Permafrost Soils (Stordalen, Sweden).
  - Opfergelt, S., *et al.* Role of Dissolution-Precipitation of Mineral Organic Carbon Interactions on Carbon Loss and Gain upon Permafrost Thaw.
- Earth Sciences in a Changing World, 4 November 2022.
  - Thomas, M., *et al.* Coupling geophysical data, microtopography and high-resolution imagery to map a permafrost degradation gradient at the Stordalen mire, Abisko, Sweden: implications for iron-organic carbon interactions.
- EGU General Assembly, 23-27 May 2022.
  - Osy, C., *et al.* Drivers of changes in the permafrost late shoulder season.

Outreach activities included (i) two conferences in 2022-2023 at the Printemps des Sciences *"Arctique: quand le sol dégèle sous nos pieds"*, (ii) a collaboration with the School Arts2 from Mons to produce a children's book on permafrost, (iii) a contribution from Eléonore du Bois d'Aische at the Arctic Science meets policy meeting, (iv) an exhibition of with pictures from the research group Arctique en Transition in Pommeroeul, Belgium on 2-4 February 2024, (v) a podcast on permafrost (in French), (vi) a contribution to the *La Traversée* documentary (vii) a cinema-debate about the movie Pleistocene Park at the GO FUTURE festival, (viii) a collaboration with the School Arts2 from Mons to produce a short movie on permafrost, edited by S. Seif Eddine and supervised by R. Noviello, and (ix) an interview in the letter from the *"Plateforme wallone pour le GIEC"* about permafrost.

For more information contact Sophie Opfergelt (sophie.opfergelt@uclouvain.be), Elie Verleyen (elie.verleyen@ugent.be), and Sandra Arndt (sandra.arndt@ulb.be).

CANADA

BY SHARON SMITH (GEOLOGICAL SURVEY OF CANADA)

It has been a busy two years in Canada with researchers seeing a full return to field investigations in 2022 and the preparations for ICOP2024. The permafrost community have been involved in a variety of activities and a few highlights are provided below.

CANADIAN PERMAFROST ASSOCIATION

The Canadian Permafrost Association (CPA) connects researchers, practitioners, and northern communities to improve understanding of permafrost environments and affect positive change. This was exemplified at the North Yukon Permafrost Conference (Dawson City, YT, 21-26 August 2022), co-developed by the First Nation of Na-Cho Nyak Dun, the Tr'ondëk Hwëtch'in First Nation, the Vuntut Gwitchin First Nation, and the CPA (Fig. 11). The focus was climate change effects and featured discussions, keynote and poster presentations, field excursions, and public lectures.

The CPA supports the Permafrost Terminology Action Group which is updating the *Glossary of Permafrost and Related Ground-Ice Terms*, and the Thermal Modelling Action Group, which is developing a guidance document for numerical permafrost models. An ongoing webinar series encourages learning and discussion about current developments in permafrost science and engineering. The Elements of Permafrost Science video series, sponsored by the Frozen Canoes Project (Research Council of Norway), features Dr. Chris Burn (Carleton University) and covers the basic principles of permafrost science and the behaviour and sensitivity of permafrost terrain. A mentorship program was launced to enable early career researchers and professionals to gain insight, advice, and guidance from more experienced mentors.

Fig. 11. Palace Grand Theatre, Dawson City (top) and field trip to the Klondike "muck" deposits (bottom). Photo: Julien Schroder.

INTERNATIONAL CONFERENCE ON PERMAFROST (ICOP2024), 15-20 JUNE 2024

ICOP2024 (Whitehorse, YT, Canada) will be held on the lands of the Kwanlin Dun First Nation and Ta'an Kwachan Council. The theme is *"Integrating Perspectives of Permafrost Thaw, Change, and Adaptation"*. The final program will have over 30 technical sessions across a wide range of subjects. More than 500 papers and extended abstracts have been submitted! Due to overwhelming interest and limited in-person venue capacity, ICOP2024 now includes a virtual poster hall. Local mid-conference field trips include, visits to permafrost field sites and other geohazards, and an afternoon of orienteering. Pre- and post-conference field trips will explore the Dempster Highway, Alaska Highway, and Beaufort Delta region.

PALMER ENVIRONMENTAL CONSULTING GROUP

Old Crow, home to the Vuntut Gwitchin First Nation in northern Yukon, is only accessible by air for most of the year. On an as-needed basis since the 1950s, heavy equipment has been able to reach Old Crow along a 269 km-long, winter-only access route from the Dempster Highway. The Old Crow Winter Road (OCWR) traverses an unglaciated landscape of rolling hills, broad valleys and expansive plains within the continuous permafrost zone. Ice-rich permafrost underlies much of the route, as indicated by widespread thermokarst within silt and clay deposited in Glacial Lake Old Crow during the late Pleistocene.

Old Crow is concerned about the OCWR's effect on permafrost, given observations of ground surface disturbance, including localized scraping and mounding of organics. Palmer conducted a reconnaissance-level assessment and recommended operational or restorative measures needed for permafrost protection. A desktop-based analysis

assessed broad differences in the thaw sensitivity of permafrost, based on interpretation of surficial materials and indicators of ground ice, and the nature and extent of ground disturbance. The interpretations were based on available high-resolution satellite imagery, 2 m-resolution ArcticDEM, pre-existing studies of permafrost and thermokarst, and regional-scale surficial geology and ground ice mapping.

In July 2023, helicopter-supported field reconnaissance was conducted at 20 sites to check desktop-based interpretations and measure thaw depths in areas of different thaw sensitivities and ground surface disturbances. Organic cover, surficial materials, and any visible ground ice were examined in hand-dug pits. Probing was used to measure thaw depths along a road-spanning transect. Cross-sections were generated to visualize variability in thaw depths beneath and adjacent to the OCWR, to identify and quantify any apparent impacts of the road and associated disturbance on permafrost.

Repeated establishment and maintenance of the OCWR has affected permafrost directly beneath its footprint and, locally, up to 10 m from its edges (Fig. 12). The active layer is generally thickest directly beneath the road, presumably where compaction or scraping of organics has reduced insulation and allowed unnaturally high rates of summertime warming. The active layer is generally thinnest alongside the road where permafrost aggradation occurred beneath elongated mounds of organics that accumulated from blading operations.

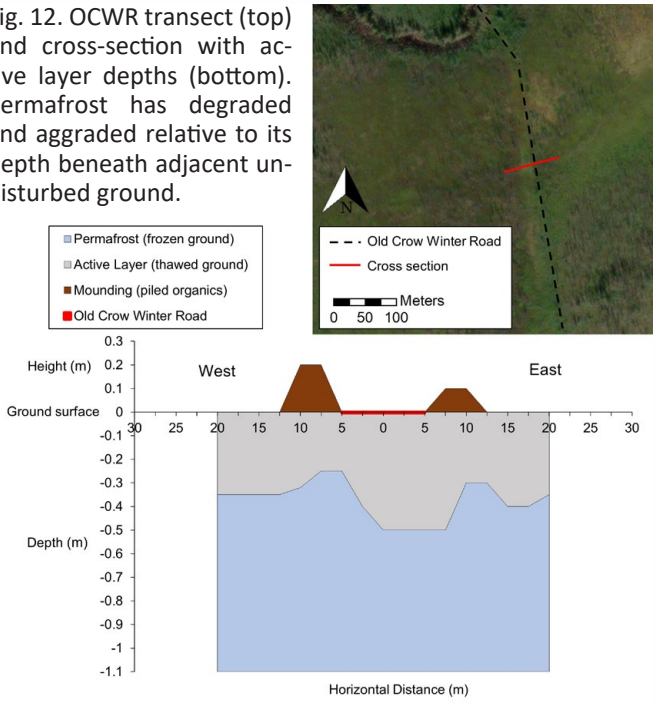
To minimize further impact, operators were advised to redistribute organics, especially where permafrost appears thaw-sensitive (to improve summertime insulation), during late-winter road decommissioning. Dispersal and compaction of plowed snow piles was recommended (to reduce wintertime insulation). Ongoing compaction of snow by snowmobiles when the road is not re-established would further promote heat loss from the ground and help to re-equilibrate permafrost along the OCWR corridor.

Contacts: Robin McKillop (robin.mckillop@pecg.ca) and Jenna Whitney.

UNIVERSITY OF CALGARY

In the Dept. of Civil Engineering research initiatives include the *PermaRail* program, recently funded by Transport Canada's National Trade Corridors Fund. This is a seven-year collaboration between University of Calgary, Université Laval, Royal Military College, Carleton University, Queen's University, and the

Fig. 12. OCWR transect (top) and cross-section with active layer depths (bottom). Permafrost has degraded and aggraded relative to its depth beneath adjacent undisturbed ground.



Arctic Gateway Group. The objectives are permafrost characterisation, thaw-related hazard prediction, and mitigative measure assessment along the Hudson Bay Railway. Field programs include drone mapping, geophysical surveying, and drilling. Ongoing research involves developing a coupled thermo-hydro-mechanical modelling tool, quantifying the influence of surface covers and anthropogenic disturbance on the ground thermal regime, and predicting subsidence and permafrost-related hazards along the railway. Researchers are also involved in NSERC PermafrostNet and NSERC CREATE LEAP, led by Carleton University. In 2022, Prof. Jocelyn Hayley delivered the R.M. Hardy Address at the 75th Canadian Geotechnical Conference on *"Permafrost thaw in a changing climate: A geotechnical perspective"*.

Research in the Dept. of Geography features two international collaborations on (1) improving remote sensing methods to monitor the rate of Arctic coastal erosion using a variety of platforms from drones to high-resolution satellites and using structure from motion and machine learning to develop high-accuracy automated shoreline classification processes, and (2) an examination of permafrost slope stability in recently deglaciated environments to better understand the character and magnitude of instability.

Research in the Dept. of Earth, Energy, and Environment includes studies on mountain permafrost in the Canadian Rockies to better understand the regional and local factors controlling the presence and extent of permafrost and its influence on hydrological processes in mountain headwater basins. Nu-

merical modelling techniques to incorporate air circulation within coarse sediments were developed to improve permafrost modelling of alpine landforms.

In 2022-2023, University of Calgary published:

- Clark, A., *et al.* (2022). Multiscale object-based classification and feature extraction along Arctic coasts. *Remote Sensing*, 14(13). DOI: 10.3390/rs14132982.
- Clark, A., Moorman, B., and Whalen, D. (2023). UAV-SfM and geographic object-based image analysis for measuring multi-temporal planimetric and volumetric erosion of Arctic coasts. *Canadian Journal of Remote Sensing*, 49(1). DOI: 10.1080/07038992.2023.2211679.
- Zegers, G. and Hayashi, M. (2022). Permafrost extent in mountain environments. *Revista de la Sociedad Chilena de Ingenieria Hidraulica*, 37(1).
- Mohammadi, Z. and Hayley, J.L. (2023). Qualitative evaluation of thaw settlement potential in permafrost regions of Canada. *Cold Regions Science and Technology*, 216. DOI: 10.1016/j.coldregions.2023.104005.

In 2022-2023, University of Calgary communicated their research at several conferences, including:

- 75th Canadian Geotechnical Conference (GeoCalgary), 2-5 October 2022.
  - Mohammadi, Z. and Hayley, J.L. An approach for evaluating permafrost thaw settlement potential, Paper 278.
  - Pekinasova, A. and Hayley, J.L. State-of-practice for synthesizing climate modelling data and risk-based estimation of geotechnical properties within the Canadian context: a literature review, Paper 145.
  - Roghangar, K. and Hayley, J.L. A review of design and adaptation of embankment infrastructure built on permafrost under a changing climate, Paper 265.
- International Arctic Observing Summit, 30 March – 1 April 2022.
  - Pekinasova, A. and Hayley, J.L. State-of-practice for synthesizing climate modelling data and risk-based estimation of geotechnical properties: a literature review.
- 76th Canadian Geotechnical Conference (Geosaskatoon), 1-4 October 2023.
  - Mohammadi, Z. and Hayley, J.L. Using particle size distribution to determine thaw strain in coarse-grained sediments.
  - Ozeritskiy, K., Hayley, J.L., and Gunar A. Understanding the influence of boundary conditions and thermophysical soil parameters on thermal modelling in permafrost regions.
  - Pekinasova, A., Hayley, J.L., and Karchewski, B. Preliminary results of thermo-hydro-mechanical modelling of large-strain deformation of ground in Canadian cold regions subject to climate change.
- 6th European Conference on Permafrost (EUCOP6), 18-22 June 2023.
  - Pekinasova, A. and Hayley, J.L. Numerical solution for the hydro-thermo-mechanical framework of one-dimensional large-strain thaw consolidation for engineering adaptation of transportation infrastructure in permafrost regions to climate change. *Book of Abstracts,* p. 502.
  - Zegers, G., Perez, R., and Hayashi, M. Improved permafrost modeling in mountain environments using convective-enhanced GeoTOP model. Book of Abstracts, p. 112.

Contact: Teddi Herring (teddi.herring@ucalgary.ca).

NSERC PERMAFROSTNET

NSERC PermafrostNet is a six-year strategic partnership network initiated in 2019, involving 12 Canadian universities, >40 partners, and >40 students and postdocs. In September 2022, a Memo of Understanding with ArcticNet was signed to promote northern research and culture while supporting the knowledge exchange and fostering the creation of synergies in Arctic research. In November 2022, the first in-person Annual General Meeting (AGM) since 2019 was held in conjunction with the 50th Yellowknife Geoscience Forum. The network hosted topical sessions on permafrost and its consequences on northern environments and communities at the ArcticNet Annual Scientific Meeting.

In March 2023, the network hosted the International Day of Permafrost, with >25 speakers from organizations and universities in 28 countries that included sessions to address critical challenges associated with research coordination, data sharing, and interoperability among countries. In June 2023, network members made six presentations at EUCOP6. In November 2023, The network hosted an interdisciplinary panel and a strategy workshop at the Canadian Science Policy Conference and convened the network's 5th AGM in Victoria, BC (Fig. 13).

In 2022-2023, the network published:

- Brown, N. (2022). tsp ("Teaspoon"): A library for ground temperature data. *The Journal of*

Fig. 13. NSERC PermafrostNet members at the 5th AGM in Victoria, BC.

Open Source Software, 7(77). DOI: 10.21105/joss.04704.

- Gruber, S., *et al.* (2023). Considerations toward a vision and strategy for permafrost knowledge in Canada. *Arctic Science*, 9(4). DOI: 10.1139/as-2023-0016.
- Herring, T., *et al.* (2023). Best practices for using electrical resistivity tomography to investigate permafrost. *Permafrost and Periglacial Processes*, 34(4). DOI: 10.1002/ppp.2207.
- Hille, E. (2022). Using river geochemistry to monitor the hydrology of Arctic watersheds. *Nature Reviews Earth and Environment*, 3(1). DOI: 10.1038/s43017-021-00257-6.
- Schetselaar, A.B., Andersen, T.S., and Burn, C.R. (2023). Performance of climate projections for Yukon and adjacent Northwest Territories, 1991–2020. *Arctic*, 76(3). DOI: 10.14430/arctic77263.
- 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(5). DOI: 10.5194/tc-17-1697-2023.
- Stewart-Jones, E. and Gruber, S. (2023). Transferring cryosphere knowledge between mountains globally: A case study of western Canadian mountains, the European Alps and the Scandes. *Journal of Alpine Research*, 111-2. DOI: 10.4000/rga.12203.
- Young, J.M., *et al.* (2022). Recent intensification (2004-2020) of permafrost mass-wasting in the central Mackenzie Valley foothills is a legacy of past forest fire disturbances. *Geophysical Research Letters*, 49(24). DOI: 10.1029/2022GL100559.
- A publication list is available on their website.

Contact: Tristan MacLean (tristan.maclean@carleton.ca).

ROYAL MILITARY COLLEGE OF CANADA

GEOCORE @ RMC, led by Ryley Beddoe and Greg Siemens, contributed to permafrost research and partnered with Transport Canada, Northwest Territories Geological Survey (NTGS) and Government of Northwest Territories (GNWT), and Hudson Bay Rail (HBR).

Fieldwork focussed on the Inuvik-Tuktoyaktuk Highway (ITH) and HBR (Fig. 14). At Gunghi Creek along the ITH, ground temperatures were retrieved and snow monitoring sensors were installed to monitor and model freeze-back of the adfreeze piles, assess influence of the creek, and predict long-term behaviour of the arch structure and embankment. HBR fieldwork focussed on frost heave mechanisms acting on the foundation supports for a rail crossing of the Owl River and using changing track geometry as a predictor for local permafrost conditions.

Fig. 14. Gunghi Creek survey (top; photo: Nick Kozachuk) and Hudson's Bay Rail bridge frost heave effects on piles (bottom; photo: Natalie Arpin).

Experimental research focussed on contaminant transport and foundations in permafrost. Innovative methods to measure migration of light non-aqueous phase liquids in frozen soils, will provide new insight into the conceptual model for differentiating impact of a contaminant spill in frozen compared with thawed ground. Work on the influence of pile foundation capacity with temperature showed the significant loss of support as temperatures rise above -2 °C. Other experimental work includes development of a 3D sand printer, infrared camera, and centrifuge modeling of thaw slumps.

- Clarkson, C., Eichhorn, G., and Siemens, G. (2023). Centrifuge modelling of axially loaded steel piles in cold and warming permafrost. *International Journal of Physical Modelling in Geotechnics*, in press. DOI: 10.1680/jphmg.22.00062.

Several graduate students defended their modeling-centric theses including: development of methodologies to simulate DEW Line landfill sites across the Arctic (Cameron Ross); modelling snow compaction effects on near surface ground temperatures adjacent to the ITH (Jay Cumming with Alice Wilson, NTGS); and simulation of Gunghi Creek arch construction and freeze-back of the adfreeze piles and embankment (Balussa Kameledenova).

Contact: Greg Siemens (greg.siemens@rmc-cmr.ca).

QUEEN'S UNIVERSITY

Permafrost Soils Around the World

Permafrost temperature is a key determinant of permafrost 'health' or stability, in large part because it determines the ice content. Over the last two years, significant advances have been made in soil freezing characteristic curves (SFCC, the relationship between temperature and unfrozen water content in cryotic soils). A repository of published historic SFCCs was developed, followed by investigations of the impact of ground ice and water content on permafrost systems, and linked engineering processes. Key to this work is community engagement; future research will address community questions about frozen soil properties and their impact on the land, as well as the interplay between soil and wildfire.

- Blaskey, D., *et al.* (2023). Perspectives on funding structures, cross-cultural collaboration and institutional support needed to support the next generation of convergence climate scientists. *PLOS Climate*, 3(1). DOI: 10.1371/journal.pclm.0000330.
- Devoie, É.G., Gruber, S., and McKenzie, J. (2022). A repository of measured soil freezing characteristic curves: 1921 to 2021. *Earth System Science Data*, 14(7). DOI: 10.5194/essd-14-3365-2022.
- Devoie, É., *et al.* (2023). Disconnected active layers and unfrozen permafrost: when exceptions matter. *Science of the Total Environment*, 912. DOI: 10.1016/j.scitotenv.2023.169017.
- Mastej, E., *et al.* (2023). An evaluation of ground-cooling systems in a saturated subarctic peatland. *Cold Regions Science and Technology*, 218(2). DOI: 10.1016/j.coldregions.2023.104095.

Contact: Élise Devoie (elise.devoie@queensu.ca).

UNIVERSITY OF BRITISH COLUMBIA

Permafrost thaw and active layer detachments on Qikiqtaruk – Herschel Island (Team Shrub)

During the exceptionally warm summer of 2023 in the ice-rich permafrost landscapes of Qikiqtaruk – Herschel Island, YT, a dramatic thaw event occurred. July temperatures were 5 °C warmer than average in late July and thaw depths reached >1 m, exceeding the previous maximum of 89.6 cm in 2017. Substantial permafrost thaw led to the formation of active layer detachments (ALDs). From 1 August 2023, disturbed tundra slid down slopes, removing the vegetation layer. ALDs formed ribbon-like patterns over hillsides with soils accumulating in valley bottoms, thus changing local hydrology by blocking streams and shifting flow paths (Fig. 15). Coastal ALDs deposited soils into the ocean increasing sedimentation of coastal waters and altering the coastline of the island. ALDs occurred during an exceptionally warm and dry summer without July precipitation on a range of slopes, aspects, inclination, encompassing varied topography. Preliminary analysis from satellite imagery reveals >50 ALDs across

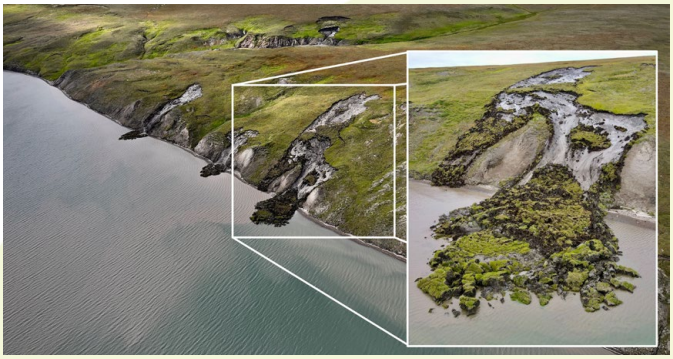


Fig. 15. Active layer detachments at Qikiqtaruk – Herschel Island, YT (photo: Isla Myers-Smith).

the island by September 2023. Future research will (i) monitor ALDs to track growth or stabilization, (ii) observe changes to local hydrology, and (iii) quantify sediment and carbon loss from disturbed landscapes. This event illustrates how summer Arctic heat waves can push systems beyond thaw tipping points with cascading impacts across landscapes.

Contacts: Madelaine Anderson (madelaine.anderson@usherbrooke.ca), Isla Myers-Smith (isla.myers-smith@ubc.ca), Cameron Eckert (cameron.eckert@yukon.ca), and Richard Gordon (richard.gordon@yukon.ca).

GEOLOGICAL SURVEY OF CANADA (GSC), NATURAL RESOURCES CANADA (NRCAN)

GSC's permafrost group is the Federal Government's Centre of Expertise on Permafrost. In 2022-2023, research activities included, (i) permafrost monitoring contributing to climate change assessment, (ii) understanding of physical processes in permafrost environments (*e.g.,* landscape change, effect of climate change on permafrost processes and dynamics, and surface-groundwater interactions), (iii) developing models and approaches to improve permafrost and terrain sensitivity mapping, assessment of ground ice occurrence, and response of permafrost environments to a changing climate, and (iv) understanding methane emissions from permafrost environments for improved characterization of northern GHG sources and sinks. GSC also contributed to national and international climate change assessments, development of standards under the Northern Infrastructure Standards Initiative, and provided expertise for the government's review of environmental assessments for northern development projects.

GSC prepared seven papers and extended abstracts for ICOP2024. In 2022-2023, the GSC permafrost group also published several papers, including:

- Faucher, B., *et al.* (2022). Assessment of physicochemical properties in lentic surface water bodies of the Rankin Inlet area (Nunavut) for sublacustrine open talik detection. *Geological Survey of Canada*, Open File 8898. DOI: 10.4095/330212.
- Leblanc, A.-M., Chartrand, J., and Smith, S.L. (2022). Regional assessment of the presence of taliks below Arctic lakes, Nunavut. *Geological Survey of Canada*, Scientific Presentation 138. DOI: 10.4095/330205.
- Morse, P.D., *et al.* (2023). Permafrost-related landforms and geotechnical data compilation, Yellowknife to Grays Bay corridor region, Slave Geological Province. *Geological Survey of Canada*, Open File 8986. DOI: 10.4095/332017.
- Oldenborger, G.A., Short, N.A., and Leblanc, A.-M. (2022). Permafrost thaw sensitivity prediction using surficial geology, topography, and remote-sensing imagery: a data-driven neural network approach. *Canadian Journal of Earth Sciences*, 59(11). DOI: 10.1139/cjes-2021-0117.
- O'Neill, H.B., Wolfe, S.A., and Duchesne, C. (2022). Ground ice map of Canada (version 1.1). *Geological Survey of Canada*, Open File 8713. DOI: 10.4095/330294.
- O'Neill, H.B., Wolfe, S.A., and Duchesne, C. (2022). Preliminary modelling of ground ice abundance in the Slave Geological Province, Northwest Territories and Nunavut. *Geological Survey of Canada*, Scientific Presentation 135. DOI: 10.4095/329815.
- O'Neill, H.B., *et al.* (2023). Widespread permafrost degradation and thaw subsidence in northwest Canada. *Journal of Geophysical Research Earth Surface*, 128(8). DOI: 10.1029/2023JF007262.
- Sladen, W.E., *et al.* (2022). Geomorphic feature inventory along the Dempster and Inuvik to Tuktoyaktuk highway corridor, Yukon and Northwest Territories. *Geological Survey of Canada*, Open File 8885. DOI: 10.4095/329969.
- Smith, S.L., *et al.* (2022). The changing thermal state of permafrost. *Nature Reviews Earth and Environment*, 3. DOI: 10.1038/s43017-021-00240-1.
- Smith, S.L., *et al.* (2023). Permafrost. In: J., Blunden, T., Boyer, and E., Bartow-Gillies (eds). *State of the Climate in 2022*. Bulletin of the American Meteorological Society, 104(9). DOI: 10.1175/BAMS-D-23-0079.1.
- Wolfe, S.A., *et al.* (2022). Ground ice degradation and thermokarst terrain formation in Canada over the past 16000 years. *Geological Survey of Canada*, Scientific Presentation 134. DOI: 10.4095/329668.
- Wolfe, S.A., *et al.* (2023). Distribution and morphometry of pingos, western Canadian Arctic, Northwest Territories, Canada. *Geomorphology*, 431. DOI: 10.1016/j.geomorph.2023.108694.

For more information contact Sharon Smith (sharon.smith@nrcan-rncan.gc.ca).

CHINA

BY YANHU MU (CHINESE ACADEMY OF SCIENCES)

THIRD NATIONAL CONFERENCE ON FROZEN SOIL ENGINEERING & COLD REGION ENVIRONMENT

The conference was held in Nanjing on 12-14 May 2022, with the theme *"Carbon peak and carbon neutrality: Sustainable Development of Engineering and Environment in Cold Regions"*. Over 500 researchers and engineers attended and 202 reports were published. Prof. Guodong Cheng, (2014 IPA Lifetime Achievement Award recipient), Profs. Wei Ma, Yuanming Lai, and Fujun Niu (members of the IPA Executive Committee) attended the conference. The conference was initiated by the State Key Laboratory of Frozen Soil Engineering, Northwest Institute of Eco-Environment and Resources, and Chinese Academy of Sciences in 2019. The conference is an important platform for the community of permafrost and cold regions engineering in China.

CHINESE ACADEMY OF SCIENCES (CAS)

Permafrost Monitoring in Mongolia

In August 2023, >20 people conducted a field investigation on permafrost in Mongolia, the transition zone between high-latitude and high-altitude permafrost regions. The team was led by Profs. Tonghua Wu and Xiaodong Wu, with Adiya Saruulzaya (Mongolian Academy of Sciences). The aim was to establish a meteorology and active layer monitoring network in typical permafrost areas of Mongolia. Five meteorological (air temperature, precipitation, wind speed and direction, radiation and vapor pressure, etc.) and active layer hydrothermal (soil temperature, soil moisture and thermal conductivity at different depths) monitoring sites were set up.

Over 80 active layer samples were collected in the Bagannuur, Darkhad, Mungut, Chuluut, and Galuut regions (Fig. 16). These areas are representative of permafrost in Mongolia. Ground surface temperatures from 16 existing sites were collected, and 25 new sites were established. Surveys on topography and geomorphology, vegetation and soil characteristics, active layer hydrothermal and periglacial landforms were also conducted.

The new meteorological and active layer monitoring network will provide support for understanding the characteristics of permafrost changes in Mongolia in the context of climate change. It will also provide basic data for high-quality development and protection of the ecological environment in the permafrost region of Mongolia.

Fig. 16. Installation of soil temperature and moisture sensors in the active layer (top) at the new meteorological and active layer hydrothermal site in Baganuur, Mongolia (bottom).

Contacts: Tonghua Wu (thuawu@lzb.ac.cn) and Xiaodong Wu (wuxd@lzb.ac.cn).

Retrogressive thaw slumps, Qinghai-Tibet Plateau

In 2022-2023, Profs. Fujun Niu and Zhanju Lin continued field investigations on retrogressive thaw slumps (RTS) in the hinterland of Qinghai-Tibet Plateau. Affected by the increase in extreme summer temperatures and rainfalls, RTS triggered by the detachment

of the active layer have widely occurred in mountainous areas in the hinterland of Qinghai-Tibet Plateau (Fig. 17). In 2022, about 1,700 RTS developed in the continuous permafrost regions of the hinterland, covering an area of about 30.8 km². These slumps are mainly distributed on gentle mountain slopes around 4700-4800 m asl. About 32% of slumps form where slope angles are 4-6°. The occurence of these slumps is likely to accelerate, exerting significant effects on the cold region environment.

Permafrost scientists conducted multiple investigations in the hinterland, including unmanned aerial vehicle (UAV) photography, ground penetrating radar (GPR), and interpretation of high-resolution remote sensing data, to reveal the effects associated with surface disaster, ecological environment, and hydrology, and provide a scientific basis for future environmental protection and ecological restoration.

- Yao, M.-M., *et al.* (2023). Development characteristics and disaster effects of thaw slump in Hoh Xil, in the hinterland of Qinghai-Tibet Plateau. *Journal of Glaciology and Geocryology*, 45(4). DOI: 10.7522/j.issn.1000-0240.2023.0095.

Contact: Fujun Niu (niufujun@lzb.ac.cn).

Permafrost characteristics, Genhe River Basin & Qiangtang depopulated zone

In June-August 2023, Prof. Guojie Hu and Prof. Lin Zhao (Nanjing University of Information Science and Technology) led >40 people to conduct a permafrost investigation in the Genhe River Basin on the western slope of the Daxinganling Mountains, northeast China (Fig. 1). The investigation focused on subsurface and permafrost characteristics in the basin, including the topography, vegetation, soil characteristics, and hydrothermal processes. 16 ground temperature boreholes were drilled, with a cumulative drilling depth of 315 m. Permafrost characteristics and ground ice were documented during drilling. The team also established an observation site on permafrost at the source of the basin for long-term monitoring. This will provide a baseline for accurately mapping permafrost depth, temperature, and spatial distribution of ground ice in the basin.

Fig. 18. Field investigation team in the Genhe River Basin on the western slope of the Daxinganling Mountains.

In November-December 2023, they also led a smaller team to the Qiangtang depopulated zone, Qinghai-Tibet Plateau (Fig. 19). The area is one of four major depopulated zones in China with an average elevation of 5000 m asl. 18 temperature boreholes were drilled, with a cumulative drilling depth of >350 m. The field investigation obtained a large amount of regional permafrost data, and constructed a comprehensive observation network over 600 km long through the continuous permafrost zone in western Qinghai-Tibet Plateau. This will be another complete north-south permafrost cross-section after the Qinghai-Tibet Highway.

Contact: Guojie Hu (huguojie123@lzb.ac.cn).

Qinghai-Tibet Railway

Embankment-bridge transition sections are always effected by differential settlement, which severely affects safe operation of roadways and railways. The

Fig. 17. Retrogressive thaw slumps in the hinterland of Qinghai-Tibet Plateau.

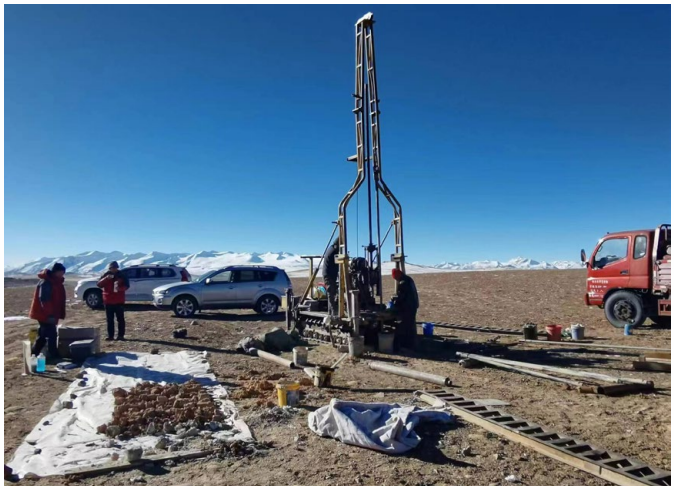


Fig. 19. Drilling in the Qiangtang depopulated zone, Qinghai-Tibet Plateau (winter 2023).

Qinghai-Tibet Railway has used many innovative cooling methods to maintain or cool the permafrost subgrade. 18 years of safe operation show the effectiveness of these methods. However, at embankment-bridge transition sections, embankment settlement is greater than the bridge pile foundation. To slow embankment settlement near the transition sections, permafrost scientists proposed a combined method to cool the underlying permafrost subgrade (Fig. 20). After two years of operation, the permafrost subgrade cooled and embankment settlement slowed significantly. This combined method is now used at >10 transition sections along the railway.

Slowing glacier melt with geotextiles

Global glacier loss has been accelerating for the past 20 years. It is particularly important to apply scientific methods to slow glacier melting, especially in places with rapid loss, scarce water resources, or tourist attractions. In July-August 2022, Prof. Feiteng Wang's team conducted a field test on glacier protection with geotextiles. Two 200 m^2 areas were designated at the end of the Urumqi Glacier No.1, Tianshan Mountains. In one area, a 0.45 cm thick geotextile was laid over the glacier, while the other area served as a control without any coverage. Both areas were equipped with identical automatic weather stations to collect meteorological data. The test showed that geotextile at this thickness can reduce the loss of glacier mass by >60%.

Fig. 20. Combined method to slow settlement at embankment-bridge transition sections, Qinghai-Tibet Railway.

- Wang, F.-T., *et al.* (2023). Geotextile protection of glacier: Observed and simulated impacts on energy and mass balance. *Advances in Climate Change Research*, 14(6). DOI: 10.1016/j.accre.2023.11.001.
- Liu, S.-S., *et al.* (2022). Quantifying the artificial reduction of glacial ice melt in a mountain glacier (Urumqi Glacier No. 1, Tien Shan, China). *Remote Sensing*, 14(12). DOI: 10.3390/rs14122802.

For more information contact Yanhu Mu (muyanhu@lzb.ac.cn).

FINLAND

BY JAN HJORT (OULUN YLIOPISTO)

FINNISH METEOROLOGICAL INSTITUTE (FMI)

Scientists combined permafrost (ESA CCI), soil freeze/thaw (SMOS), wetland (BAWLD), and climate data with atmospheric inverse modelling of methane emissions to better quantify the drivers of emissions in northern high latitudes. The highest emissions were found in the southern parts of the region, while areas with continuous permafrost, tundra climate, and tundra wetlands had the lowest emissions. Wetlands also had an impact on the emissions. The contribution of the summer thaw period emissions to the total annual emissions was much larger than the winter period in all regions. The freeze back period contributed to annual emissions most in the warmest regions.

- Erkkilä, A., *et al.* (2023). Environmental and seasonal variability of high latitude methane emissions based on Earth observation data and atmospheric inverse modelling. *Remote Sensing*, 15(24). DOI: 10.3390/rs15245719.

FMI also focused on permafrost thaw and emerging high-latitude dust (HLD) sources. With more permafrost thaw and ice-free land, dust emissions from soils are projected to increase, making HLD, *i.e.*, mineral dust emitted in areas north of 50°N and south of 40°S, an emerging and critical component in the Arctic and globally. Aeolian dusts are known to influence human health, environment, weather, and the Earth's climate, *e.g.*, directly by scattering or absorbing solar/terrestrial radiative fluxes and indirectly by serving as ice nucleating particles or cloud condensation nuclei in clouds. With the support from the Ministry for Foreign Affairs of Finland (*MFA IBA-BCDUST* project), Outi Meinander (FMI) leads a large international team from 15 countries to identify 64 new high latitude dust sources and quantify their source intensity values, based on fieldwork, modeling, and satellite observations. New northern sources were identified in Alaska, Canada, Denmark, Greenland, Iceland, Svalbard, Sweden, and Russia, and new southern sources in Antarctica and Patagonia. A review of the multiple effects of permafrost thaw in the Arctic was published in Arctic Year Book 2022. Subsequently, a policy brief on effects of permafrost was published (in Finnish) in 2023.

- Hildén, M., Meinander, O., and Kuntsi-Reunanen, E. (2023). Policy Brief (in Finnish). Ikiroudan sulaminen, vaikutukset ja sopeutumistoimet. *Ilmastokatsaus*. DOI: 10.35614/ISSN-2341-6408-IK-2022-12-02.
- Meinander, O., *et al.* (2022). Permafrost thaw and adapting to its multiple effects in the Arctic. In: L., Heininen, H. Exner-Pirot, and J., Barnes (eds). *Arctic Year Book 2022*. II Climate, Society and Development, 17 p.
- Meinander, O., *et al.* (2023). The northern high latitude dust belt. *EGU General Assembly 2023*, Vienna, Austria, 23-28 April 2023, EGU23-6167. DOI: 10.5194/egusphere-egu23-6167.

Contact: Outi Meinander (outi.meinander@fmi.fi).

UNIVERSITY OF HELSINKI

Arctic Avenue is a strategic partnership between the University of Helsinki and Stockholm University. Minna Väliranta, Atte Korhola, Emilia Tuomaala, and Teemu Juselius are working on the *Permafrost peatlands under climate warming pressure* project, which aims to increase knowledge of ground thermal conditions in Fennoscandian permafrost peatlands along a climatic and topographic gradient, and predict how future climate change will affect these environments. In 2022-2023, five sites were visited to collect ground thermal data (Fig. 21). The temperature measurements are supported by a set of cameras to record year-round snow depth.

Väliranta's previous project, *Response of high-latitude peatlands to past and recent warming – predictions for future climate feedbacks,* was conducted based on the data collected. The data show habitat type changes from wet to drier habitat conditions with Sphagna in permafrost peatlands of Fennos-

Fig. 21. Palsa peatland in Kilpisjärvi, NW Finland. Photo: Jussi-Pekka Manner.

candia and northwest European Russia. A data compilation of hydrological shifts in high latitude peatlands was published in Nature Communications. The data show drying in Eurasia, while on the American continent the signal is more inconsistent.

- Piilo, S., *et al.* (2022). Consistent centennial-scale change in European sub-Arctic peatland vegetation towards Sphagnum dominance and - implications for carbon sequestration. *Global Change Biology*, 29(6). DOI: 10.1111/gcb.16554.
- Zhang, H., *et al.* (2022). Recent climate change has driven divergent hydrological shifts in high-latitude peatlands. *Nature Communications*, 13. DOI: 10.1038/s41467-022-32711-4.

The paleopeatland research group conducted research in subarctic areas related to peatland fires and newly establishing organic soils.

- Kuosmanen, N., *et al.* (2023). Repeated fires in forested peatlands in sporadic permafrost zones in western Canada. *Environment Research Letters*, 18(9). DOI: 10.1088/1748-9326/acf05b.
- Juselius, T., *et al.* (2022). Newly-initiated carbon stock, organic soil accumulation patterns and main driving factors in the High Arctic Svalbard, Norway. *Scientific Reports*, 12. DOI: 10.1038/s41598-022-08652-9.

The *Increasing Carbon Accumulation in Arctic Peatlands (ICAAP)* project is coordinated from UK and funded by NERC. Collaborating with Minna Väliranta, a team surveyed permafrost peatlands in Finland and Norway using palaeoecological and remote sensing techniques.

Contact: Minna Väliranta (minna.valiranta@helsinki.fi).

UNIVERSITY OF OULU

In August 2022, the *Spatial ensemble prediction of permafrost thaw, soil carbon and ground-ice in the Arctic (ArcticSHOC)* project ended. An extensive circumpolar dataset on permafrost features (*e.g.,* palsas, peat plateaus, and retrogressive thaw slumps) and environmental conditions (*e.g.,* climate and ground properties) were compiled and utilized in statistical analyses. The results provided new insights on how to improve the accuracy of circumpolar models of permafrost features. For example, model uncertainties and challenges in high-resolution circumpolar predictions revealed thematic and geographical gaps in central data sources. Moreover, the results revealed a substantial loss in the future of environmental conditions suitable for ground ice and carbon-rich permafrost landforms. The project produced several publicly available circumpolar datasets of permafrost features at ca. 1 km spatial resolution (*e.g.,* PANGAEA and Zenodo). For example, permafrost projections were used in an exhibition at the Guggenheim Museum in New York and by Reuters Graphics (*"How thawing permafrost could fuel climate warming"*).

- Leppiniemi, O., *et al.* (2023). Environmental spaces for palsas and peat plateaus are disappearing at a circumpolar scale. *The Cryosphere*, 17(8). DOI: 10.5194/tc-17-3157-2023.

Geospatial data-based statistical modelling of permafrost and related earth surface systems continued for the *Hybrid modelling for improved permafrost risk assessments* project. The aim is to produce high-resolution permafrost projections based on a hybrid modelling setting (*i.e.,* statistical and physically-based approaches) and identify permafrost hazards (*e.g.,* retrogressive thaw slump susceptibility) across the circumpolar permafrost area. Warming permafrost and melting ground ice threatens fundamental engineered structures and has negative effects on natural systems, built-up environments, and socio-economic activities in the permafrost environment. Thus, spatial predictions of the current state and potential changes in permafrost systems are of importance for planners and policymakers to identify risk areas also at a circumpolar scale.

- Hjort, J., *et al.* (2022). Impacts of permafrost degradation on infrastructure. *Nature Reviews Earth & Environment*, 3. DOI: 10.1038/s43017-021-00247-8.

Temperature monitoring and active layer thickness measurements continued in a palsa mire in NW Finland. Permafrost temperatures have remained close to 0 °C and the active layer thickness has varied between 54-67 cm without a temporal trend.

For more information contact Jan Hjort (jan.hjort@oulu.fi).

FRANCE

BY ANTOINE SÉJOURNÉ (UNIVERSITÉ PARIS-SACLAY)

LABORATOIRE MORPHODYNAMIQUE CONTINENTALE ET CÔTIÈRE, UNIVERSITÉ DE CAEN-NORMANDIE

PERMOLARDS, led by Prof. Susan Conway (University of Nantes), tracks the degradation of mountain permafrost with proxy landforms called "molards". Molards are debris cones formed by thawing of ice-rich sediments mobilized by landslides. The degradation of ice-cemented blocks into molards, both in a continental and submerged environment, was physically modelled (Fig. 22). For initial downscaled experiments, 30 cm^3 blocks of frozen sediment were thawed under constant controlled conditions. The blocks were monitored by timelapse photogrammetry to create a 3D model and study its formation process and spatial evolution. For idealized sediment (gravel and fine gravel) different average temperatures did not affect the formation processes and shape. The team is currently investigating fine clay and plan to investigate the scalability of results.

Active layer thickness (ALT) is only assessed by stations, thus, its spatial distribution is lacking for model evaluation, especially under the boreal forest. InSAR is only partially sensitive to ALT through ground movements and is restricted to non-forested areas. To overcome these limitations, the team generalized ground movement estimates under a forest by exploiting SAR polarimetric information, and isolated the thermodynamical component from the hydrological component during freezeback using a land surface model to extract ALT.

- Garestier, F., *et al.* (2023). Imaging permafrost active layer thickness under forest for climate model improvement. *International Journal of Applied Earth Observation and Geoinformation*, 125. DOI: 10.1016/j.jag.2023.103582.

Contact: Susan Conway (susan.conway@univ-nantes.fr).

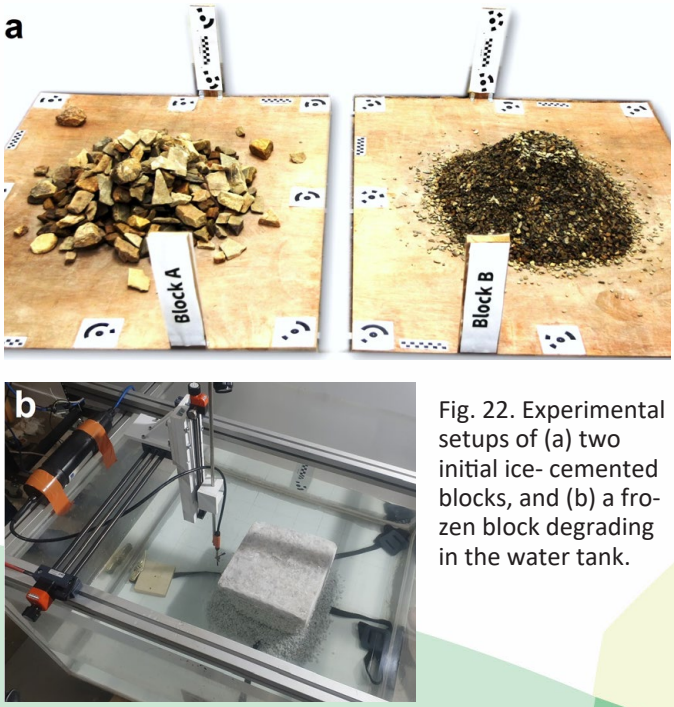


Fig. 22. Experimental setups of (a) two initial ice- cemented blocks, and (b) a frozen block degrading in the water tank.

EDYTEM, UNIVERSITÉ SAVOIE MONT BLANC & UNIVERSITÉ GRENOBLE ALPES

Nine boreholes equipped with thermistors in 2009-2021 in the French Alps show that temperatures at 10 m depth increased up to 1.1 °C per decade in north-facing ice poor rockwalls, while sub-zero temperatures in rockwall permafrost are stable. ALT has significantly increased since 2015, except in one borehole, likely the effect of local snow cover.

- Magnin, F., *et al.* (2024). Main results of permafrost monitoring in the French Alps through the PermaFrance network over the period 2010-2022. *Permafrost and Periglacial Processes*, 35(1). DOI: 10.1002/ppp.2209.

For the ANR-funded *WISPER* project, a water collection system was installed at Aiguille du Midi (Fig. 23) to measure water flow, timing, and electrical conductivity. Fluorescent dye was spread on snow and found at the early stage of water flows (May-July) in the collecting system while water continued to flow for months after the snow melting period with increasing electrical conductivity at some points.

INSTITUT DES SCIENCES DE LA TERRE (ISTERRE), UNIVERSITÉ GRENOBLE ALPES

ISTerre maintains seismic instrumentation on three rock glaciers (Laurichard in France, and Gugla and Tsarmine in Switzerland). Seismic data processing and results are automatically computed and shared on the webservice Evorisk from Géolithe, as part of Labcom Geo3iLab (funded by ANR-Plan de relance and AURA Region). Seismological methods have demonstrated their ability to detect microseismic events and to monitor mechanical properties at

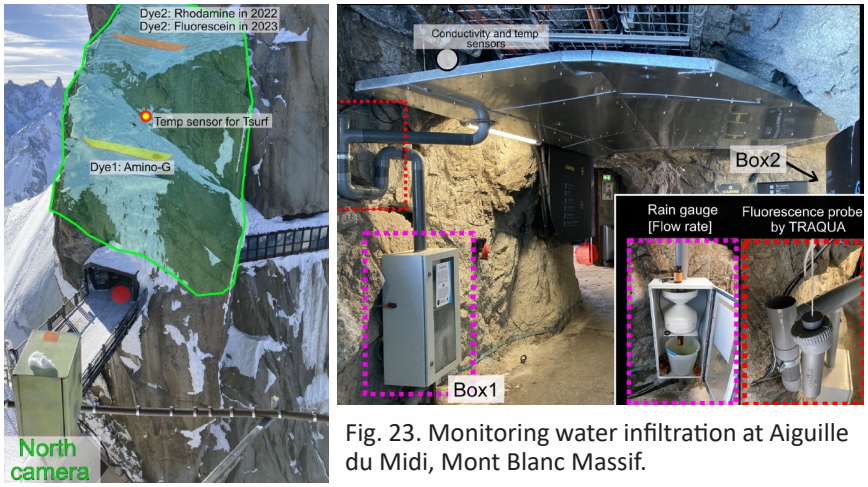


Fig. 23. Monitoring water infiltration at Aiguille du Midi, Mont Blanc Massif.

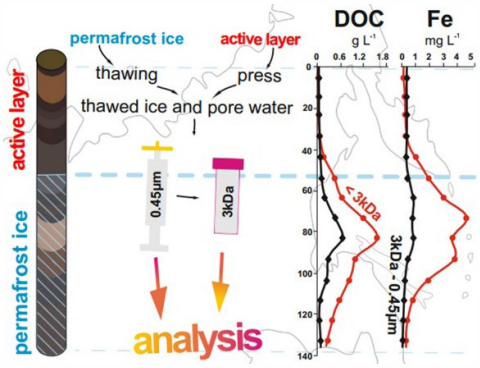


Fig. 24. Dissolved organic carbon (DOC) and Iron (Fe) in labile low-molecular form in the ground ice of permafrost peatlands.

depth. A comprehensive study on pluriannual seismic monitoring is being drafted and aims to provide insights on the role of water on rock glacier seasonal dynamics using ambient noise seismology. This work is conducted by Antoine Guillemot (Géolithe), Eric Larose and Laurent Baillet (ISTerre), Xavier Bodin (Edytem), Reynald Delaloye (Fribourg University, Switzerland), and the Canton du Valais.

GÉOSCIENCES ENVIRONNEMENT TOULOUSE (GET), UNIVERSITÉ PAUL SABATIER TOULOUSE

Permafrost peatlands

Scientists from GET and Tomsk State University quantified the pools and lability of dissolved organic matter in permafrost peat and underlying mineral horizons (Fig. 24). Another study demonstrated the potential of dispersed ice from peatlands to store low molecular weight (<3 kDa and potentially bioavailable) organic matter and trace metals. The team used a similar approach to quantify the pools and lability of dissolved organic and inorganic nutrients and trace metals in permafrost peat and demonstrate that aqueous leachates of permafrost peat yield high concentrations of dissolved organic carbon, nutrients, carboxylic acids, and trace metals, which are comparable or higher to those in dispersed peat ice.

- Kuzmina, D., *et al.* (2023). Dispersed ice of permafrost peatlands represents an important source of labile carboxylic acids, nutrients and metals. *Geoderma*, 429. DOI: 10.1016/j.geoderma.2022.116256.
- Lim, A., Loiko S.V., and Pokrovsky, O.S. (2022). Sizeable pool of labile organic carbon in mineral soils of permafrost peatlands: an experimental approach. *Geoderma*, 409. DOI: 10.1016/j.geoderma.2021.115601.
- Lim, A., *et al.* (2022). Organic carbon, and major and trace elements reside in labile low-molecular form in the ground ice of permafrost peatlands: a case study of colloids in peat ice of Western Siberia. *Environmental Science: Processes and Impacts*, 24. DOI: 10.1039/D1EM00547B.

HiPerBorea

HiPerBorea aims to simulate climate change impacts on permafrost using high performance computing. Simon Cazaurang (PhD candidate, l'Institut de Mécanique des Fluides Toulouse) is studying the thermo-hydrological properties of boreal moss and lichen covers in Khanymey Research Station, western Siberia. Thibault Xavier (postdoctoral researcher, GET) is using permaFoam to forecast the permafrost status of soils at Evenkian Field Station, central Siberia. The team also visited the Abisko Scientific Research Station, Sweden, to start work on remote-sensing based conditioning of permafrost numerical simulations.

- Cazaurang, S., *et al.* (2023). Numerical assessment of morphological and hydraulic properties of moss and lichen from a permafrost peatland. *Hydrology and Earth System Sciences*, 27(2). DOI: 10.5194/hess-27-431-2023.

CENTRE EUROPÉEN DE RECHERCHE ET D'ENSEIGNEMENT EN GÉOSCIENCES DE L'ENVIRONNEMENT (CEREGE), AIX MARSEILLE UNIVERSITÉ

ENVDYN, led by Léo Martin, aims to understand how permafrost thaw affects the water cycle in High Mountain Asia. Large endorheic lakes in Tibet have had significant water level fluctuations in recent decades, highlighting changes in the water balance of Tibetan catchments in response to climate change. Key processes are under investigation, and recent studies show that glacier melt alone cannot explain the lake-level rise observed over most of the pla-

teau (and even less the lake-level decline observed in the southeast). The team have so far worked at the catchment scale, attempting to close the water budget of the Paiku catchment (southeastern Tibetan Plateau) over the last 40 years using field observations, lake and land cryo-hydrological modeling, and glacier remote sensing (Fig. 25).

- Martin, L., *et al.* (2023). Recent ground thermo-hydrological changes in a southern Tibetan endorheic catchment and implications for lake level changes. *Hydrology and Earth System Sciences*, 27(24). DOI: 10.5194/hess-27-4409-2023.

Contact: Léo Martin (martin@cerege.fr).

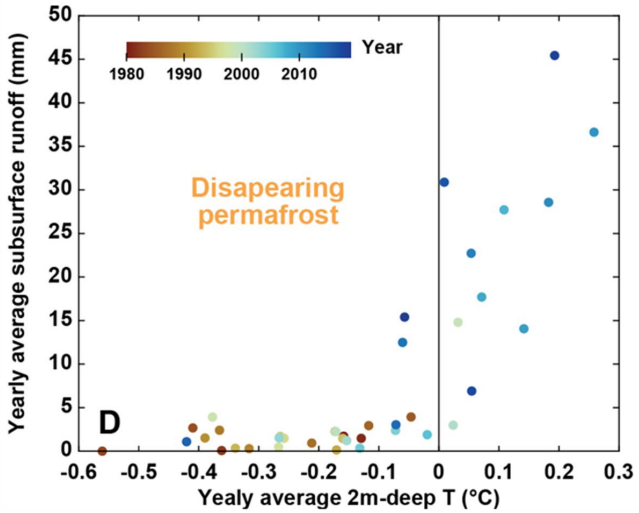


Fig. 25. Relation between the ground thermal regime and subsurface runoff in the Paiku catchment (1980-2019) where permafrost disappeared during simulations.

GÉOSCIENCES PARIS-SACLAY, UNIVERSITÉ PARIS-SACLAY

PRISMARCTYC aims to understand the impacts of permafrost thaw on soils, surface/groundwater fluxes and carbon cycle, and their controlling factors. The study focuses on small watersheds in central Yakutia and eastern Yukon where localized and rapid thermokarst occurrences remain under-studied. The objectives are to understand the hydrogeomorphological, geochemical, and microbiological changes on near-surface permafrost-hydrosystem continuum, and socio-economic impacts on local communities. In 2022-2023, a team of French, Canadian, American, and Japanese researchers visited the new site in eastern Yukon to study actively developing thermokarst lakes as permafrost thaws. The fieldwork aimed to collect water, GHG gas, and soil and permafrost samples. This area of boreal forest, subject to frequent fires, is under-studied compared to the tundra.

LABORATOIRE DE GÉOGRAPHIE PHYSIQUE: ENVIRONNEMENTS QUATERNAIRES ET ACTUELS, UNIVERSITÉ PARIS 1 PANTHÉON-SORBONNE, UNIVERSITÉ PARIS-EST-CRÉTEIL

The Lena River drains a large basin (2.9 million km²) entirely within the permafrost realm (77% with deep and continuous permafrost). The team previously demonstrated climate change induces an important increase in river water discharge that destabilizes the fluvial bed. They now focus on the dynamics of fluvial islands by examining islands with permafrost and islands without permafrost. Morphological parameters of about 100 islands have been surveyed using GIS on seven series of aerial photographs and satellite images of a 100 km-long reach from 1967-2017. Field surveys and monitoring of islands show the floodplain consists of a juxtaposition of seasonally and permanently frozen islands. A major change was observed for islands with permafrost at the beginning of the 21st century: islands have undergone stronger erosion for the last twenty years. During the same period, numerous small and non-frozen islands have been formed. Second, water discharge (duration of bar-full, bankfull and flood discharges, number and season of flood peaks, etc.) and temperature of the river water and ground on the islands has increased. Thus, the study highlights the complexity of large river responses across Arctic periglacial environments.

CONSERVATOIRE BOTANIQUE NATIONAL ALPIN

ROCVEG aims to monitor the evolution of three alpine rocky habitats directly linked to permafrost: abyssal forest ecosystems (cold scree), rocky glaciers, and alpine glacier forefields. In 2022-2023, monitoring on four cold screes in the French Alps was conducted to understand relations between flora and temperature: Lélex (Ain), Pellafol (Isère), and La Rollaz and La Baume (Haute-Savoie). This required the installation of about 30 thermistors to 5-10 cm depth. 1 m² botanical surveys of vascular flora and bryophytes were conducted around each thermistor. A third of bryophytes are nival, alpine, or subalpine species. The first analysis provided an understanding of the spatial distribution of species. On Pellafol, three groups with different floristic and thermal characteristics were identified and mapped. The work is redone every five years to monitor flora and temperature change linked to global warning.

For more information contact Antoine Séjourné (antoine.sejourne@universite-paris-saclay.fr).

GERMANY

BY LUTZ SCHIRRMEISTER AND MICHAEL FRITZ (ALFRED WEGENER INSTITUTE, POTSDAM)

UNIVERSITY OF FREIBURG

Gauging stations were installed below two rock glaciers in the Argentinian Andes with the Argentina Institute of Nivology, Glaciology and Environmental Science (IANIGLA). Remote sensing was also used to investigate surface kinematics of rock glaciers in the Cachi Range. The *GeoHype* team conducted annual UAV and geophysical surveys and collected hydro-chemical and ground surface temperature measurements at the Kaiserberg rock glacier in the Kaunertal Valley, Tyrol, Austria. In 2023, a time-lapse camera was installed to analyze seasonal dynamics.

Contacts: Jan Blöthe (jan.bloethe@geographie.uni-freiburg.de) and Sabine Kraushaar (sabine.kraushaar@univie.ac.at).

TECHNICAL UNIVERSITY OF MUNICH (TUM)

In 2023, the TUM Center for ALPine HAzards and Risk (TUM ALPHA) was founded. TUM ALPHA plans to interact with stakeholders from industry, politics, NGOs, and international organizations to enable cooperative research with partners from Alpine countries and create integrative funding opportunities.

Since March 2023, Prof. Krautblatter has coordinated the Virtual Alpine Observatory (VAO) with Sabine Kraushaar and Verena Stammberger. VAO seeks to contribute to climate change research and adaptation strategies in mountain areas with partners from 11 countries. The network promotes international cooperation and scientific exchange between several high-altitude research stations.

TUM investigates permafrost-affected slopes in the European Alps, Canada, Greenland, and Ecuador. Few highly destructive and mobile rock-ice avalanches >1 million m³ have been documented. Prof. Krautblatter's team aims to understand the factors that prepared and triggered the high-volume rock slope failure on the Fluchthorn (Austria-Switzerland border) in June 2023. They will use seismic analysis, InSAR, geology mapping, morphology and cryospheric features, and mechanical modeling.

Felix Pfluger investigated the effect of glacier-permafrost interactions as a possible trigger for a deep-seated landslide in Kaunertal, Tyrol, Austria in 2007. Geoelectrical measurements, ground surface temperatures, climate and weather data, historical orthophotography, and glacier models were used. The impact of the dynamically evolving environment on slope stability is assessed using mechanical models, taking into account the presence of ice-filled fractures and their implications.

In 2023, Maike Offer continued high-alpine permafrost monitoring at the Open-Air-Lab Kitzsteinhorn in Austria. Monthly geoelectric measurements and deep ground temperatures contributed to an improved process understanding of permafrost dynamics and water fluxes in permafrost bedrock.

On Arctic slopes, Saskia Eppinger investigated retrogressive thaw slumps (RTS) using ERT and laboratory investigations. Data was collected at Herschel Island, YT, Canada and the Zackenberg Research Station, Northeast Greenland National Park, and for the *3DIRTS* project. The aim was to understand the internal structures and polycyclic behavior of RTS.

Contact: Michael Krautblatter (m.krautblatter@tum.de).

UNIVERSITY OF WUERZBURG

In 2022, a project on the surface and subsurface characterization of various periglacial landforms and landscape units in the Mackenzie Delta Region was completed. In 2022-2023, the German Research Foundation funded two projects, led by Christof Kneisel: *PerGInt* and *Pingo3D*. *PerGInt* concerns permafrost-glacier interactions with a focus on the internal structures of thrust moraine complexes and their relations to recent morphological surface dynamics at high-alpine glacier forefields in the European Alps. *Pingo3D* investigates the formation and development of open- and closed-system pingos in northwestern Canada. In collaboration with Peter Morse (Geological Survey of Canada), several pingos in the Mackenzie Delta Region and Ogilvie Mountains will be investigated using 3D geophysics and in-situ methods. *Pingo3D* aims to understand the internal structure of pingos, and their development and connections to surface and subsurface hydrology. Sebastian Buchelt also continued remote sensing research on rock glacier dynamics in the European Alps. In Switzerland, valuable long-term borehole and geoelectrical monitoring on coarse-blocky landforms was maintained.

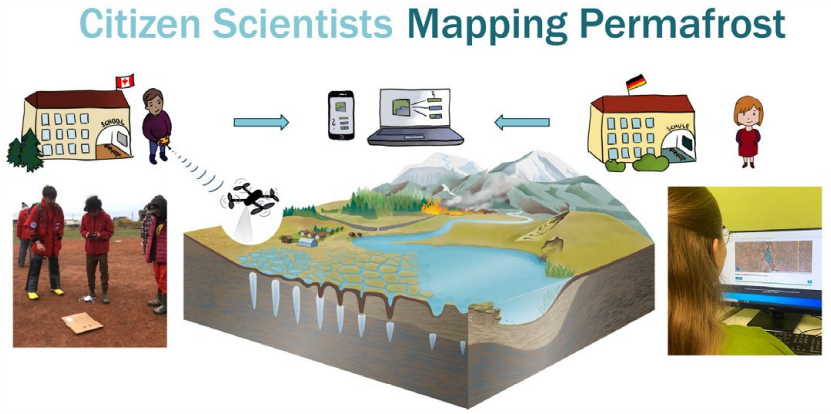


Fig. 26. Concept of *UndercoverEisAgenten*. Young citizen scientists in Canada collect drone imagery of changing permafrost landscapes which are analyzed by school children in Germany (credits: M. Muchow, AWI, and UndercoverEisAgenten).

Contacts: Julius Kunz (julius.kunz@uni-wuerzburg.de) and Christof Kneisel (christof.kneisel@uni-wuerzburg.de).

ALFRED WEGENER INSTITUTE HELMHOLTZ CENTRE FOR POLAR AND MARINE RESEARCH (AWI)

UndercoverEisAgenten

UndercoverEisAgenten is a BMBF Citizen Science project coordinated by AWI with the German Aerospace Center (DLR), Heidelberg Institute for Geoinformation Technology (HeiGIT), and youth and school children in Germany and Canada. The aim is to collect data on the state and rate of permafrost thaw (Fig. 26). In September 2022, young citizens from Moose Kerr School in Aklavik, NT worked with researchers to collect high-resolution aerial photographs from drone flights in the Mackenzie Delta. Unfortunately, a revisit in September 2023 was impossible due to wildfires and was postponed to 2024. In the meantime, drone imageries were processed and school children from several secondary schools in Germany analyzed the images in small mapping tasks, so-called "micro-tasks". Several mapathons, outreach events, and school workshops were held in 2022-2023. Contributions from young citizen scientists creates a unique reference dataset that improves the quality of remote sensing-based monitoring and prediction of permafrost thaw.

Contacts: Josefine Lenz (Josefine.Lenz@awi.de) and undercovereisagenten@awi.de.

FluxWin

FluxWin is funded by the European Research Council starting grant. In 2022-2023, peat cores, soil porewater, and greenhouse gas fluxes were sampled from the Peera palsa mire in Finnish Lapland to gain insight into biogeochemical cycles. CO_2, CH_4, and N_2O fluxes were also freqeuntly measured at the Siikaneva boreal peatland. Data indicate the wet bog is emitting up to 30% of its annual CH_4 budget during the shoulder seasons and winter, highlighting the importance of the non-growing season for budgets. Drone imagery was used to classify vegetation around the *FluxWin* automated chamber system at the peatland. The datasets will contribute to better carbon flux estimates from these carbon-rich soils and result in more accurate Earth System Models.

Contacts: Claire Treat (claire.treat@awi.de), Lona van Delden (lona.van.delden@awi.de), and Mackenzie Baysinger (mackenzie.baysinger@awi.de).

Detecting Upriver Climate Change Effects in the Mackenzie River (DUCCEM)

DUCCEM is a new high-frequent sampling program of the Mackenzie River with Western Arctic Research Station (WARC). *DUCCEM* aims to observe strong seasonal variable organic carbon concentrations and chemistry of the Mackenzie River and, thus its fluxes to Arctic coastal waters. Weekly sampling is being conducted by WARC. Analysis of water samples with a focus on the loads and quality of dissolved organic carbon will help to identify potentially changing environmental processes within the catchment, such as permafrost thaw, that are linked to climate change. The first phase (May-October 2023) was supported by EU-INTERACT TA-RA.

Contacts: Bennet Juhls (bennet.juhls@awi.de), Anne Morgenstern (anne.morgenstern@awi.de), and Paul Overduin (paul.overduin@awi.de).

ThinIce

Thawing industrial legacies in the Arctic - a threat to permafrost ecosystems (ThinIce) launched in September 2023. It is part of the BMBF-funded MARE:N program and involves AWI, RWTH Aachen, Leibniz University Hannover, and the Technical University of Braunschweig. *ThinIce* aims to assess the short- and long-term environmental risks associat-

ed with the potential release of contaminated industrial waste from thawing permafrost. Canada in western Arctic has >230 drilling mud sumps, built during intensive oil and gas exploration. *ThinIce* will focus on sumps as an example of industrial waste disposal in permafrost areas and aims to provide knowledge of soil mechanical, thermohydrological, and biogeochemical processes relevant for the mobilization of contaminants and their ecological impact. *ThinIce* works with the Northwest Territories Geological Survey, Northwest Territories Department of Lands, and Inuvialuit Land Administration.

Contact: Moritz Langer (moritz.langer@awi.de).

FLO CHAR

In 2023, the BNP Paribas Foundation funded the *Fluxes from Land to Ocean: How Coastal Habitats in the Arctic Respond (FLO CHAR)* project. *FLO CHAR* will investigate climate change impacts on the shallow near shore and coastal waters near the Mackenzie Delta, NT, Canada. *FLO CHAR* will build on recent terrestrial and marine campaigns and close a gap in the shallow water zone (0-20 m). Project partners include Stockholm University, University of Basel, ETH Zurich, Geological Survey of Canada, and Université du Québec à Rimouski. The team seeks to (i) determine the changing seasonality, magnitude, and composition of fluvial and coastal fluxes (carbon, nitrogen, sediment, contaminants) from the land to the ocean and its impact on marine biodiversity, (ii) assess the fate of this material in the shallow coastal zone, focusing on how it is impacted by climate change, and, (iii) investigate the role of recently submerged permafrost in sediment-water gas exchange.

Correlations between permafrost distribution and sediment characteristics will help determine the role of subsea permafrost in ecosystem dynamics. *FLO CHAR* will provide baseline data on present and past coastal biodiversity, including responses of Arctic coastal ecosystems over the past ~300 years, using sedaDNA approaches. Investigations will focus on the impacts of sea ice reductions on population connectivity and range expansion of key vertebrate resources (Beluga whale and salmon) and the effects of increased organic matter input on benthic microbial and planktonic communities. Collaboration with local research assistants will bridge the gap between scientific data and indigenous knowledge of ecosystem change and nearshore marine biodiversity.

Contact: Bennet Juhls (bennet.juhls@awi.de).

MOMENT

In 2022, a four-week field campaign to understand vegetation-permafrost-snow feedbacks in Ilulissat and the Blæsedalen glacial valley, Disko Island, Greenland was conducted for the *Permafrost Research Towards Integrated Observation and Modelling of the Methane Budget of Ecosystems (MOMENT)* project. The team installed temperature and soil moisture sensors, collected soil and water samples, conducted vegetation and drone surveys, measured land surface albedo, and recorded soil temperature profiles. In Ilulissat, the team anchored "subsidence sticks" into the permafrost to observe surface lowering due to permafrost thaw. In 2023, a climate monitoring station was installed to record meteorological data, soil parameters, snowpack temperatures and physical properties, and time-lapse photography. Soil sampling and sensor installations and read-outs were also conducted to record and understand the drivers spatial variability across vegetation units and soil conditions, and provide background data for project partners. In Ilulissat, 242 thaw depth measurements were taken at the Circumpolar Active Layer Monitoring (CALM) site, and three new soil temperature and moisture sensors were installed.

Contacts: Julia Boike (julia.boike@awi.de) and Simone Stuenzi (simone.stuenzi@awi.de).

Nunataryuk

Nunataryuk, an EU-funded Horizon 2020 project coordinated by AWI, carried out a six-year investigation into the rapidly changing permafrost regions in the northern hemisphere. The project answered questions about the role of permafrost thaw in the global climate system and the consequences for ecosystems, economies, and people. The Arctic Permafrost Atlas is a ground-breaking publication launched during the 2023 Arctic Circle Assembly. It was created in collaboration with 26 project partners and GRID-Arendal, and features 176 pages of maps, illustrations, photographs, and concise descriptions of permafrost and its transformations, and portraits of individuals who reside and work on permafrost. The atlas is downloadable and printed copies will be available soon.

Contact: Hugues Lantuit (hugues.lantuit@awi.de)

DEPTHAW

Land-to-ocean permafrost transitions north and south of Tuktoyaktuk Island, NT, Canada, were stud-

ied using passive seismic seabed sensors and amphibious electrical resistivity tomography. Coastline reinforcement, starting 2024, will lead to changes in the energy balance of permafrost below the shoreface. This data will provide a baseline. These activities combined the efforts of AWI with GeoForschungsZentrum (GFZ) and Canadian partners. Further south, University of Potsdam researchers teamed up with AWI to employ various geophysical techniques for the detection and delineation of ice and contaminants in the shallow subsurface.

Contact: Paul Overduin (paul.overduin@awi.de).

Arctic PASSION Permafrost Service

Remote sensing can be applied to detect and map permafrost disturbances at high spatial resolution across large regions to quantify landscape change, hydrological dynamics, and permafrost vulnerability. The ERC PETA-CARB, ESA CCI Permafrost, and NSF Permafrost Discovery Gateway projects produced a 20-year pan-Arctic time series using Landsat TM, ETM+, and OLI imagery. To make the scientific findings and large remote sensing dataset accessible, the Arctic PASSION team designed a web-based portal specifically targeting non-scientific user communities, stakeholders, and rightsholders as part of the project's Permafrost Service. Arctic Landscape EXplorer (ALEX; Fig. 27) provides interactive maps for recent information on land surface changes, hot spots of disturbances, and potential areas of active permafrost thaw and erosion. Data presented in the tool can help understand the spatial explicitness of land surface changes and provide valuable support for local decision-making.

Contact: Guido Grosse (guido.grosse@awi.de), Tillmann Lübker (tillmann.luebker@awi.de), and Anna Irrgang (anna.irrgang@awi.de).

Klondike Goldfields

In 2023, AWI Potsdam and the University of Toronto Mississauga worked on ice-rich Yedoma deposits in the Klondike Goldfields, YT, Canada. This area holds the easternmost major Yedoma deposits of the late Pleistocene Beringia region and is renowned for gold mining since the late 19th century. In the tributary valleys, the ice-rich permafrost overlying gold-bearing gravels is thawed with water cannons and removed with excavators to create short-term opportunities to investigate fresh permafrost exposures. Ice wedges and surrounding ice-rich sediments were examined and sampled. The team plan to analyse stable water isotopes of wedge and pore ice and date the sediments and ground ice. Sediments will be analyzed for grain size, carbon and nitrogen content, and biomarkers and will be available for paleo-ecological studies to reconstruct the environmental conditions before, during, and after the last ice age.

Contact: Thomas Opel (thomas.opel@awi.de) and Lutz Schirrmeister (lutz.schirrmeister@awi.de).

PermaRisk

PermaRisk is BMBF-funded young research group focused on publishing scientific results, including several articles on the impact of permafrost on ecosystems (boreal forests), infrastructures (contaminated industrial sites), and permafrost modeling. New insights into permafrost dynamics across large spatial and temporal scales have been achieved, taking into account uncertainties in soil thermal properties and ground ice content. This work has led to several publications on the thermal balance of permafrost and its role in the global energy budget.

Contact: Moritz Langer (moritz.langer@awi.de).

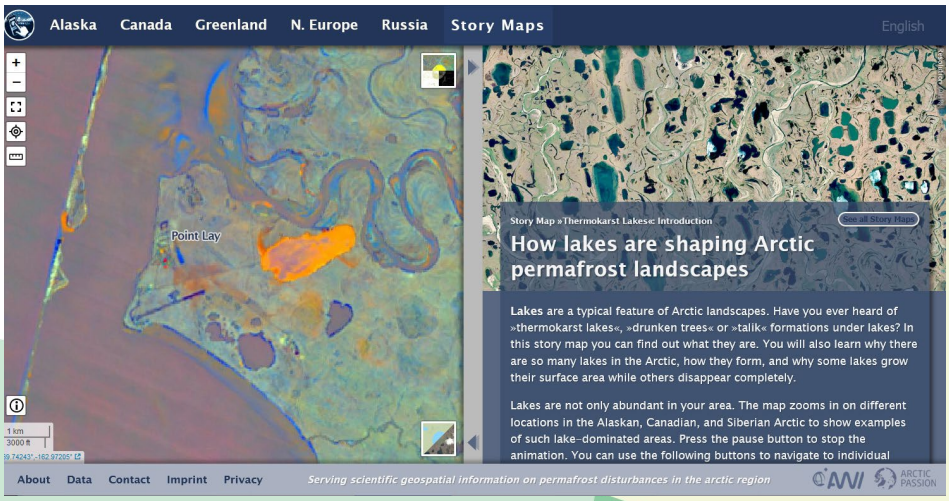


Fig. 27. The Arctic Landscape EXplorer (ALEX) tool showing change data for Point Lay, AK (left) and a story map on thermokarst lakes (right).

Russia

Since the beginning of Russia's war against Ukraine, AWI has frozen scientific cooperation with Russia within the framework communicated by the German Federal Ministry of Education and Research and the Helmholtz Association. All activities with Russian state institutions have stopped, including Russian-German permafrost activities to the Long-Term Observatory and Research Station on Samoylov Island, Siberian Lena Delta. However, science-to-science communication with Russian scientists on an individual basis without government involvement is being continued to some extent and includes joint publications of research results.

Contact: Anne Morgenstern (anne.morgenstern@awi.de).

The Hidden Image of Thawing Permafrost

In 2022, the connection between vegetation and soil temperature and properties was studied during a three-week field campaign for the Helmholtz imaging project, *The Hidden Image of Thawing Permafrost*. Measurements were collected at 126 survey points at the Trail Valley Creek Research Station, NT, Canada. 34 air and soil temperature and moisture loggers were installed below a range of vegetation types. The goals were to understand airborne radar data, compare local variability of soil properties and vegetation with regional differences, and analyze how vegetation parameters relate to soil parameters. Long-term measurements of subsidence and soil temperature profiles also continued.

Contact: Inge Grünberg (inge.gruenberg@awi.de).

Bayelva LTO AWIPEV

The Bayelva site near Ny-Ålesund, Svalbard, offers unique long-term observations of permafrost, active layer, and climate variables since 1998. In 2019 and 2023, GNSS points were measured at bedrock outcrops to estimate local subsidence rates and act as a reference for the comparison of multiple digital elevation models. The spatial variability of subsidence rates helps to understand permafrost loss and landscape vulnerability.

Contact: Julia Boike (julia.boike@awi.de).

Perma-X

In 2022-2023, *Perma-X* continued airborne and field surveys of rapid permafrost landscape dynamics in Alaska and Canada using the AWI airplane Polar-6, close-range remote sensing platforms (UAV), and ground-based instruments (DGPS, mobile backpack laserscanner, bathy-boat surveyor, GHG laser analyzer). In NW Alaska, the project re-surveyed thermo-erosional gullies, retrogressive thaw slumps, lakes, and recently drained lake basins from 2021 with a UAV and ground-based equipment. Thermistors were also installed in thermo-erosional gully systems. In NW Canada, the project surveyed Trail Valley Creek, the Inuvik-Tuktoyaktuk Highway (ITH), the Yukon coast west of the Mackenzie Delta, and Herschel Island using Polar-6 equipped with the Modular Aerial Camera System (MACS) developed by the German Aerospace Center (DLR) and a full-waveform LiDAR system (Fig. 28). They also surveyed retrogressive thaw slumps on the Peel River Plateau, lakes and mud sumps in the Mackenzie Delta, coastal segments of the outer Mackenzie Delta, and several communities. The surveys were conducted in collaboration with partners in Alaska and Canada.

Contact: Guide Grosse (guido.grosse@awi.de), Ingmar Nitze (ingmar.nitze@awi.de), Tabea Rettelbach (tabea.rettelbach@awi.de), and Cornelia Inauen (cornelia.inauen@awi.de).

For more information contact Lutz Schirrmeister (lutz.schirrmeister@awi.de) and Michael Fritz (Michael.Fritz@awi.de).

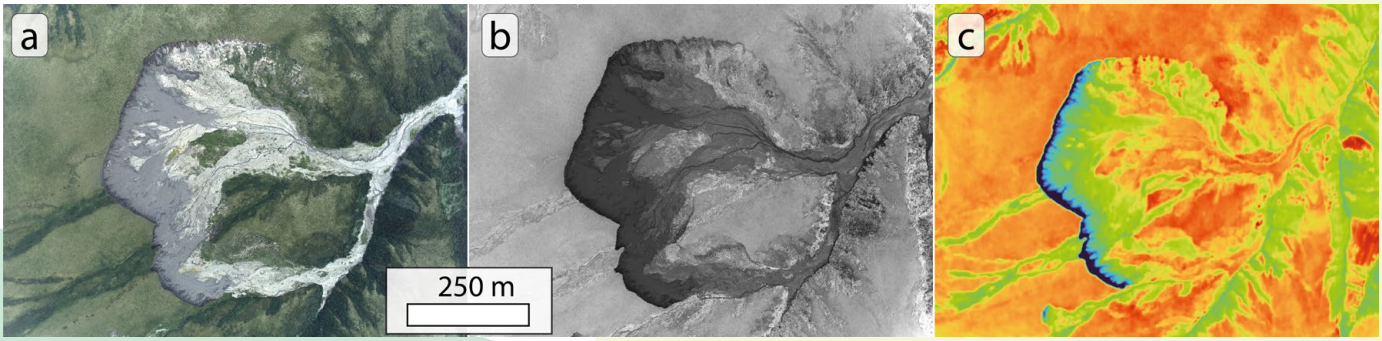


Fig. 28. Retrogressive thaw slump in (a) red-green-blue, (b) near-infrared, and (c) thermal infrared imagery using the MACS camera.

ITALY

BY RENATO R. COLUCCI, MAURIZIO AZZARO, ANGELINA LO GIUDICE, GUIDO NIGRELLI (CONSIGLIO NAZIONALE DELLE RICERCHE), ANDREA SECURO (UNIVERSITÀ CA' FOSCARIVENICE AND CONSIGLIO NAZIONALE DELLE RICERCHE) AND LUCA PARO (ARPA PIEMONTE)

POLAR REGIONS: ANTARCTICA

In 2022-2023, research was mainly conducted for the Italian National Antarctic Research Program (PNRA).

Interactions between permafrost and ecosystems in Continental Antarctica (IPECA)

In 2022, hypersaline liquids enclosed in glaciers lying in permafrost areas were sampled by the ISP-CNR of Messina for the *IPECA* project, led by Emanuele Forte (University of Trieste). A unique hypersaline flowing endoglacial brine sampled through a borehole cored on the Boulder Clay Glacier (BCG) in Northern Victoria Land was microbiologically analyzed. BCG is a coastal cold based debris covered glacier near the Italian Antarctic station Mario Zucchelli. Geochemistry and microbial diversity revealed a uniqueness to other known Antarctic brines and suggested a probable ancient origin due to a progressive cryoconcentration of seawater. The prokaryotic community showed some peculiarities, such as sequences of Patescibacteria (which can thrive in nutrient-limited water environments) or few Spirochaeta, and archaeal sequences of Methanomicrobia, a methanogen commonly detected in marine and estuarine environments and closely related to Methanoculleus.

- Azzaro, M., *et al.* (2022). Antarctic salt-cones: an oasis of microbial life? The example of Boulder Clay Glacier (Northern Victoria Land). *Microorganisms*, 10(9). DOI: 10.3390/microorganisms10091753.
- Forte, E., *et al.* (2022). Investigations of polygonal patterned ground in continuous Antarctic permafrost by means of ground penetrating radar and electrical resistivity tomography: Some unexpected correlations. *Permafrost and Periglacia Processes*, 33(3). DOI: 10.1002/ppp.2156.

CLICPERECO

A second study to assess the prokaryotic community found a mirabilite and thenardite efflorescence deriving from a highly saline water body of BCG. Phylogenetic analysis identified Bacteroidota, Actinobacteriota, Firmicutes, and Gammaproteobacteria as the main bacterial lineages, in addition to Archaea in the phylum Halobacterota. Several bacterial and archaeal sequences were related to halotolerant and halophilic genera, previously reported in a variety of marine environments and saline habitats, also in Antarctica. The salt community also included members that may play a major role in the sulfur cycle.

- Guglielmin, M., *et al.* (2023). A possible unique ecosystem in the endoglacial hypersaline brines in Antarctica. *Scientific Reports*, 13. DOI: 10.1038/s41598-022-27219-2.

POLAR REGIONS: ARCTIC

SNOW-BALL

In 2022-2023, active layer sampling was conducted in the permafrost areas of Hornsund (Svalbard Islands) and Kuujjuarapik (QC, Canada) for the INTERACT *SNOW-BALL* project, led by Maria Papale (CNR-ISP Messina). The aim was to describe the prokaryotic community composition and activities.

ISP-CNR Trieste

The *ISP-CNR Trieste* team, led by Renato R. Colucci, conducted drone mapping with RTK-precision of three rock glaciers along the Amerloq Fjord (West Greenland) to provide insights into their morphology. The research was done with the ArcticDTU Research Station. Measurements will be repeated in the next few years to assess the rock glacier's dynamics. Potential ice cored moraines and rock walls prone to collapse were mapped north of Nasaasaq using Structure from Motion (SfM). This will be repeated next year to quantify the collapses.

ALPINE ENVIRONMENT: WESTERN ALPS

ARPA Piemonte

Permafrost and periglacial studies in the Piemonte region began in 2006 and were developed through partnerships with EU Interreg projects including, *Permafrost long-term monitoring network (PermaNet)*, *PrévRisk HauteMontagne*, and *ReservAqua*.

Ground temperature monitoring includes (i) six stations with 5-100 m boreholes at 2500-3020 m asl, (ii) Mt. Rocciamelone with a 30 m borehole at 3150 m asl, (iii) Sommeiller and Mt. Moro Pass (Fig. 29), (iv)

Fig. 29. GNSS-ERT survey at Forneaux (top) and a permafrost monitoring station at Mt. Moro Pass (bottom). Photo: Luca Paro.

analysis of data related to climatic conditions, and (v) 14 ground surface temperature monitoring sites. Monitoring was also conducted at five ice caves with Polytechnic of Torino. A rock and air temperature monitoring site was installed in Balma ghiacciata del Mondolè, a hystorical cryo-cave in the Ligurian Alps.

ERT and HVSR surveys were conducted with University of Pisa (Adriano Ribolini with Simone Sartini) at the Le Caldaie (Lepontine Alps) and Fourneaux (Cottian Alps) rock glaciers. GNSS and UAV photogrammetry surveys were used at the latter site with Arpa Valle d'Aosta (Umberto Morra di Cella) (Fig. 30).

Cold springs monitoring to develop a hydrogeological model in periglacial and permafrost environments was finalized for *ReservAqua*. Water was sampled for chemical analysis (with CNR-IRSA, Michela Rogora, and Gabriele Tartari) at six sites in Piedmont Alps (Le Caldaie, Vej del Bouc, Schiantalà, Mt. Granero, Prato Ciorliero, Fourneaux). At one site, laboratory inter-comparison data involved Arpa Piemonte, Arpa VdA, and CNR-IRSA Verbania. Sensors were also installed at Alpe Stanti (Ligurian Alps) and Mt. Granero's cold springs (Cottian Alps).

- Rogora, M., *et al.* (2023). Chemical characterization of rock glacier outflows. Technical Report: Wp3 - Assessment of the available water resources in the transboundary area. Reservaqua, Interreg.
- Paro, L. and Vigna, B. (2022). Studio e monitoraggio delle grotte con ghiaccio nelle Alpi piemontesi. Neve e Valanghe (AINEVA), 96.

CNR-IRPI GeoClimAlp

In 2022-2023, *GeoClimAlp* focused on (i) documentation and collection of data on natural instability processes at high elevation (>1500 m asl) in the Italian Alps, (ii) evolution of Alpine glaciers in the last 150 years (post LIA) and related hazards, (iii) analysis of temperature trends in the Alps, specifically glacial and periglacial environments, and (iv) rockfall risk mitigation in the Italian Alps. Field activities continued at the Bessanese high-elevation experimental site (Graian Alps). This site is representative of glacial and periglacial environments in the western Alps. Glaciers have been the main morphogenetic agent. The head of the basin hosts a well-developed glacial cirque, while the LIA has left an imposing moraine on the left side of the glacier. The area is also shaped by cryogenic, atmospheric, and fluvial processes which are becoming increasingly important. Most of the area once occupied by the glacier is now covered with ice-rich debris. Downstream of the main basin lake (2580 m asl), the debris forms a large rock glacier. Rockfalls are common and hazardous. The old hut was renovated to host dissemination, training, and research activities at high elevation (Fig. 30).

- Chiarle, M., *et al.* (2022). Large glacier failures in the Italian Alps over the last 90 years. *Geografia Fisica e Dinamica Quaternaria*, 45(1). DOI: 10.4461/ GFDQ.2022.45.2.
- Hallen, S., *et al.* (2022). Assessment Principles for Glacier and Permafrost Hazards in Mountain Regions. *Oxford Research Encyclopedia of Natural Hazard Science*. DOI: 10.1093/acrefore/9780199389407.013.356.
- Nigrelli, G., *et al.* (2024). First national inventory of high-elevation mass movements in the Italian Alps. *Computers and Geosciences*,

Fig. 30. The Bessanese high-elevation experimental site with Uja di Bessanese in the background. The old hut (left) and current Bartolomeo Gastaldi hut (right). Photo: Guido Nigrelli.

184. DOI: 10.1016/j.cageo.2024.105520.
- Nigrelli, G. and Chiarle, M. (2023). 1991–2020 climate normal in the European Alps: focus on high-elevation environments. *Journal of Mountain Science*, 20(8). DOI: 10.1007/s11629-023-7951-7.
- Nigrelli, G., *et al.* (2022). Rock temperature variability in high-altitude rockfall-prone areas. *Journal of Mountain Science*, 19(3). DOI: 10.1007/s11629-021-7073-z.

Uninsubria University

The research group proposed a new application for UAV in thermal photogrammetry to model the active layer thickness (ALT) of an alpine rockwall through the computation of thermal inertia. Results were compared with a widespread ALT model on the Gran Zebrù South rockwall. They also worked in the Mt. Stelvio area (central Alps) performing photogrammetric and thermal observations of the spatial distribution of needle ice creep. Results show that local conditions govern the development of needle ice, with low cooling rates necessary for an intense process. Greater development also occurred under finer sediment than small clasts due to differential thermal conductivity.

- Ponti, S., Girola, I., and Guglielmin, M. (2024). Thermal photogrammetry on a permafrost rock wall for the active layer monitoring. *Science of the Total Environment*, 26. DOI: 10.1016/j.scitotenv.2024.170391.
- Ponti, S. and Guglielmin, M. (2023). Advances in understanding the cooling rates and bending of needle ice: Photogrammetric and thermal observations leading to the spatial distribution of needle ice creep. *Earth Surface Processes and Landforms*. 48(13). DOI: 10.1002/esp.5639.

ALPINE ENVIRONMENT: EASTERN ALPS

ISP-CNR in Trieste

Led by Renato R. Colucci, the group researched various topics related to permafrost in the Julian Alps area (SE Alps), with a focus on the Canin Massif. 3D mass balance measurements were made using SfM and terrestrial LiDAR on permanent ice deposits in two caves. Monitoring started in 2014 with 3D techniques beginning in 2017-2020. Four caves containing ice deposits underwent continuous air and rock temperature monitoring. These observations helped a nuanced analysis of temperature variations within the caves, offering crucial information for understanding microclimatic conditions affecting ice and rock stability, and rapid permafrost degradation.

Fig. 31. The Buso della Neve ice cave on Mt. Zingarella near the ice plug blocking the entrance. Photo: Renato R. Colucci.

The group also revised the Regional Speleological Inventory for the *Cryosphere in the Karstic environments of Friuli Venezia Giulia (CryoKarst)* project, with the Geological Survey of the Administrative Region Friuli Venezia Giulia. They focused on ice in caves and evidence of permafrost and ground ice in the region. Using drones, SfM, and LiDAR, the team quantified surface elevation changes in potential dead ice areas over Holocene moraines. In 2022, geophysical and photogrammetry was performed in the Buso della Neve ice cave on Mt. Zingarella with Francesco Sauro an the ®MilesBeyond team (Fig. 31). The group's activities are shown in the Curiosity Stream documentary, *Lift The Ice*.

- Securo, A., *et al.* (2022). Long-term mass-balance monitoring and evolution of ice in caves through structure from motion–multi-view stereo and ground-penetrating radar techniques. *Progress in Physical Geography: Earth and Environment*, 46(3). DOI: 10.1177/03091333211065123.

For more information contact Renato R. Colluci (renato.colucci@cnr.it).

JAPAN

BY TETSUO SUEYOSHI (NIPR)

The Japanese Permafrost Association (JPA) is a voluntary organization with >30 scientists and engineers.

ARCTIC CHALLENGE FOR SUSTAINABILITY II (ARCS II)

Since 2020, Japan has run *ArCS II (Arctic Challenge for Sustainability II)*, a five-year national Arctic research project. *ArCS II* is a comprehensive and interdisciplinary project with >200 researchers. It aims to promote research on the current and future status of climate and environmental change in the Arctic, and assess the impact of rapid change on society.

Mercury (Hg) abundance and dynamics in permafrost and aquatic environments, Alaska

Measurements and sampling were carried out in permafrost and glacial areas around the Alaska Range to elucidate the abundance and dynamics of Hg. Samples from a large area of the Alaskan permafrost zone were also analyzed. High levels of Hg found in permafrost generally coincide with previous studies, while the average concentration values may be slightly revised downwards. Hg release to the atmosphere through the soil surface was observed from the active layer, and the presence of a threshold in soil temperature suggests that subsurface microbial activity may contribute to Hg release.

Improving the physical process model for permafrost dynamics

Tomohiro Hajima and colleagues improved the permafrost scheme in the Japanese Earth System Model (MIROC-ES2L) by including several important subsurface thermal processes, such as changes in the thermophysical properties between freezing and thawing soil, insulating layers, and unfrozen water. The refined version of the global land surface model reproduced a more realistic distribution of permafrost regions, especially at the southern limit, leading to more plausible future projections.

OVERSEAS RESEARCH ACTIVITIES

Permafrost landforms in Svalbard

Norikazu Matsuoka (Ibaraki University) and Tatsuya Watanabe (Kitami Institute of Technology) studied *how permafrost landforms in Svalbard respond to global warming*. Svalbard offers excellent possibilities to study changing periglacial environments due to a variety of permafrost landforms within a small area undergoing rapid warming. Based on field observations during the last two decades in central Spitsbergen, they discussed contemporary dynamics and future changes of permafrost landforms, including ice-wedge polygons, mudboils, sorted circles, open-system pingos, and rock glaciers. These landforms respond differently to continuous warming and resulting permafrost thawing.

InSAR analysis and field observations in the Poker Flat Research Range (PFRR), interior Alaska

Takahiro Abe (Mie University), Go Iwahana (University of Alaska Fairbanks), Gaku Amada (JAMSTEC), and Yoshihiro Iijima (Tokyo Metropolitan University) conducted field observations in the Poker Flat Research Range (PFRR). The objective was to reveal the process of seasonal surface displacement due to ground freeze-thaw cycles and to develop a geophysical model to explain it. In October 2023, the team measured thaw depth and elevation, and installed soil temperature, moisture, and displacement sensors to validate InSAR analysis results and the model development. They will continue to monitor the freeze-thaw processes within the PFRR by combining InSAR analysis and field observations.

InSAR image analysis and joint field observations around Beaver Creek, YT, Canada

Kazuki Yanagiya (Japan Aerospace Exploration Agency) and colleagues conducted InSAR image analysis and field observations around Beaver Creek, YT, Canada for PRISMARCTYC. In summer 2023, JAXA's L-band SAR satellite ALOS-2/PALSAR-2 acquired high-resolution SAR images around Beaver Creek. InSAR image analysis detected thaw subsidence in the post-wildfire area, around the thermokarst lakes, and in the polygon terrains. In a second field visit the team collected thaw depths, GNSS, and drone aerial photography in subsided areas. They plan a third field visit in 2024 to verify ground subsidence values and compare with other observational data. This research was partially supported by JSPS KAKENHI grant number 23H01251.

The effect of snow distribution on permafrost and hydrothermal processes

Hotaek Park is developing a land surface model, CHANGE, focusing on permafrost and other climate elements, including snow and river water discharge. An improved snow component was introduced to assess the influence of blowing snow on permafrost temperatures and the associated greenhouse gases for an observational site in northeastern Siberia and over the pan-Arctic scale for 1979-2018. The experiment with blowing snow simulated well the seasonal and interannual variability of snow depth of the observational site. The results suggest the land surface models without the blowing snow component are likely to overestimate the simulated greenhouse budget over the tundra regions. There is a strong need to improve land surface models for better simulations and future projections of the northern environmental changes.

Food Life History of the North

Kazuyuki Saito and colleagues continued to work on the interdisciplinary topic of *"Food Life History"*, the relation between the environment of cold regions and the lifestyle of local people with regard to food. A two-day hybrid workshop was held in September 2022 and jointly supported by RIHN and NSF. Following a panel discussion by the core members, the first day presented case studies from several study sites (Mongolia, Alaska, Japan), and the second day revisited the Food Life History concept.

DOMESTIC RESEARCH ACTIVITIES

Earth hummocks in eastern Hokkaido

In 2022-2023, Yuki Sawada conducted observations of frost heave of earth hummocks on the Tokachi plain, eastern Hokkaido (MAAT 6.3°C). Heaving occurs up to 20 cm at the top and north-facing side of the earth hummocks. The average height and diameter of the earth hummocks are 0.3 m and 2 m, respectively. In October 2023, further observations were made on the Nemuro Peninsula (MAAT 6.4°C), eastern-most Hokkaido.

Palsas and periglacial landforms in Daisetsuzan mountains, Japan

Toshio Sone and colleagues monitored permafrost ground temperature and the observation of periglacial landforms (palsas, frost wedge polygons, solifluction lobes, etc.) in Daisetsuzan region. The total area of palsas is decreasing. Ground temperatures in the windward bear ground (wind-blown sand and gravel surface) are influenced by snowfall, rainfall, and air temperature. Recent research activities have also been affected by bears.

OUTREACH

A book for the general public is being led by Kazuyuki Saito, in collaboration with JPA researchers.

For more information contact Tetsuo Sueyoshi (sueyoshi.tetsuo@nipr.ac.jp).

KYRGYZSTAN

BY TAMARA MATHYS, MARTIN HOELZLE, CHRISTIN HILBICH, CHRISTIAN HAUCK, TOMAS SAKS (UNIVERSITY OF FRIBOURG, SWITZERLAND), TIMUR MUSAEV, ZHOODARBESHIM BEKTURSUNOV, BOLOT MOLDOBEKOV, ERLAN AZISOV, RUSLAN KENZHEBAEV, RYSKUL USUBALIEV (CENTRAL ASIAN INSTITUTE FOR APPLIED GEOSCIENCES, KYRGYZSTAN), JOEL FIDDES (WSL INSTITUT FOR SNOW AND AVALANCHE RESEARCH SLF, SWITZERLAND), MURATALY DUISHONAKUNOV (KYRGYZ NATIONAL UNIVERSITY, KYRGYZSTAN), AND SERGEY MARCHENKO (UNIVERSITY OF ALASKA FAIRBANKS, USA)

In 2022-2023, the *Cryospheric Observations and Modelling for improved Adaptation in Central Asia (CROMO-ADAPT)* project continued to monitor permafrost across Kyrgyzstan (Fig. 32). This included drilling and re-equipping boreholes, installing ground surface temperature (GST) loggers, and geophysical surveys such as electrical resistivity tomography (ERT) and refraction seismic tomography (RST).

In 2022, a new site in the Akshiirak region was equipped with a meteorological station and 30 m borehole to measure air and ground temperatures. It is near boreholes from the 1980s, one of which was re-equipped with thermistors to provide comparative data. The data show a warming of ~0.9 °C since the 1980s (Fig. 33).

Using the Petrophysical Joint Inversion (PJI) model the team gained insight into the ground ice content of various landforms, including fine-grained sediments, talus slopes, moraines, and rock glaciers. The efforts yielded data from 28 ERT and 17 RST profiles, which improved understanding of permafrost occurrence in Kyrgyzstan. Fig. 34 is a ground ice content model for a profile with fine grained sediments and a rock glacier. An automated ERT system was installed at the borehole.

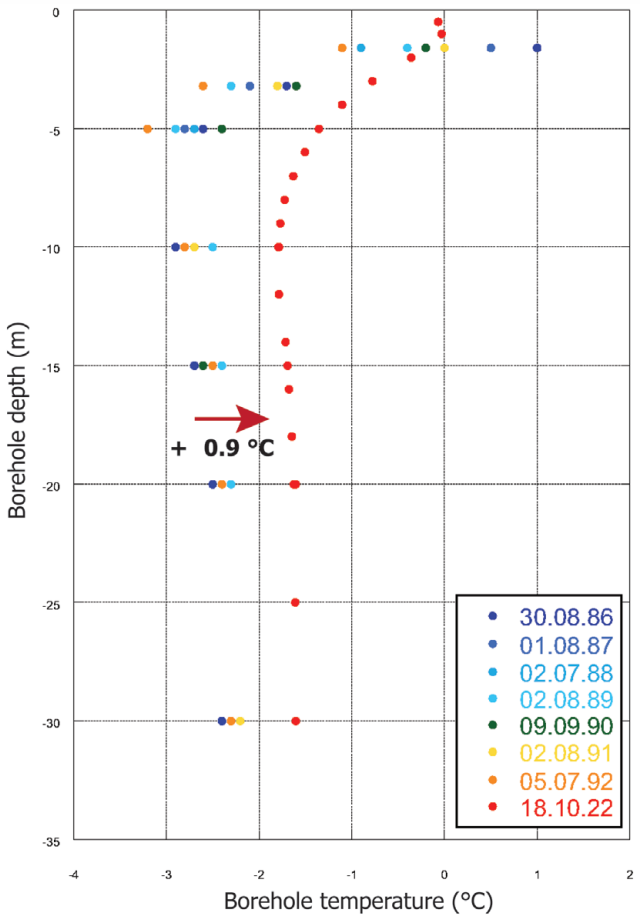


Fig. 33. Ground temperatures increased ~0.9 °C, 1986-2022.

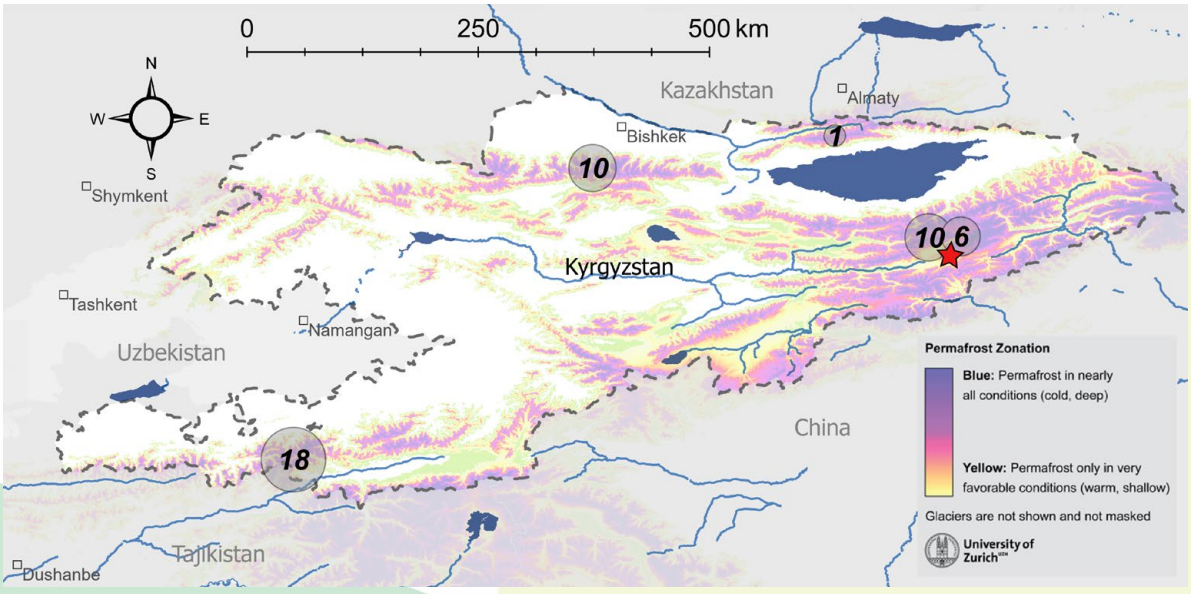


Fig. 32. Study sites with the number of geophysical profiles (bubbles) and new borehole in the Akshiirak region (red star).

Extensive capacity building also continued (Fig. 35). In 2023, the team organised a summer school on geophysical measurements in permafrost environments. 14 students from Kyrgyzstan, Uzbekistan, and Kazakhstan attended the 10-day course with theoretical lessons on permafrost and practical experience of geophysical methods. Several CAIAG scientists also continued their training in permafrost monitoring techniques. This will allow them to repeat ERT measurements in the future to assess the impact of climate change on permafrost in Kyrgyzstan.

For more information contact Tamara Mathys (tamara.mathys@unifr.ch).

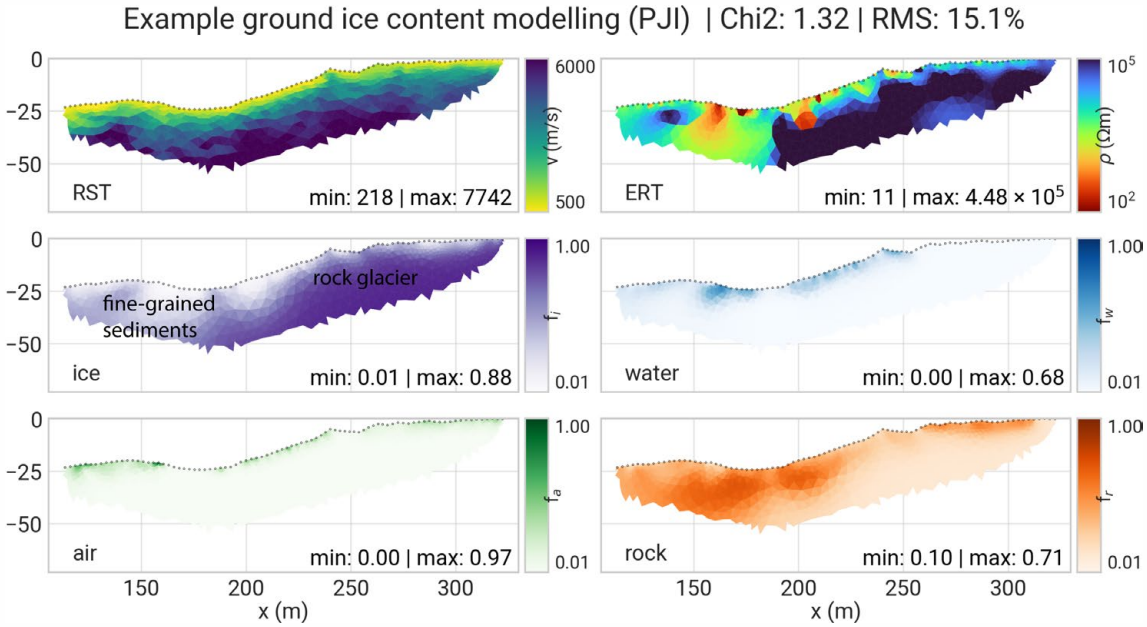


Fig. 34. Modelled ground ice content for a profile with ice-poor fine-grained sediments (left) and an ice-rich rock glacier (right). The ground ice contents vary significantly between the different landforms.

Fig. 35. 2023 summer school on permafrost monitoring techniques (Photos: Tamara Mathys, Christin Hilbich, Malika Nurmanova).

MONGOLIA

BY YAMKHIN JAMBALJAV (MONGOLIAN ACADEMY OF SCIENCES)

NATIONAL UNIVERSITY OF MONGOLIA

Since 1996, long-term monitoring of permafrost at >40 boreholes in the Hovsgol, Hangai, and Hentii mountain regions has been conducted under the GTP-N and CALM programs. Permafrost temperatures and active layer thicknesses have increased, mainly due to frigid weather in the mid-2000s compared to the preceding 25 years.

In 2017, the team began monitoring the thermal impact of climate warming and livestock grazing on peat permafrost ecosystems. Observations were carried out at peat permafrost and seasonal freezing sites in the Khurkh Valley of the Hentei mountains. Six fenced sites were established with warming, grazing, and control treatments. At 24 plots measurements included, air and ground temperatures (2, 20, and 50 cm depth), summer soil moisture content (20 cm depth), vegetation biomass, and spring thaw thickness. Peat was an effective insulator; mean annual soil temperatures at 50 cm depth were 3.6 °C colder than the surface.

The mean annual soil temperatures at 2 and 20 cm depth increased more at plots with than without warming treatment and between grazed and control plots. This study was sponsored by the Wildlife Science and Conservation Centre of Mongolia.

Fig. 36. Road embankments with looped thermosyphons in Buraat pass (top) and inclined thermosyphons in Tsagaannuur, both Western Mongolia.

The *Oslo CryoSTRESS* project explores the impacts of livestock grazing and forest logging on permafrost ecosystems. Since 2021, the team have studied soil temperatures at open and fenced plots in heavily grazed and lightly grazed areas, as well as forested and logged areas in the Hovsgol and Hentei mountainous regions. Data show that mean annual soil temperatures at 50 cm depth in logged plots were ~2 °C higher than in larch forest plots, and heavily grazed plots were ~0.3 °C higher than lightly grazed plots.

GEOCRYO LLC & NEWCON LLC

Permafrost degradation in Mongolia has been shown by several studies and is seen in various forms, such as active layer thickening, talik formation, thawing of shallow permafrost, and weakening of the bearing capacity of permafrost. These changes impact the hydrological, thermal, and moisture conditions of the upper layers of permafrost.

Mongolia is divided into 21 provinces, each with several sub-provinces called soums. Permafrost covers an area of about 105 soums and around 1,400 km

Fig. 37. Foundation with open crawl space and inclined thermosyphons in Arbulag soum, Hovsgol province, Northern Mongolia.

of road pass through permafrost areas. The country is planning new road corridors from north to south, connecting Russia and China through Mongolia along five lines. Each soum has administration buildings, hospitals, schools, and kindergartens, and is home to 2,000-10,000 people. Mongolia is the most sparsely populated country in the world, but in recent years over half of the population has moved to cities. The government is developing new policies to improve port accessibility, support village development, and encourage an even distribution of the population throughout the country.

About 57 soums and village centers are located on permafrost. Within 1-5 years after construction, buildings and roads are being damaged due to thawing, in both the north and south of the permafrost region. In recent years, technology has been used to mitigate and adapt to thawing permafrost beneath infrastructure, including several types of thermosyphons (Figs. 36, 37).

For more information contact Yamkhin Jambaljav (jambaljav@gmail.com).

THE NETHERLANDS

BY JORIEN VONK (VRIJE UNIVERSITEIT AMSTERDAM)

UTRECHT UNIVERSITY (UU)

AlpineRockSlopes

Predicting the effects of climate change on alpine rock slopes: Evaluation of paraglacial and periglacial drivers of rockfall in the European Alps (AlpineRockSlopes) was a DFG-funded project (2016-2020). Daniel Draebing investigated how rockwall erosion by rockfall processes is currently influenced by glacier retreat, permafrost and frost weathering, which results in an elevation-dependent erosion pattern. The team also investigated past rockwall erosion and found that periglacial and paraglacial control results in higher Holocene-average erosion rates compared to current rates due to colder climate.

- Draebing, D., *et al.* (2022). Alpine rockwall erosion patterns follow elevation-dependent climate trajectories. *Communications Earth & Environment*, 3(21). DOI: 10.1038/s43247-022-00348-2.
- Draebing, D., *et al.* (2024). Holocene warming of alpine rockwalls decreased rockwall erosion rates. *Earth and Planetary Science Letters*, 626. DOI: 10.1016/j.epsl.2023.118496.

*Contact: Daniel Draebing (*d.draebing@uu.nl*).*

Go or grow? Moving mountain slopes meet migrating mountain plants

Go or grow? Moving mountain slopes meet migrating mountain plants is a NWO-funded project. Jana Eichel investigated links between permafrost degradation, slope movement processes, and vegetation changes in several alpine valleys in Valais (Switzerland). The research team consisting of Jana Eichel, Daniel Draebing, Wiebe Nijland, Florine Kooij, Isa Meirink (all UU), Sam McColl (GNS Science) and Philipp Gewalt (Tübingen University) set up a soil temperature and moisture monitoring network at solifluction lobes (Turtmann Valley), a rock glacier (Val d'Hérens, with Université Lausanne) and several other alpine landforms (Fig. 38). They also surveyed vegetation and sediment properties, measured plant functional traits, and conducted annual high-resolution UAV flights to assess landform movement and vegetation changes.

A semi-automated approach to monitor solifluction movement in time and space using high-resolution UAV imagery was developed and published by MSc student Marije Harkema (now University of Zurich).

Fig. 38. Installation of soil temperature and moisture loggers on a solifluction slope in Turtmann glacier foreland (Switzerland). Stone- and turf-banked solifluction lobes on a distal moraine slope of Turtmann glacier in the background.

- Harkema, M.R., *et al.* (2023). Monitoring solifluction movement in space and time: a semi-automated high-resolution approach. *Geomorphology*, 433. DOI: 10.1016/j.geomorph.2023.108727.

A conceptual "biogeomorphic balance" approach for high mountains was also developed to evaluate how climate change will impact high mountain landscapes and ecosystems. It highlights the role of close feedbacks between thawing permafrost, increasing slope movements, and changing plant species distributions and biodiversity.

- Eichel, J., Stoffel, M., and Wipf, S. (2023). Go or grow? Feedbacks between moving slopes and shifting plants in high mountain environments. *Progress in Physical Geography: Earth and Environment*, 47(6). DOI: 10.1177/03091333231193844.

Contact: Jana Eichel (j.eichel@uu.nl).

ClimRock

Characterizing Rockwall Weathering from Microclimate, Rock Moisture and Rockfall Activity (ClimRock) is a DFG-funded project. Daniel Draebing's team monitored rock temperatures and rockfall activity at Dachstein (Austria) and Dammkar Valley (Germany). In the laboratory, PhD student Till Mayer (University of Bayreuth) quantified frost cracking activity in Wetterstein limestone by acoustic emission and found

that frost cracking is controlled by initial crack density and temperatures below -7°C. Tjalling de Haas, Wiebe Nijland, and Daniel Draebing with the Swiss Federal Institute for Forest, Snow and Landscape Research WSL instrumented rockwalls in the Illgraben with temperature loggers and acquired high-resolution topographic data to investigate the influence of periglacial processes on debris flow activity.

- Mayer, T., Eppes, M.C., and Draebing, D. (2023). Influences Driving and Limiting the Efficacy of Ice Segregation in Alpine Rocks. *Geophysical Research Letters*, 50(13). DOI: 10.1029/2023GL102951.

*Contact: Daniel Draebing (*d.draebing@uu.nl*).*

WAGENINGEN UNIVERSITY & RESEARCH (WUR)

Rainfall impacts on the soil thermal regime

With a forced end to a longstanding collaboration with IBPC Yakutsk, researchers of the Plant Ecology & Nature Conservation Group shifted their work on impacts of summer rainfall extremes on permafrost, ground thermal regimes, and tundra plant growth to new research sites on Svalbard (Adventdalen, Endalen and Ny-Alesund). The *Tundra Rainfall Extremes (T-REX)* project is led by Rúna Magnússon and Juul Limpens (WUR) with researchers from UNIS, NIOO, NIOZ, Arctic Centre of Groningen University, and Stockholm University. Irrigation studies are used to experimentally tests impacts of heavy rainfall events (Fig. 39). Preliminary findings indicate limited sensitivity of Svalbard permafrost thaw depth and ground thermal regime to extreme rainfall events.

The work contributes to a combined synthesis and modelling study on regional differences in rainfall sensitivity of permafrost active layer thickness and ground temperatures. Both show higher rainfall sensitivity of permafrost in continental climates, compared to no effect or a cooling effect of rainfall in maritime permafrost regions. This aligns well with findings of low rainfall sensitivity of Svalbard permafrost soils from *T-REX*.

- Hamm, A., *et al.* (2023). Continentality determines warming or cooling impact of heavy rainfall events on permafrost. *Nature Communications*, 14. DOI: 10.1038/s41467-023-39325-4.

Fig. 39. Applying additional summer rainfall in Adventdalen, Svalbard. Photo: Peter Lin.

Plans 2024 WUR

Rúna Magnússon and Juul Limpens will finalize and publish results from *T-REX* on Svalbard, including impacts of heavy rainfall events on soil temperatures, permafrost thaw depth, plant productivity and phenology, tree ring development, and arthropod emergence. New collaborations with UNIS will focus on the role of vegetation communities, soil characteristics, and hydrological gradients in regulating the climate sensitivity of permafrost soils on Svalbard and potentially other regions.

Rúna Magnússon and Monique Heijmans will publish remaining field data from previous fieldwork in the Kytalyk reserve, NE Siberia. They expect long-term data on permafrost thaw and thermokarst development following a shrub removal experiment initiated in 2007, and data on methane emissions across a gradient of thermokarst development stadia.

Contact: Rúna Magnússon (runa.magnusson@wur.nl).

VRIJE UNIVERSITEIT AMSTERDAM (VUA)

The *THAWSOME* project, led by Jorien Vonk, ended in 2022. The team studied the fluvial and marine impacts of thawing permafrost.

- Jong, D., *et al.* (2023). Contrasts in dissolved, particulate, and sedimentary organic carbon from the Kolyma River to the East Siberian Shelf. *Biogeosciences*, 20(1). DOI: 10.5194/bg-20-271-2023.
- Jong, D., *et al.* (2024). Selective sorting and degradation of permafrost organic matter in the nearshore zone of Herschel Island (Yukon, Canada). *Journal of Geophysical Research: Biogeosciences*, 129(1). DOI: 10.1029/2023JG007479.
- Keskitalo, K.H., *et al.* (2023). Seasonal carbon dynamics of the Kolyma River tributaries, Siberia, *EGUsphere* [preprint]. DOI: 10.5194/egusphere-2023-1792.

VUA contributed to *Nunataryuk's* Arctic Permafrost Atlas (see p.29) and published a circum-arctic database of coastal watersheds that was highlighted in an accompanying publication (Fig. 40).

- Speetjens, N.J., *et al.* (2023). The pan-Arctic catchment database (ARCADE). *Earth System Science Data*, 15(2). DOI: 10.5194/essd-15-541-2023.
- Vonk J.E., Speetjens N.J., and Poste A.E. (2023). Small watersheds may play a disproportionate role in arctic land-ocean fluxes. *Nature Communications*, 14. DOI: 10.1038/s41467-023-39209-7.

Contact: Jorien Vonk (j.e.vonk@vu.nl).

VUA showed that permafrost thaw from legacy industrial contamination and pollutants can lead to problems. *ILLUQ: permafrost, pollution, health,* is a new EU-consortium project led by Moritz Langer. With several European and Canadian partners, ILLUQ will investigate impacts of permafrost thaw on pollution and health in the Arctic (Fig. 41).

- Langer, M., *et al.* (2023). Thawing permafrost poses environmental threat to thousands of sites with legacy industrial contamination. *Nature Communications*, 14. DOI: 10.1038/s41467-023-37276-4.

Contact: Moritz Langer (m.langer@vu.nl).

VUA also showed that 9 out of 10 sub-catchments along the Yukon River are increasingly non-linear (since 1950), indicating more seasonal flow regimes.

- Hinzman, A.M., *et al.* (2023). Overview: Cascading spatial, seasonal, and temporal effects of permafrost thaw on streamflow in changing nested Arctic catchments. *EGUsphere* [preprint]. DOI: 10.5194/egusphere-2023-2391.

Contact: Alexa Hinzman (a.m.h.hinzman@vu.nl).

For more information contact Jorien Vonk (j.e.vonk@vu.nl).

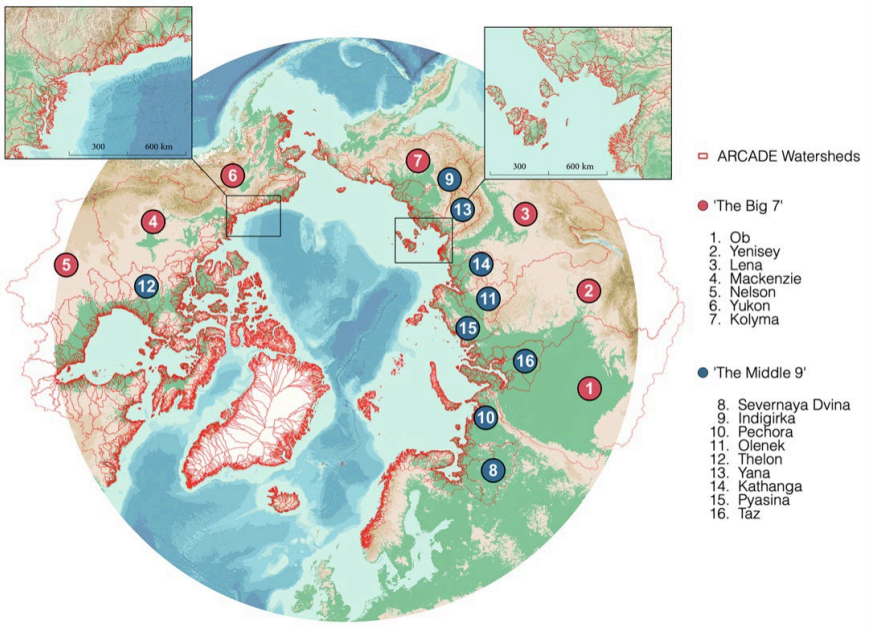


Fig. 40. Circumpolar map of all ARCADE watersheds (≥1 km²), Strahler order 5 and higher (Speetjens *et al.*, 2023).

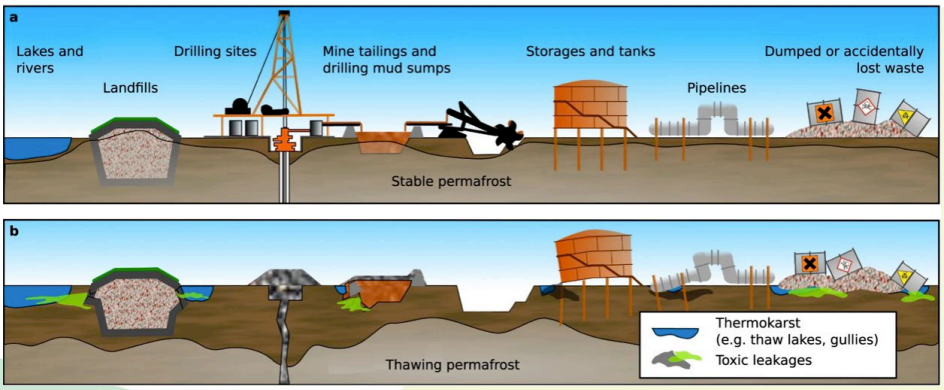


Fig. 41. (a) Warming and thaw of near surface permafrost unlocks frozen disposal sites and destabilizes foundations and containment structures. (b) Permafrost thaw intensifies thermo-hydrological erosion and increases the lateral flow of water, fostering the dispersion of contaminants (Langer *et al.*, 2023).

NEW ZEALAND

BY TANYA O'NEILL (UNIVERSITY OF WAIKATO) AND MARJOLAINE VERRET (VICTORIA UNIVERSITY OF WELLINGTON)

UNIVERSITY OF WAIKATO, MANAAKI WHENUA - LANDCARE RESEARCH, & UNIVERSITY OF CANTERBURY

Soil permafrost temperature monitoring

Manaaki Whenua - Landcare Research, the University of Waikato, and the Natural Resource Conservation Service of the United States Department of Agriculture maintain a network of soil-permafrost climate stations in the Ross Sea region of Antarctica. Pete Wilson (University of Canterbury) and Ben Roche (Waikato University) travelled to Antarctica in early December 2022, followed by Justin Harrison (University of Canterbury) and Marte Hofsteenge (University of Otago) in late November 2023, to undertake annual maintenance and data download (Fig. 42). The team also downloaded two 30 m borehole temperature strings, run in collaboration with Mauro Guglielmin (Italy). The data contribute to the Circum-polar Active Layer Monitoring (CALM) programme and Global Terrestrial Network for Permafrost (GTN-P). Permafrost and soil climate data were published in a joint Antarctic-wide paper.

- Hrbáček, F., *et al.* (2023). Active layer and permafrost thermal regimes in the ice-free areas of Antarctica. *Earth-Science Reviews*, 242. DOI: 10.1016/j.earscirev.2023.104458.

Fig. 42. Bull Pass borehole in the McMurdo Dry Valleys. Photo: Justin Harrison.

VICTORIA UNIVERSITY OF WELLINGTON

The *Friis Hills Drilling Project* team continued to uncover past climatic conditions in the Transantarctic Mountains based on the oldest permafrost record. The middle Miocene climate period is relevant to understand the response of the East Antarctic Ice Sheet to future anthropogenic climate change. The team also investigated the late Miocene onset of hyper-aridity in East Antarctica indicated by meteoric beryllium-10 in permafrost, which addresses the question "When were the Dry Valleys of Antarctica last wet?".

Preliminary work on the near-surface organic processes at Friis Hills (Fig. 43) was done in collaboration with the New Zealand Institute of Geological and Nuclear Sciences and showcased at the 31st International Meeting on Organic Geochemistry in September 2023. Finally, a review paper on Antarctic permafrost and ground ice conditions was submitted to ICOP2024 to summarize decades of research in ice-free areas of Antarctica.

- Chorley, H., *et al.* (2023). East Antarctic Ice Sheet variability during the middle Miocene Climate Transition captured in drill cores from the Friis Hills, Transantarctic Mountains. *GSA Bulletin*, 135(5-6). DOI: 10.1130/B36531.1.
- Verret, M., *et al.* (2023). Late Miocene onset of hyper-aridity in East Antarctica indicated by meteoric beryllium-10 in permafrost. *Nature Geoscience*, 16. DOI: 10.1038/s41561-023-01193-4.

For more information contact Tanya O'Neill (toneill@waikato.ac.nz).

Fig. 43. The top of Friis Hills across the sedimentary basin containing Miocene permafrost. Photo: Richard Levy.

NORWAY

BY ARNE INSTANES (UNIVERSITY CENTRE IN SVALBARD, UNIS) AND BERND ETZELMÜLLER (UNIVERSITY OF OSLO)

NORWEGIAN GEOTECHNICAL INSTITUTE (NGI)

35-years of deep ground temperatures

In 1987, NGI instrumented four boreholes on Svalbard to record coastal soil temperatures. The boreholes (70-100 m depth) were established in the coal-mining settlement of Svea and in the town of Longyearbyen. Only two boreholes remain, one in each location, and comprise the longest continuous records of permafrost temperatures in Svalbard. In 2022, the surficial part of the last remaining site in Svea was accidentally destroyed by contractors tasked with erasing traces of 100-years of coal mining activities. Thankfully, they realized the mistake in time and collaborated with NGI to facilitate the re-establishment of the borehole. Luckily, the thermistor cable was still in place, and instrumentation was successfully reconnected by Kjersti Gisnås and Graham Gilbert in May 2023 (Fig. 44).

The valuable data sets from Svea and Longyearbyen can be used for educational and research purposes. Results from 35-years of deep ground temperatures show a clear warming to 25 and 50 m depth in Longyearbyen and Svea, respectively, with an accelerated warming in the past 20 years.

- Gisnås, K.G., Gilbert, G.L., and Ketil, I. (2023). 35-years of coastal permafrost warming in Svalbard – analysis of two, 70-100 m deep, boreholes. *EUCOP6: Book of Abstracts*, p. 532.

GPR-investigations of cultural heritage sites

In 2022, NGI with the Norwegian Institute for Cultural Heritage Research (NIKU) conducted GPR surveys at the archaeological site at Russekeila, Kapp Linné, Svalbard. GPR was an efficient tool for mapping the wooden remains of the huts. The preferred antenna frequency was 500 MHz, which provided the best balance between the required penetration depth and the desired resolution. GPR data processing improved the signal-to-noise (S/N) ratio and eliminate background signal and noise, which highlighted the reflectors that represented the features of interest. Conclusions from interpretations of the GPR data:

1. Strong signals can be observed to ~0.5 m depth. After processing, several reflectors can be observed to 2 m, but the amplification of the signal is associated with additional noise.
2. The signal deteriorates where the radar pulses hit the wooden drifts of the huts (lower dielectric constant for wood than sediments). This is the most significant indicative feature of all the cultural heritage features surveyed.
3. Understanding the extent of the grave depths was challenging due to the precautions necessary to protect the fragile cultural heritage and the signal attenuation due to low S/N ratio over the uneven surfaces of the graves.

- Tavakoli, S. *et al.* (2023). First geophysical investigations to study a fragile Pomor cultural heritage site at Russekeila – Kapp Linné), Svalbard. *Journal of Cultural Heritage*, 63. DOI: 10.1016/j.culher.2023.08.005.

Fig. 44. Re-establishment of the Svea borehole (May 2023). Photo: Kjersti Gisnås.

Arctic landfill investigations

NGI is involved in several projects on the state and fate of Arctic landfills. Among others, Gijsbert Breedveld and colleagues have developed a *multi-criteria risk assessment of waste disposal sites under Arctic conditions* which allows a qualitative evaluation of the risk from Arctic waste disposal for both human health and the environment. The method is generic and can be applied to landfills and waste deposits across the Arctic. Thereby enabling practitioners and stakeholders to find solutions that are sustainable and take the future climate into consideration.

Another study looked at ground temperatures and chemical conditions in an Arctic landfill outside Longyearbyen. Borehole temperatures reveal there is no permafrost in the landfill today. Water measurements upstream and downstream show water passing the landfill has a 10x increase in electrical conductivity (from the dissolution of solids), confirming there is contaminant transport from the landfill. Permafrost no longer meets the requirements of a

geological barrier at this site. Its degradation with malfunctioning water mitigation structures might open more pathways for pollutants to enter the vulnerable Arctic ecosystem downstream of the landfill.

Ground deformation monitoring of Arctic tailings

NGI and University of Quebec (RIME-UQAT) mapped displacements at an Arctic tailings storage facility (TSF) in northern Canada using satellite-based radar interferometry. The long snow-covered seasons presented a challenge since they result in large data gaps that make consistent measurements across seasons difficult. Processing with a 60-day temporal baseline shows how these data gaps affect the analyses. Increasing the temporal baseline to 320 days, which (among others) allows the analyses to span over the winter period led to clearly improved results. Results show slight indications of upward and downward movements at the TSF surface during the analyses period, respectively on different slopes of the TSF. Yet, the measured displacement velocities at the TSF were generally small (<5 mm/year).

- Vöge, M., *et al.* (2022). Satellite-based radar interferometry for monitoring ground surface deformation of filtered tailings storage facilities in continuous permafrost regions. *75th Canadian Geotechnical Conference (GeoCalgary)*.

Svalbard Integrated Arctic Earth Observing System (SIOS)

In 2023, NGI became a member of SIOS and aims to contribute to state-of-the-art research in Svalbard and other polar regions with SIOS partners. NGI is currently represented in four groups, and is searching for new collaborations on relevant Arctic research projects and ongoing or new calls for proposals.

- Science Optimization Advisory Group (SOAG)
- Research Infrastructure Coordination Committee (RICC)
- Remote Sensing Working Group (RSWG)
- SIOS Data Management System Working Group (SDMS WG)

UNIVERSITY CENTRE IN SVALBARD (UNIS)

AG-352 'Geohazards and geotechnics in high Arctic permafrost regions' course

In 2019, AG-352 was developed under the INTPART-funded project, *Landscape & infrastructure dynamics of frozen environments undergoing climate change in Canada, Norway and Svalbard*. In 2022-2023, AG-352 was full with about 20 Norwegian and international students, and provided an opportunity to combine geoscience and engineering challenges for groups of combined backgrounds (Fig. 45). Unfortunately, UNIS doesn't have capacity to operate the course on an annual basis.

UArctic

In March 2023, UNIS co-organised the UArctic Interdisciplinary permafrost workshop in Longyearbyen, Svalbard. Several projects exchanged ideas and a community open evening workshop was hosted to inform and learn from locals about permafrost.

UNIS is a partner in the UArctic led project, *Designing and developing permafrost internships in the Arctic (PermaIntern)*, funded by the Danish UArctic (2022-2024). *PermaIntern* assists students in obtaining work experience in permafrost, finding internships and supervision. In spring 2023, masters student Mederic Lorry (France) studied at UNIS and assisted with permafrost drilling and cryostratigraphical analyses for *PermaMeteoCommunity*, supervised by PhD student, Knut Tveit. The *PermaIntern* online platform will launch during ICOP2024.

Under the Framsenter-funded project, *Advanced Mapping and Monitoring for Assessing Permafrost Thawing Risks for Modern Infrastructure and Cultural Heritage in Svalbard (PermaRICH)*, four bore-

Fig. 45. AG-352 course students using an electrical hand drill in upper Longyearbyen. Photo: Knut Tveit.

holes were drilled with other projects and partners close to cultural heritage sites in Longyearbyen to allow more understanding of how ongoing climatic changes are affecting the sites. *PermaRICH* aims to assess the risks related to terrain movement in inhabited permafrost landscapes and the deformation of modern infrastructure and cultural heritage sites in and around Longyearbyen and Ny-Ålesund.

In 2022, Hanne H. Christiansen started a 5-year role as UArctic Chair in Permafrost Physical Processes.

PermaRICH

The Fram Centre *PermaRICH* project, in collaboration with SINTEF, NIKU, NGU, and UNIS, works on assessing the hazards and risks related to terrain movement and deformation of modern infrastructure and cultural heritage sites in and around Longyearbyen and Ny-Ålesund.

PermaMeteoCommunity

Under the *Developing a permafrost and meteorological climate change response system to build resilience in Arctic communities (PermaMeteoCommunity)* project, a series of shallow (4-5 m) boreholes equipped with thermistors were drilled to cover landform variability in Longyearbyen. In 2023, a full-scale and three small-scale meteorological stations were set-up. All data flows into a response system which is being digitally developed with local companies, Where2O and Kolibri Geo Services. Geotechnical modelling is led by Instanes AS with NTNU, and will feed directly into the response system. How to develop the response system is being discussed with local partners, primarily Longyearbyen Lokalstyre. In 2022, Marius Jonassen and Hanne H. Christiansen received the Frederik Paulsen Arctic Academic Action Award for their work on the project.

Climatic forcing of terrestrial methane gas escape through permafrost in Svalbard (CLIMAGAS)

CLIMAGAS, a Norwegian Research Council funded project, mapped the dynamics and amount of GHG based on field sampling of methane from pingos and springs in central Svalbard, and developed models.

SIOS infrastructure project: InfraNor

Final installations were made for *InfraNor*. All boreholes send data directly to the Norwegian Meteorological Institute where it appears on Cryo and is fed into the SIOS data management system.

NORWEGIAN RESEARCH CENTRE (NORCE)

At NORCE Energy&Technology, several projects focus on exploiting spaceborne Interferometric Synthetic Aperture Radar (InSAR) to detect ground surface movement related to permafrost creep and freeze/thaw in the Norwegian Arctic.

InSAR Svalbard

InSAR Svalbard, a development project funded by the Norwegian Space Agency, in partnership with NGU, started in 2023. It will set the foundation of an upcoming Ground Motion Service (GMS) tailored for permafrost terrain, complementing existing services in the mainland (e.g., InSAR Norway and EGMS).

ESA CCI Permafrost

Within *ESA CCI Permafrost*, NORCE collaborates with UiO in a pilot project aiming to exploit InSAR to indirectly document subsurface properties and constrain ground thermal models in permafrost regions. NORCE is also part of the mountain permafrost group of *ESA CCI Permafrost*, which develops remotely sensed climate change indicators tailored for cold mountain ranges. The objective is to document the creep rate of rock glaciers, known to be sensitive to changing climatic conditions.

- Rouyet, L., *et al.* (2021). Regional Morpho-Kinematic Inventory of Slope Movements in Northern Norway. *Frontiers in Earth Science*, 9. DOI: 10.3389/feart.2021.681088.
- Lilleøren, K.S., *et al.* (2022). Transitional rock glaciers at sea level in northern Norway. *Earth Surface Dynamics*, 10(5). DOI: 10.5194/esurf-10-975-2022.
- Bertone, A., *et al.* (2022). Incorporating InSAR kinematics into rock glacier inventories: insights from 11 regions worldwide. *The Cryosphere*, 16(7). DOI: 10.5194/tc-16-2769-2022.

PRISM

The INTPART-funded, PRISM, led by NORCE Climate&Environment focuses on enhancing international collaborations to discuss the consequences of permafrost thaw on nature and society. In 2022-2023, various networking and educational activities were organized in Europe and Asia.

EMERALD

For the *EMERALD* project, NORCE Climate&Environment continued field observations of CO_2 and CH_4 emissions along permafrost thaw gradients in a

Fig. 46. Research site in a degrading permafrost peatland, Iškoras, northern Norway.

degrading permafrost peatland at Iškoras, northern Norway (Fig. 46). An Eddy Covariance system run by the UiO is also measuring continuous CO_2 and CH_4 emissions over the entire palsa complex to assess the net carbon balance. The site has been integrated into the Land Sites Platform, a novel tool to make climate-ecosystem modelling more accessible.

NORWEGIAN METEOROLOGICAL INSTITUTE (MET NORWAY)

MET Norway renewed permafrost stations with a new setup that provides data in near real-time and direct transmission for operational monitoring in Norway and Svalbard. In 2023, the Dovrefjell station (DB1), which has been in operation for over 20 years, underwent an upgrade (Fig. 47). The data can now be viewed on Cryo. Collaborative efforts between MET Norway, UiO, UNIS, and AWI are underway to renew existing permafrost monitoring stations and establish new ones that transmit ground temperature data in real time. In July 2023, AWI and MET Norway carried out field campaigns at Bayelva and Kvadehuken in Ny-Ålesund. They intend to establish a CryoNet site for the Global Cryosphere Watch Surface Network.

UNIVERSITY OF OSLO (UiO)

The Department of Geosciences conducted field campaigns in Mongolia in spring and summer, with the Institute for Geography and Geoecology, Mongolian Academy of Sciences, and the National University of Mongolia (Fig. 48). The goal is to (i) understand the role of forest cover for the winter and summer surface energy balance, including the impact on permafrost, and (ii) the impact of grazing on ground surface temperatures in winter and summer.

Fig. 47. Dovrefjell station (DB1) and Snøhetta mountain (left). Logger box used at DB1 for permafrost monitoring (right).

Fig. 48. Steppe and forest in a typical valley setting in Mongolia. Photo: Robin Zweigel.

UiO also visited the Brøgger Peninsula, Ny-Ålesund, to read out ground temperature loggers.

Permafrost peatlands in northern Norway were investigated for the *BioGov* project to understand the carbon balance and GHG emissions. The team conducted eddy covariance measurements and collected samples for incubation experiments and biogeochemical analysis in the laboratory.

UiO participated in a regional research project in Jotunheimen, central southern Norway, to investigate how changes in the cryosphere influence and possibly threaten mountaineering activities in the area. This is in cooperation with the Norwegian Competence Center for Mountain Security, Mountain Museum in Lom, MET Norway, and others.

In northern Norway/Finnmark rock glacier dynamics and temperature observations continued, focusing close to sea level in the Tana and the Varanger region. Active rock glaciers close to sea level were observed in areas outside the topographic sites where permafrost is expected. With NORCE, InSAR interpretation shows intermediate rock glacier velocities.

UiO is a partner for *PermaIntern* (see p. 46) and organized a pilot internship at MET Norway in 2023.

For more information contact Arne Instanes (arne@instanes.no) and Bernd Etzelmüller (bernd.etzelmuller@geo.uio.no).

POLAND

BY RAJMUND PRZYBYLAK (UNIWERSYTET MIKOŁAJA KOPERNIKA), ARTUR MARCINIAK (INSTYTUT GEOFIZYKI POLSKIEJ AKADEMII NAUK), ŻANETA POLKOWSKA (POLITECHNIKA GDAŃSKA), MATEUSZ STRZELECKI (UNIWERSYTET WROCŁAWSKI), AND WIESŁAW ZIAJA (UNIWERSYTET JAGIELLOŃSKI)

INSTITUTE OF GEOPHYSICS, POLISH ACADEMY OF SCIENCES

In 2022-2023, several manuscripts were published on the shape and variability of permafrost around Hornsund. The bottom of permafrost was imaged for the first time, and the extent of seasonal variation in the physical parameters of the active layer and ground in the cryotic state was determined.

- Majdański, M., *et al.* (2022). Variations of permafrost under freezing and thawing conditions in the coastal catchment Fuglebekken (Hornsund, Spitsbergen, Svalbard). *Permafrost and Periglacial Processes*, 33(3). DOI: 10.1002/ppp.2147.
- Marciniak, A., *et al.* (2022). Multi-method geophysical mapping of ground properties and periglacial geomorphology in Hans Glacier forefield, SW Spitsbergen. *Polish Polar Research*. DOI: 10.24425/ppr.2022.140363.
- Marciniak, A., *et al.* (2024). The hypothesis of the shape of the permafrost in Hornsund, Spitsbergen and the potential impact of its degradation on the Arctic. *Catena*, 235. DOI: 10.1016/j.catena.2023.107689.

GDAŃSK UNIVERSITY OF TECHNOLOGY & KAZIMIERZ WIELKI UNIVERSITY

In 2022-2023, permafrost research was jointly conducted by Kazimierz Wielki University (Danuta Szumińska, Krystyna Kozioł, Sergiej Chalov, Sebastian Czapiewski) and Gdańsk University of Technology (Żaneta Polkowska, Tomasz Dymerski, Filip Pawlak, Joanna Jóźwik, Małgorzata Szopińska), in collaboration with the University of Gdańsk (Kamil Nowiński, Wojciech Tylman, Ewa Formela), Adam Mickiewicz University, Poznań (Marcin Frankowski), and UMCS (Sara Lehmann-Konera). The aims are to determine whether permafrost acts as a secondary source of pollution in surface waters, what types of pollutants are subject to such a problem – and what are their primary sources? This was conducted within the scope of two externally funded research projects:

1. *Organic pollution in freshwaters of the Russian Arctic – does it originate from permafrost thaw? (PollAct)*. 2021-2022. PI: Danuta Szumińska; funded by INTERACT (Fig. 52).
2. *PERsistent organic pollutant remobilisation from PERmafrost into surface Waters (PER-2Water)*. 2022-2026. PI: Danuta Szumińska with Żaneta Polkowska (Gdańsk Tech); funded by the National Science Centre of Poland.

Water and sediment samples were collected from lakes and streams of various order in Siberia (2021), Finland (2022), and Alaska (2023), including rivers terminating in the Arctic Ocean fed by Yedoma thaw (Fig. 49). The research is collaborated with University of Fairbanks Alaska (Torre Jorgenson, Mikhail Kanevsky, and Benjamin Jones). Results were presented at (i) Arctic Science Summit Week in Vienna, Austria, (ii) XII Scientific Assembly of the International Association of Hydrological Sciences in Montpellier, France, (iii) "Influence of local sources vs. long-range transport of organic contaminants in the Arctic" workshop in Lyngby, Denmark, and (iv) two Polish conferences.

- Szumińska, D., *et al.* (2023). Reemission of inorganic pollution from permafrost? A freshwater hydrochemistry study in the lower Kolyma basin (North-East Siberia). *Land Degradation & Development*, 34(17). DOI: 10.1002/ldr.4866.

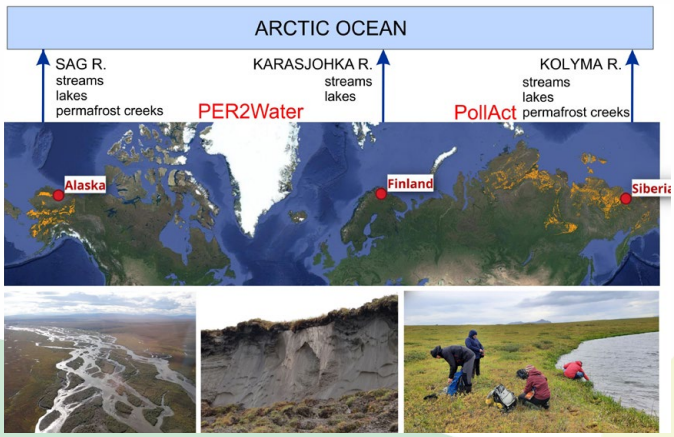


Fig. 49. Study sites for PollAct and PER2Water (prepared with Natural Earth, ©2023TerraMetrics). Photo: Danuta Szumińska.

UNIVERSITY OF WROCŁAW

2023 has been one of the most important years for the development of periglacial and permafrost research in Poland. Important milestones included the active participation of Polish scientists at EU-

COP6. Mateusz Strzelecki chaired the debate *"The Future of Permafrost Research"* with Gonçalo Vieira, Isabelle Gartner-Röer, and Hugues Lantuit, and will organise EUCOP2030 in Poland. The Alfred Jahn Cold Regions Research Centre, dedicated to the study of permafrost and periglacial environments opened in September 2023 (Fig. 50).

Under the Cryosphere Integrated Observatory Network on Svalbard (CRIOS) project (Polish-Norwegian initiative) scientists planned to drill boreholes at four Polish stations in Spitsbergen, Svalbard: the Hyttevika-Steinvika area (Hornsund Fjord region), the UMCS station in Calypsobyen, the UMK station in Kaffioyra, and the UAM station in Petuniabukta (Fig. 51). The boreholes (up to 10 m depth) were instrumented with an 18 sensor thermistor string to observe changes in ground temperature. Permafrost on Svalbard is subject to increasing degradation under climate change. Ground temperature monitoring will record changes occurring directly below the land surface. Three boreholes were successfully drilled under difficult geological and weather conditions.

- UMK station in Kaffioyra: located at the existing meteorological garden ~100 m from the shoreline (Fig. 52). The substrate is dominated by loose sandy-gravel beach sediments. A large amount of fine material made it possible to reach a depth of 10 m.
- UAM station in Petuniabukta: located ~50 m from the shoreline in the zone between the Polish and Czech stations. Siltstone and sandstone is covered by thick-bedded beach sediments. A depth of 7 m was reached.
- UMCS station in Calypsobyen: siltstone and sandstone forms relict abrasion platforms covered by loose sand and gravel beach sediments. Located near the mouth of the Scott River ~75 m from the shoreline and 900 m from the station. A depth of 5 m was reached.

For more information see:

- Ziaja W., *et al.* (2023). Coastal landscape degradation and disappearance of Davislaguna Lake, Sørkappland, Svalbard, 1900–2021. *Land Degradation & Development*, 34(16). DOI: 10.1002/ldr.4765.

For more information contact Rajmund Przybylak (rp11@umk.pl).

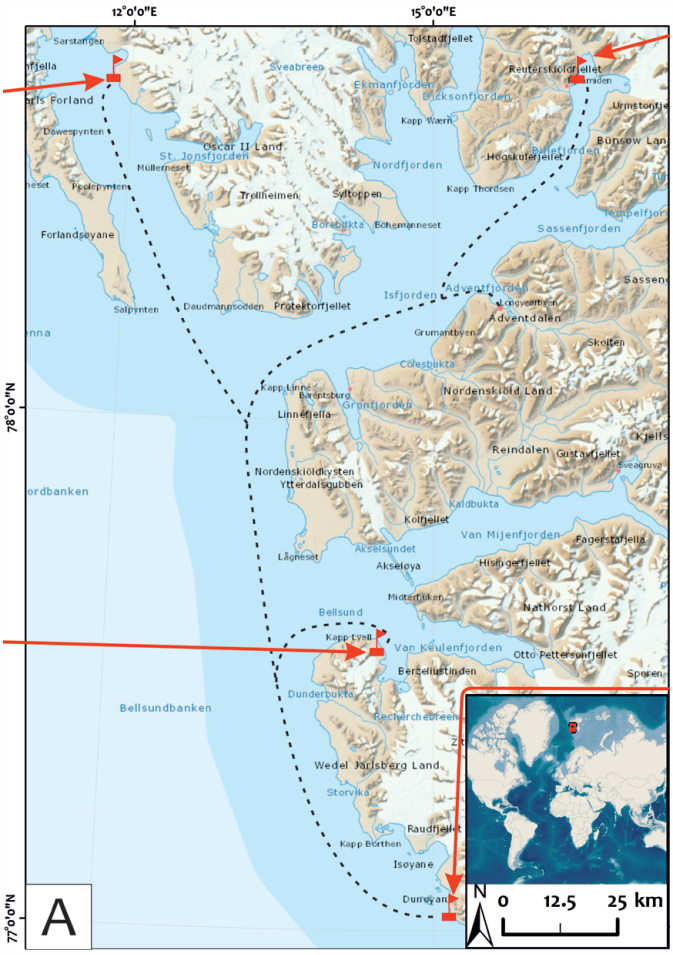


Fig. 51. Boreholes at the UMK (top left), UMCS (middle), and UAM (top right) stations. Failed borehole drilling in the Hyttevika-Steinvika area (bottom right). Topographic map and orthophoto provided by the Norwegian Polar Institute.

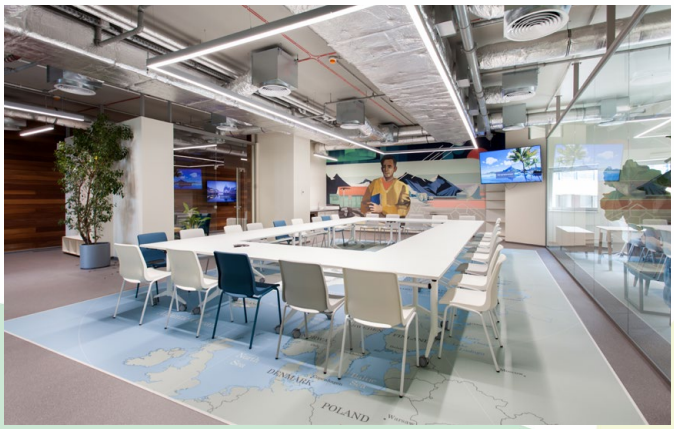


Fig. 50. Alfred Jahn Cold Regions Research Centre in Wrocław.

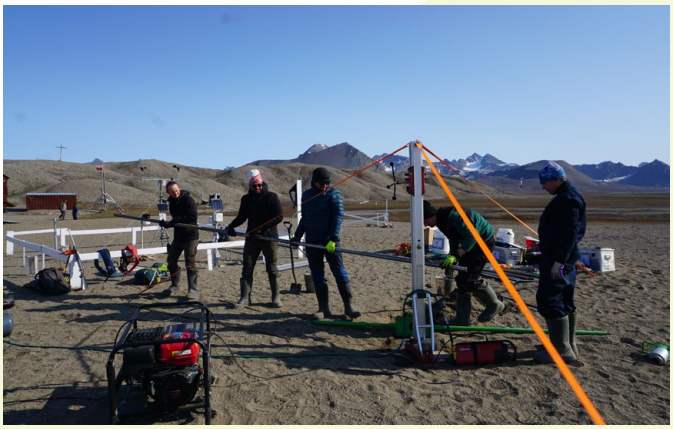


Fig. 52. Drilling boreholes at UMCS in Kaffiøyra, Spitsbergen.

PORTUGAL

BY PEDRO PINA (UNIVERSIDADE DE COIMBRA)

In 2022-2023, permafrost activities in Portugal were still affected by COVID-19, but started to return to normality in the amount, duration, and number of researchers in the field.

INSTITUTO DE GEOGRAFIA E ORDENAMENTO DO TERRITÓRIO (IGOT), UNIVERSIDADE DE LISBOA

The team at Centre of Geographical Studies, Associate Laboratory TERRA, led by Gonçalo Vieira, continued to focus on (i) Antarctic Peninsula permafrost and climate change; (ii) Beaufort Sea coastal erosion; and (iii) thaw lakes in Nunavik, Canada. The *Antarctic Peninsula permafrost under a changing climate: sensitivity, fate and impacts (THAWIMPACT)* is a new three year FCT-funded project that links permafrost temperature observations from the PERMANTAR network, geomorphological and vegetation mapping, and contaminant samples (mainly Hg), with thermal modelling using the CryoGrid Community Model to assess recent and future changes in the terrestrial environments of the NW Antarctic Peninsula. *THAWIMPACT* is led by Gonçalo Vieira with João Canário as co-PI. It also involves Pedro Pina (University of Coimbra) and Sofia Ermida (IPMA), and international partners from Austria, Brazil, Bulgaria, Czechia, Korea, Norway, and Spain. *THAWIMPACT* frames the PhD theses of Henrique Zilhão (contaminants), Joana Baptista (permafrost modelling), and Vasco Miranda (vegetation), and the MSc theses of Bárbara Afonso (snow and vegetation) and Vasco Veríssimo (geoecology).

The *BIOCRUST* project, led by Paula Matos, researches topo- and microscale controls on vegetation communities in the ice-free areas of the South Shetlands. Research in the Beaufort Sea coast was conducted as a continuation of Nunataryuk and ESA EO4PAC, through a collaboration with the Geological Survey of Canada (Dustin Whalen) and the University of Northumbria (Michael Lim). Bernardo Costa participated in the field season for their research on coastal changes in the Tuktoyaktuk Peninsula using field mapping and monitoring and remote sensing.

Research on the permafrost thaw lakes in Nunavik is conducted in the framework of the *PERMAMERC* (co-PI: Gonçalo Vieira) and *THAWPOND* (PI: Carla Mora) projects. The CEG team focusses on the analysis of optical and chemical properties of small lakes and ponds using field data and remote sensing imagery (drones and very high-resolution satellites). The projects are collaborations with Centro de Química Estrutural of Instituto Superior Técnico (João Canário), CIIMAR at University of Porto (Catarina Magalhães), Centre of Northern Studies at Université Laval (Warwick F. Vincent and Raoul Couture), and Trent University (Holger Hintelmann). PhD student, Pedro Freitas, has developed an algorithm for automatic delineation of small lakes and ponds applied to PlanetScope imagery, which allowed the mapping of over 300,000 water bodies in Nunavik. This unprecedented high-resolution data set will be publicly available in 2024 and will be used for analysing lake morphometry and optical properties, and their relations with water biogeochemical parameters. Master's student, Diana Martins, is conducting ultra-high resolution vegetation mapping and geoecological analysis of a tundra-forest transition sector in Kangiqsualujjuaq with Pascale Roy-Léveillée (Université Laval).

CENTRO DE QUÍMICA ESTRUTURAL (CQE), UNIVERSIDADE DE LISBOA

The team researched the impact of permafrost thaw in carbon and contaminant dynamics in Nunavik (Canada), Fairbanks (Alaska), Greenland, and South Shetland Island (Antarctica). Concerning the carbon dynamics, the aim is to access the chemical composition of natural organic matter in thermokarst lakes and their role in the biogeochemical processes that lead to greenhouse gases release. A special benthic flux chamber was developed to access the benthic fluxes of natural organic matter and some contaminants in the sediment/water interface. Several structural chemical techniques have been used and the major functional groups were identified. Work has been done in the Arctic and Antarctic to quantify the release of contaminants once permafrost thaws and understand the biogeochemical processes that may alter their speciation to estimate their impacts in the environment. Special attention has been given to mercury and arsenic. This is supported by *PERMAMERC*, *THAWIMPACT*, *THAWFLUX*, and Nunataryuk.

UNIVERSIDADE DE ÉVORA

In 2022-2023, the Institute of Earth Sciences (IES) did not conduct field activities. Cooperation between

IES and the Peruvian Polar Program (*HYDROPERMA 3*) was cancelled. In 2024, *HYDROPERMA 3* and *PERMALAPSE* will be conducted with the Korean Polar Research Institute (KOPRI) at the King Sejong Station in King George Island. Data from previous field campaigns was processed and analysed for publication. In 2023, António Correia presented (i) "Why studying the poles? My experience in Antarctica" to a general audience for the Day of the Earth; (ii) a webinar to the Portuguese Association of Geologists; and (iii) "Antarctica, a continent poorly understood" to the Portuguese Centre for Underwater Activities.

UNIVERSIDADE DE COIMBRA

Activities developed at the Instituto Dom Luiz (IDL) focused on the synergistic use of remote sensing to map and monitor vegetation at large scale (in the Antarctic Peninsula) and locally patterned ground, such as sorted stone circles (at Barton Peninsula in King George Island). Since 2020, mapping of the vegetation for the *VEGETANTAR* project (PI: Pedro Pina) has developed an original methodology to identify and discriminate the main types of vegetation (lichens and mosses) at the scale of Landsat satellites (30 m spatial resolution), which are the only data series that can allow an extended temporal evaluation (since 1970s). The occurrence of the vegetation in small and sparse patches (normally below the resolution of Landsat images) makes this identification very challenging. The use of other satellite images (WordView and Sentinel) and specially UAV (Unoccupied Aerial Vehicles) imagery at a much better resolution has allowed to unmix the content of the Landsat pixels and build robust machine learning classifiers to create accurate vegetation maps. The classification models were developed and calibrated with recent remote sensing datasets in Barton Peninsula, where ground-truthing was intensively performed and later applied to previous datasets up to the mid-1980s. Currently, the same classification models are being applied (with some fine tuning) to other ice-free areas in the South Shetlands and in the western Antarctic Peninsula by PhD student, Vasco Miranda. The CAMOES project (PI: Pedro Pina) began developing a framework to map and monitor sorted stones circles using ultra-high-resolution images (millimetric). Field activities to Barton Peninsula with KOPRI were delayed until 2024.

The *ANTERMON* project, led by Mohammad Farzamian, focused on maintaining three autonomous Electrical Resistivity Tomography (A-ERT) monitoring sites on Deception, Livingston, and King George Islands during the last two years. Additionally, Farzamian co-led the *PERM2ERT* techno grant project funded by the Swiss Polar Institute, which aimed to develop new robust, low-cost A-ERT setups with satellite datalink (real-time data transmission) for installation in remote permafrost regions worldwide. Four A-ERT systems were built at CEG/IGOT and deployed in James Ross Island (Antarctica), the Swiss Alps (Europe), Kyrgyzstan (Central Asia), and Yukon (Canada). The objective was to establish an international A-ERT monitoring network to analyse ground ice evolution and active layer/permafrost dynamics in regions experiencing climate change. Farzamian collaborated with various international institutions to develop open-source processing tools for A-ERT data. These were published in *Geophysical Research Letters* and *The Cryosphere*. The ERT and A-ERT data were incorporated into the IPA Action Group, *Towards an International Database of Geoelectrical Surveys on Permafrost (IDGSP)*, where Farzamian served as a steering committee member. IDGSP aims to integrate historical and recent ERT surveys in permafrost regions, define standardized QA/QC criteria, promote ERT measurement repetition, develop standard permafrost resistivity data, and raise awareness of geophysical data value within the permafrost community.

Several members of IPA-Portugal participated at EUCOP6, including Gonçalo Vieira's keynote plenary lecture on a review of the state of the art of the permafrost in the NW Antarctic Peninsula.

For more information contact Pedro Pina (ppina@dct.uc.pt).

ROMANIA

BY PETRU URDEA (UNIVERSITY OF TIMIŞOARA)

In 2022-2023, the West University of Timişoara (WUT) and Bucharest University (UB) studied periglacial geomorphology and permafrost in Carpathians Mountains. *The response of climate-sensitive environments to global warming, sea-level rise and increasing extremes: the Carpathians and Danube Delta (ClimaLAND)* is conducted with University of Oslo (UiO) and funded by Iceland, Liechtenstein, and Norway. It aims to enrich the global picture of geomorphic responses to recent climate changes, zooming in two contrasting, but equally sensitive environments: Romanian Carpathians and Danube Delta. The objectives are to identify the intervals of high-geomorphic impact during Holocene (geochronology of events, processes, climate correspondence) and estimate the evolution of the periglacial landforms in relation to climatic triggers (permafrost degradation, rock glacier chronology, rock falls activity, etc.).

In 2021, fieldwork was conducted at Galeșu (Retezat Mountains) and Căldarea Pietroasă rock glaciers (Făgăraş Mountains) with Dr. Christin Hilbich (University of Fribourg), managing geophysical surveys. The purpose was to collect (i) seismic refraction tomography and electric resistivity tomography data, (ii) topographic surveys using TLS and UAV to provide high accuracy digital elevation models of the landforms and start dynamics monitoring, (iii) surface exposure samples for absolute relative dating, and (iv) data from temperature sensors (Fig. 53).

In March 2022, WUT measured the bottom temperature of the snowpack (BTS) at seven rock glaciers in Retezat Mountains (Galeșul, Valea Rea, Pietricelele, and Pietrele) and Parâng Mountains (Roșiile I, Roșiile II, and Geamănarea). About 240 BTS points were measured. Snow depth was 80-300 cm and the temperature was 0.3 to -12 °C. At all rock glaciers, BTS values showed surface variations, however, the values specific to the areas characterized by the presence of permafrost predominated. The results help interpret the characteristics of permafrost and local conditions that favor its preservation.

In 2022, an automatic Campbell Scientific meteo station was installed on the western flank of the Căldarea Pietroasă cirque (Făgăraş Mountains) (Fig. 54). Remote sensing measurements were repeated for landform dynamics monitoring (UAV and TLS surveys). Geodetic and geophysical investigations were also carried out in the Pirin Mountains (Bulgaria).

In February 2023, snow layer measurements were collected in the upper sector of Galeșu valley (Retezat Mountains) to estimate snow volume by comparing between the terrain surface model with and without snow. In July 2022, PhD student, Oana Berzescu, collected samples for rock hardness with a Digital Schmidt Hammer from the rock glacier in Valea Rea. In 2022-2023, temperature measurements and chemical and physical samples from rock glacier springs were collected in Retezat Mountains.

Fig. 53. Geophysical surveys on Căldarea Pietroasă rock glacier (Făgăraş Mts.). Photo: Petru Urdea.

Fig. 54. Installation of the automatic Campbell Scientific meteo station on Căldarea Pietroasă cirque. Photo: Alexandru Onaca.

In the field temperatures were measured using a digital thermometer, while thermistors installed in the springs were used for continuous monitoring. Measurements made seasonally (summer/autumn) and continuously recorded cold temperatures, below the thermal limit of permafrost springs (2°C).

In April 2022, two boreholes were drilled in the alpine area of Făgăraş Mountains at Bâlea Lake (2034 m asl, 9.5 m deep) and Buda Lake (2068 m asl, 5 m deep) to establish the dynamics of the slope processes and paleo-environmental conditions.

Another project with results of great importance for our permafrost community was that of Răzvan Popescu (UB). The objectives of the *Low altitude permafrost from temperate regions: response to climate variability and environmental drivers* project were to (i) advance knowledge on the ground air circulation and subsurface permafrost changes in relation to environmental drivers; (ii) start a long-term temperature monitoring program of the permafrost and cold reservoir at Detunata Goală (1066 m asl), a key site for monitoring the climate variability impact on cold screes; and (iii) conduct inter-site analysis and comparison of multiple Low Altitude Permafrost sites. This was the first drilling site with permafrost in Romania. The borehole (15 m deep) was equipped with thermistors to test the presence and inter-annual persistence of permafrost, and monitor climate variability and impact at a regional level (Fig. 55).

Fig. 55. Borehole at Detunata Goală. Photo: Răzvan Popescu.

Two field campaigns to Galeșul rock glacier were conducted for Andrei Ioniţă's PhD on *"Monitoring snow depth distribution and coverage over the Retezat Mountains rock glacier using UAVs and SfM Photogrammetry"* (Fig. 56). The purpose was to collect UAV images for photogrammetric processing and snow depth measurements using a snow probe and RTK GPS in order to create high-resolution maps of snow depth distribution and coverage during both periods and analyze changes between the surveys using the DEM of Difference technique and orthomosaic supervised classification. The results served to evaluate the accuracy and limitations of the method and laid the groundwork for future snow research and monitoring endeavors in Retezat Mountains. The data will be correlated with permafrost distribution models and studies on ground temperature for further analysis.

Răzvan Popescu's book on *Permafrostul din Carpații Românești. Studiu de Geomorfologie* (Permafrost from the Romanian Carpathians. Study of Geomorphology) was honored in December 2023 with the *Simion Mehedinţi Award* of the Romanian Academy.

A second project on *Climate- and tectonics-related surface processes in the Southern Carpathians and Northern Balkan Mountains. A geochronological approach at different timescales (ChronoCaRP)* (2023-2026) focuses on the response of the periglacial environment to climate variations subsequent to glacier retreat, including: (i) rock glaciers and rock slope failures (RSF) mapping; (ii) rock glacier inventory, cartographic GIS database; (iii) sampling for CRN datng of periglacial landforms; and (iv) modelling the spatial extent of permafrost during the Holocene in Southern Carpathians (Romania), and Rila and Pirin Montains (Bulgaria).

For more information contact Petru Urdea (petru.urdea@e-uvt.ro).

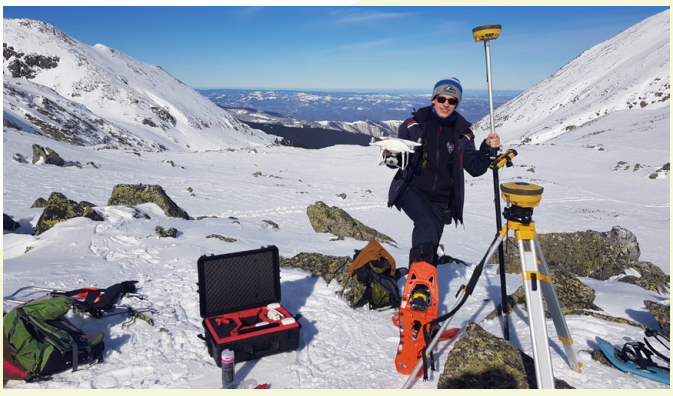


Fig. 56. Field campaigns at Galeșu rock glacier. Photo: A Ioniță.

SOUTH KOREA

BY YOO KYUNG LEE (KOPRI)

KOREA POLAR RESEARCH INSTITUTE (KOPRI)

Circum-Arctic Environmental Changes: Monitoring, Assessment, Projection, and Adaptation Strategy Development (CA-MAP)

CA-MAP is supported by the Ministry of Science and ICT (MSIT) and National Research Foundation (NRF) of Korea. Since April 2021, the project has observed, analyzed, and predicted environmental change in areas most vulnerable to climate change (permafrost, the atmosphere, and Arctic coast) and developed response technologies.

In 2021-2023, the team acquired an environmental data set of 29 environmental factors (83 over three years) at five circum-Arctic permafrost sites in United States, Canada, Svalbard, Greenland, and Iceland. They created quantitative results in applying for three domestic patents, including a thermal control technology of polar-battery and an artificial intelligence-based air mass path prediction method. Representative achievements include elucidating the impact between atmospheric Dimethyl Sulfide (DMS) and changes in marine phytoplankton in the Arctic Ocean, revealing the interaction between increased soil nitrogen availability and reduced methane oxidation in the Arctic ecosystem, and securing a large number of sediment samples from Svalbard in the Arctic through Korea-Norway cooperation.

Ny-Ålesund site, Svalbard

For long-term monitoring of aerosol particles and climate-relevant gases in the Arctic atmosphere, multiple analytical devices are operating at the Ny-Ålesund site with KOPRI, POSTECH, GIST, Stockholm University, University of Florence, Norwegian Polar Research Institute, and Norwegian Institute for Air Research. In 2022-2023, the team analyzed atmospheric DMS (a precursor of aerosol particles) mixing ratios, molecular complex of airborne particles, and cloud condensation nuclei measured at the Zeppelin and Gruvebadet observatories. Multiple data-sets obtained at the Ny-Ålesund site were used to identify the physiochemical processes controlling atmospheric aerosol particles and their relation to biogenic sources in a changing Arctic environment.

They have also reconstructed past climate and environmental conditions in Svalbard since the last deglaciation through international joint marine geological cruises to the Svalbard complex fjord systems to provide a paleo-analog to improve our understanding of ongoing environmental changes. The Korea-Norway international cruises were conducted several times in 2015-2023 using a research vessel of RV Helmer Hanssen, affiliated with UiT in Tromsø, Norway. In 2023, new geophysical data of the submarine seafloor and some glacimarine sediment cores were collected from Kongsfjorden and surrounding fjord systems. These sediment cores are being analyzed at KOPRI to improve our understanding of past and ongoing environmental changes in response to climate variability in the Svalbard archipelago from the last deglaciation through the modern warming period.

- Jang, K., *et al.* (2023). Non-linear response of glacier melting to Holocene warming in Svalbard recorded by sedimentary iron (oxyhydr) oxides. *Earth and Planetary Science Letters*, 607. DOI: 10.1016/j.epsl.2023.118054.
- Kim, D., *et al.* (2023). Large contributions of petrogenic and aged soil-derived organic carbon to Arctic fjord sediments in Svalbard. *Scientific Reports*, 13.

Council site, Alaska

In 2022-2023, CO_2 flux was measured between the atmosphere and ground surface as well as weather condition and radiative energy. In 2022, the team also surveyed CH_4 concentrations for the first time within 2 km of the Council site and discovered some CH_4-emitting spots. In 2023, they acquired CH_4 concentration at two levels above ground to estimate CH_4 flux between the atmosphere and ground surface. The team also enhanced vegetation monitoring by adding an NDVI sensor (Fig. 57).

In 2023, geophysical surveys at a snow manipulation experiment site showed soil moisture distribution, the boundary between frozen and thawed layers, and higher snow depths resulted in a deeper active layer. Gas, soil, and water samples are being analyzed at KOPRI to investigate the effects of snowfall.

- Kim, Y.J., Kim, J., and Jung, J.Y. (2023). Responses of dissolved organic carbon to freeze–thaw cycles associated with the changes in microbial activity and soil structure. *The Cryosphere*, 17(7). DOI: 10.5194/tc-17-3101-2023.

Fig 57. Monitoring CH_4 flux (top; June 2022) and NDVI and PAR (bottom; July 2023) at the Council site, Alaska.

- Lee, J., *et al.* (2023) Attenuation of Methane Oxidation by Nitrogen Availability in Arctic Tundra Soils. *Environmental Science & Technology*, 57(6). DOI: 10.1021/acs.est.2c05228.

Cambridge Bay site, Canada

Since 2012, the team have monitored long-term CO_2 and energy exchange between the atmosphere and the ecosystem using an eddy covariance flux system coupled with a net radiometer. During the COVID-19 pandemic they mostly focused on data retrieval and the status of instruments. However, data was not fully retrieved resulting in significant data loss. They trained a Cambridge Bay resident to backup data and maintain instruments during winter. Since July 2013 an aethalometer has moitored real-time ambient black carbon concentration with a time resolution of 10 minutes. Lastly, the team investigated the response of tundra ecosystem to changing snowfall in Cambridge Bay and Council, Alaska. In 2022, a field campaign found higher nitrogen contents in plant leaves under high snow. Since 2022, soil gas flux has been measured through a chamber-based method and/or continuous gas monitoring system.

- Kim, Y.J., *et al.* (2022). Chronological changes in soil biogeochemical properties of the glacier foreland of Midtre Lovenbreen, Svalbard, attributed to soil-forming factors. *Geoderma*, 415. DOI: 10.1016/j.geoderma.2022.115777
- Rixen, C., *et al.* (2022). Winters are changing: snow effects on Arctic and alpine tundra ecosystems. *Arctic Science*, 8(3). DOI: 10.1139/as-2020-0058.

Nord site, Greenland

In 2022, the eddy covariance flux system, operated with University of Aarhus and Villumn Research Station in Denmark, was refurbished. It is a harsh site with barren soil and <5 % vegetation. Soil physical properties and fluxes of heat, water vapor, and carbon are measured to estimate the contribution of areas experiencing glacier retreat to the surface energy balance and carbon exchange of the Arctic.

Stórhöfði site, Iceland

To determine the relation between marine biota and atmospheric DMS, the team conducted a field experiment at the Stórhöfði observatory in Heimaey, Iceland (Fig. 58). Seasonal variations in atmospheric DMS levels were measured using a customized analytical system that included a component for trapping and elution of DMS connected to a gas chromatograph. They also measured seawater DMSP, DMSP lyase activity, and chlorophyll concentration around Iceland with the Marine and Freshwater Research Institute in Hafnarfjörður. The correlation between marine biota and DMS-related components varies among ocean domains and between years.

- Lee, K., *et al.* (2023). Observational evidence linking ocean sulfur compounds to atmospheric dimethyl sulfide during Icelandic Sea phytoplankton blooms. *Science of the Total Environment*, 879. DOI: 10.1016/j.scitotenv.2023.163020.

For more information contact Yoo Kyung Lee (yklee@kopri.re.kr).

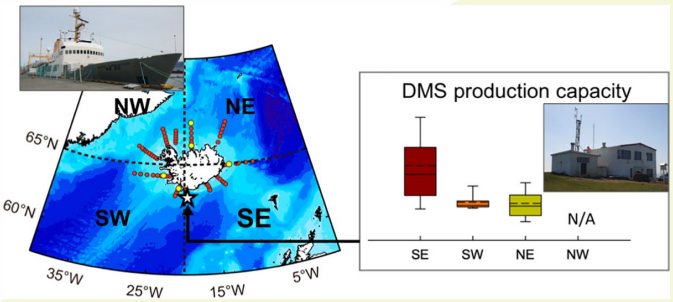


Fig 58. Location of the research sites around Iceland.

SPAIN

BY MARC OLIVA (UNIVERSITAT DE BARCELONA), MIGUEL ÁNGEL DE PABLO (UNIVERSIDAD DE ALCALÁ), AMELIA GÓMEZ-VILLAR (UNIVERSIDAD DE LEÓN), AND DAVID PALACIOS (UNIVERSIDAD COMPLUTENSE DE MADRID)

ACTIVITIES OF IPA-SPAIN

IPA-Spain focused field ativities on the Iberian mountain ranges (Pyrenees, Cantabrian Mountains, Sierra Nevada, Iberian mountain range, Central Iberian mountain range) and polar regions (Antarctica and Greenland). There have been several collaborations between the Universities of Barcelona, Valladolid, Complutense and Autónoma of Madrid, Alcalá, Extremadura, León, the Pyrenean Institute of Ecology, and the Basque Centre for Climate Change, as well as international organisations.

IPA-Spain's main achievement was the 6th European Conference on Permafrost (EUCOP6) in the Pyrenees, in Puigcerdà. The conference was coordinated by the Department of Geography at the University of Barcelona and supported by several other institutions in Spain. 450 researchers from 33 countries gathered in the capital of Cerdanya to enjoy lectures, meetings, workshops, and excursions. It was the largest scientific meeting held in the Pyrenees and a logistical challenge for Puigcerdà with no congress hall for large events (Fig. 59). The conference was an excellent opportunity to showcase permafrost science in the Pyrenees and the landscape and culture of Catalonia. International experts presented their findings in 24 scientific sessions held at the Casino Ceretà, Cinema Avinguda, Museu Cerdà, and Municipal Library. A dozen specific seminars throughout the conference and a public event on 20 June were held at the Casino Ceretà with a round table on "*The future of permafrost research*". Five excursions to glacial and periglacial landforms in the Malniu, Carlit, Vall de Núria, and Andorra valleys, and emblematic historical and archaeological sites in Cerdanya were available to participants. Tents were set up in the Plaça del Call for daily poster presentations (*Posters, Beers & Cheese*). In the Bibliollac area, participants enjoyed daily lunches and a welcome party embracing Catalan culture, including a workshop on human towers and popular music. The conference closed with a banquet at the Nordic Restaurant.

RESEARCH BY SPANISH GROUPS

The Antarctic, Arctic and Alpine environments (ANTALP) research group at the Department of Geography, University of Barcelona, conducted research in the Central Pyrenees and Greenland.

Field campaigns in the Pyrenees (Cadí, Pallars, Andorra, and Cadí areas) aimed to reconstruct the glacial and post-glacial evolution of the landscape. The team collected dozens of samples for cosmogenic dating from glacial records (moraines, erratic boulders, polished surfaces) and rock glaciers to understand the origin, evolution, and stabilisation of permafrost-related features. The work was complemented by detailed geomorphological surveying and UAV mapping. The team also installed data loggers in several rock glaciers in the Catalan Pyrenees (Besiberri, Broate) and Andorra (Clot de la Menera) to monitor ground thermal conditions in the highest peaks of the Pyrenees (Fig. 60). In 2023, the team was awarded a major European project grant to study permafrost conditions in the Pyrenees with several Spanish, French, and Andorran institutions.

In Greenland, ANTALP conducted expeditions in 2022 (north of Ilulissat) and 2023 (Nugssuaq Pen-

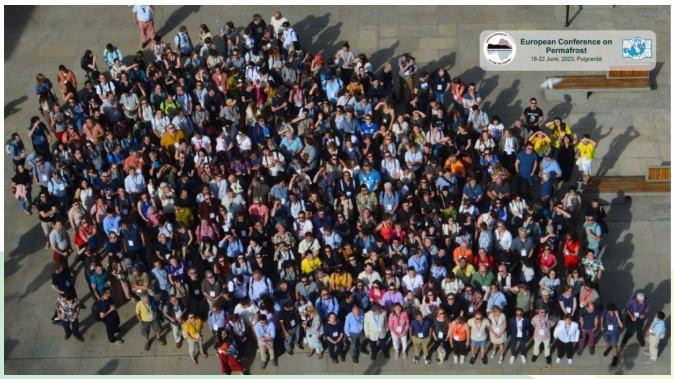


Fig 59. EUCOP6 group photograph.


Fig 60. Rock glaciers in the Pyrenees.

insula) to reconstruct past and recent glacial oscillations and deglaciation dynamics, with a focus on periglacial processes.

The Physical Geography of High Mountain and Polar Regions (GFAM) research group at Universidad Complutense de Madrid and University of León studied the chronology and dynamics of several active rock glaciers in the Tröllaskagi Peninsula, Iceland. The methodology included 36Cl cosmic ray dating and lichenometry, with the construction of high-resolution Digital Surface Models (DSMs) from ground and aerial UAV photography and radar satellite imagery, processed by the Structure from Motion (SfM) photogrammetric technique and temporal satellite monitoring by SAR interferometry, respectively. Results show the flow of rock glaciers has been limited since the Holocene Thermal Maximum (9-5 ka) and is now mainly related to subsidence due to ice melting. As a result, the occurrence of collapse depressions is becoming more frequent (Fig. 61). The team aims to apply these methods to other rock- and debris-covered glaciers in NE Iceland, Kebnekaise (northern Sweden), and Svalbard, to make a comparative study across an eastern North Atlantic/Arctic transect.

GFAM with the Peruvian Geological Survey, University of Aberdeen (UK), University of Santiago, and National University of Distance Education (Spain) conducted studies on glaciers, rock glaciers, and permafrost in the tropical Andes over long-term (millenia) and short-term (decades/centuries) periods. By measuring weathering (Schmidt Hammer) and 10Be cosmic ray exposure, the team obtained a glacial record of climate change over millennia in four Andean mountain ranges: Cordillera Blanca (~9° S), Pariacaca and Huaytapallana (~12° S), and the Coropuna and Quelccaya ice caps (~14-16° S). The results (~31-26, ~17-15, ~13-11, ~0.5 ka) indicate interhemispheric teleconnections: advances or glacial standstills synchronised with palaeolake transgressions in the Bolivian Altiplano (Sajsi, Tauca, Coipasa) and cold boreal events (Heinrich 1-3 and Younger Dryas). In addition, there are periods of maximum ice extent around ~120-60 ka (Cordillera Blanca) and ~50-40 ka ago, preceding the global Last Glacial Maximum (LGM). As expected, the chronology of deglaciation is increased by greater aridity south of the Andes.

Fig 61. Collapsing Grjotardalur rock glacier, Iceland, with numerous depressions formed in recent years.

Fig 62. GPR application in Coropuna, Peru.

Permafrost temperature monitoring in the volcanoes of southern Peru was improved. The network provides hourly measurements at one metre intervals up to 10 m deph. Geophysical applications, including electrical tomography, vertical electrical survey, and ground penetrating radar (GPR) were used in the Coropuna volcanic complex (Fig. 62). These surveys on white glaciers, covered glaciers, proglacial areas, and rock glaciers revealed ice thicknesses >20-30 m. At Coropuna, ground temperature monitoring shows periods of permafrost degradation or development that correlate with positive (El Niño) or negative (La Niña) phases of the ENSO phenomenon. At Quelccaya, a maximum glacial ice thickness of >150 m was detected with GPR.

In 2023, the Spanish Polar Committee for the Antarctic Temporal Series funded the University of Alcalá to maintain the PT and CALM stations of the *PERMATHERMAL* monitoring network on Livingston and Deception Islands, Antarctica. Dataloggers were downloaded and active layer thicknesses were measured at all sites (Fig. 63). In 2022-2023, iButtons and Tinytag were replaced with Geoprecision instruments at most stations to reduce maintenance and standardise data characteristics (e.g., resolution, accuracy, format). A full equipment upgrade will be completed in 2023-2024. In 2023, data from the *PERMATHERMAL* stations were uploaded to inter-

national databases for the wider scientific community, including time-lapse images from CALM sites to the Phenocam database, and temperature data (air, surface, soil) to the Soiltemp database.

In 2023, the *Geomorphology, Landscape and Territory (GEOPAT)* group at University of León researched periglacial (and glacial) landforms, snow cover and snowfall in the Cantabrian Mountains, and rock glaciers in the Tröllaskagi peninsula.

A Schmidt hammer was used for relative dating of 48 sites in five different massifs in the Cantabrian Mountains, including glacial and periglacial sites. Results show the rock glaciers formed at different times after deglaciation (just after LGM, Bölling/Allerød, Holocene), suggesting a paraglacial dependence rather than a climate-driven landform. The sampled blockfields stabilised after the almost complete deglaciation of the cirques, but their origin and significance remain poorly understood. Progress continued on snow cover and snowfall events using satellite imagery in the mountains, compared with WRF multiphysics ensembles based on terrestrial and multi-satellite observations. This will be reinforced by the installation of a snow measuring station (SPA-2) to monitor snow cover conditions and the evolution of snow properties from a highly detailed sampling point. Some results were published in *Atmospheric Research* and presented at the 10th EARSeL Workshop on Land Ice and Snow in Bern, Switzerland.

Fig 63. GPR application in Coropuna, Peru.

GEOPAT with Universidad Complutense de Madrid, led by Nuria de Andrés and David Palacios, studied debris-covered and rock glaciers in northern Iceland. Some preliminary results were presented at EUCOP6 and the 4th International PalaeoArc Conference in Akureyri, Iceland.

For more information contact Marc Oliva (marcoliva@ub.edu).

SWITZERLAND

BY CÉCILE PELLET (UNIVERSITY OF FRIBOURG), CHANTAL DEL SIRO, CRISTIAN SCAPOZZA (UNIVERSITY OF APPLIED SCIENCES AND ARTS OF SOUTHERN SWITZERLAND), DANIEL FARINOTTI (ETH ZURICH), ISABELLE GÄRTNER-ROER (UNIVERSITY OF ZURICH), NILS HÄHLEN (OFFICE FOR FORESTS AND NATURAL HAZARDS OF THE CANTON OF BERN) CHRISTOPHE LAMBIEL (UNIVERSITY OF LAUSANNE), AND MARCIA PHILLIPS (WSL INSTITUTE FOR SNOW AND AVALANCHE RESEARCH SLF)

SWISS PERMAFROST MONITORING NETWORK (PERMOS)

PERMOS has systematically documented the state and changes of permafrost in the Swiss Alps since 2000. The long-term funding of the project is ensured by the Swiss Federal Office of Meteorology and Climatology (MeteoSwiss), Swiss Federal Office for the Environment (FOEN), and Swiss Academy for Sciences (SCNAT) with seven research institutions in charge of data collection and maintenance of field sites: ETH Zurich (ETHZ), University of Fribourg (UNIFR), University of Lusanne (UNIL), University of Zurich (UZH), University of Applied Sciences and Arts of Southern Switzerland (SUPSI), University of Innsbruck, and WSL Institute for Snow and Avalanche Research (WSL-SLF). Jeanette Noetzli and Cécile Pellet (PERMOS office) coordinate monitoring activities, including in-situ measurements of (i) deep and ground surface temperatures, (ii) permafrost resistivity, and (iii) rock glacier velocities.

In 2023, the network had 27 field sites: 22 near surface temperature and 15 deep ground temperature sites (27 boreholes), six weather stations, five permanent electrical resistivity tomography profiles, and 15 rock glaciers (eight are equipped with permanent GNSS). Results show the hydrological years of 2022-2023 were characterized by record warm conditions at the surface and record active layer thickness at most sites, while permafrost temperature at 10-20 m depth slightly decreased. The heterogenous signal between the near surface and larger depth results from the delayed cooling effect of snow poor winters in 2021-2022 which is also highlighted by the general rock glacier velocity decrease in 2022. A detailed overview of 2022 is published in PERMOS (2023).

IPA ACTION GROUPS

Rock Glacier Inventories and Kinematics (RGIK)

RGIK (2018-2023) was supported by GCOS Switzerland in 2021-2023. The objectives were to (i) define community-based standard guidelines for inventorying rock glaciers, including indices of their activity rates; (ii) promote rock glacier velocities as a new associated parameter to ECV Permafrost and provide monitoring requirements and guidelines; and (iii) establish an operational service (RGIKS) for the coordination, centralization, and promotion of rock glacier observations. Current monitoring guidelines are available. With IPA support, *RGIK* is in the process of transitioning to a permanent Standing Committee which will officially start at ICOP2024. Since 2022, *RGIK* has organized monthly online seminars. *RGIK* is open and can be joined by subscribing to the mailing list.

Towards an international database of geoelectrical survey on permafrost (IDGSP)

The objectives of *IDGSP* (2020-2022) were to (i) create an international database centralizing geoelectrical surveys on permafrost; (ii) develop community-based standards for the repetition and processing of geoelectrical surveys; and (iii) financially and strategically support the repetition of legacy measurements. A database is now openly accessible. *IDGSP* is open to researchers and can be joined by emailing ertdb@unifr.ch.

NEWS FROM RESEARCH PROJECTS & ACTIVITIES

The High Mountain Geomorphology group at UNIL, led by Christophe Lambiel, continued monitoring for PERMOS. Two new boreholes were drilled at the Col des Gentianes (2985 m asl) to replace a hole from 2002 (Fig. 64). Investigations on hanging glaciers continued, with several GPR profiles completed at the Pointes du Mourti (3563 m asl) and the Aiguilles du Midi (3842 m asl). In 2022, Sebastián Vivero completed his PhD on the use of close-range remote sensing techniques to study rock glacier dynamics. Thibaut Duvanel began his PhD for *Rock Glacier Dynamics in the Swiss Alps (RoDynAlpS)* under the co-supervision of Reynald Delaloye (UNIFR). The thesis aim is the comprehensive mapping and kinematic characterization of rock glaciers in Switzerland, with the analysis of controlling factors. Benjamin Robson started a PhD thesis under the co-supervision

Fig 64. Drilling a new borehole in the frozen moraine at Gentianes (2022) to secure the 20-year permafrost temperature time series. Photo: Christophe Lambiel.

of Florence Magnin (Université Savoie Mont Blanc, USMB) on the distribution and characterization of permafrost in intermediate slopes (40° to 60°) which are often characterised by highly fractured rock and may therefore contain a certain amount of debris on the surface. Finally, work continues to improve modelling of permafrost distribution at high resolution, through various collaborations.

In addition to the thermal and kinematics monitoring of rock glaciers in the Southern Swiss Alps (with PERMOS and the Cantonal administration), Cristian Scapozza (SUPSI) started a new interdisciplinary project. The masters thesis of Giona Crivelli (with Isabelle Gärtner-Roer, UZH) and PhD thesis of Chantal Del Siro (with Christophe Lambiel, UNIL) are part of this project. Giona Crivelli focuses on the analysis of the seasonal variability of morphodynamics of four active rock glaciers. Chantal Del Siro focuses on the analysis of three active rock glaciers and their potential as water resources (Monte Prosa A, Piancabella, and Ganoni di Schenadüi), with the aim to understand the impacts of ground

Fig 65. Sampling of the seasonal ground ice at the Monte Prosa rock glacier. Photo: Chantal Del Siro.

ice melting on high mountain water resources, on a seasonal and multi-year scale. The project is based on an interdisciplinary approach, combining the morphodynamics analysis of active rock glaciers at very high resolution through geodetic methods (i.e., repeated UAV and dGNSS surveys) with the physical-chemical monitoring of the water emerging from these periglacial landforms (Fig. 65).

WSL-SLF continued long-term monitoring of permafrost temperatures for *PERMOS*. Two new permafrost monitoring boreholes were drilled to 25 m depth near the summit of the Jungfrau (4120 m asl) with Canton Bern. Investigations continued on permafrost slope deformations, and kinematics and controlling processes using terrestrial laser scanning, GNSS, and seismology techniques. The role of permafrost and water in deep-seated rock slope instabilities is investigated at selected sites under the *Climate Change and Alpine Mass Movements (CCAMM)* program using in-situ borehole data and thermo-mechanical modelling. WSL-SLF continued to study the conditions leading to rock slope failures in mountain permafrost; documented events occurring in the Swiss Alps are made available through PERMOS. For *RoDynAlps*, WSL-SLF are investigating changing ice and water contents in rock glaciers and their impact on rock glacier dynamics with UNIFR, UNIL, and UZH. The team are monitoring the characteristics of three rock glaciers using cross-borehole electrical resistivity tomography (ERT), borehole temperatures, borehole deformation data, and piezometric pressure data. Mountain infrastructure stability and temperatures around structures are monitored with various engineering companies. With biologists, WSL-SLF are investigating the emissions (microorganisms, gases, heavy metals, etc.) from thawing permafrost and ice melt for the *WSL EXtremes* research program.

ETH Zurich WSL Birmensdorf continued observations for *PERMOS* at the Murtèl/Corvatsch and Muragl sites. In 2024, redrilling is planned at Muragl to replace ageing equipment (Fig. 66).

UTZh monitored ground surface temperatures and rock glacier velocity at Murtèl for PERMOS and *RGIK*. Unfortunately, the Murtèl site, with the oldest and longest borehole monitoring series from a rock glacier (est. 1987), was hit and partly destroyed by a rock fall in September 2023. The group started *RoDynAlpS* which focuses on the long-term development of rock glaciers in Switzerland, as derived from historical and recent aerial images. It is complemented by investigations on the genesis and Holo-

Fig 66. Electrical Resistivity Tomography investigation on Muragl rock glacier. Photo: Cécile Pellet.

cene evolution of Murtèl using ^{14}C-dates from borehole material and simulating flow modelling of the age-depth relation. In 2023, investigations on rock glaciers on Disko Island, Greenland (*RockDynDisko* project) continued without dedicated funding. The project is challenging (logistics, weather conditions, defective equipment caused by wild animals) but results provide an important insight into ground-surface temperatures and rock glacier kinematics.

In 2015, the Office for Forests and Natural Hazards of the Canton of Bern started continuous monitoring. Since 2021, two new boreholes at Tossen in the eastern Bernese Oberland (3100 m asl) and Jungfrau (4130 m asl) have been drilled with SLF. The measuring network of Canton of Bern comprises 28 boreholes at 12 sites. Representatives of the Canton of Bern are actively taking part in PERMOS.

The Cryosphere & Geophysics research group at UNIFR focus on developing geophysical measurements and modelling techniques to quantify ground ice content and its temporal evolution. The development and application of the so-called petrophysical joint inversion (PJI) scheme to quantify ground ice content, water content, and porosity continued. Spectral induced polarization (SIP) and Transient Electromagnetic (TEM) methods to quantify ground ice were investigated for the Swiss-German-Austrian project, SPICE, by combining laboratory measurements (University of Bonn) with field-based SIP and TEM surveys (TU Wien and UNIFR) in the Swiss and Italian Alps. PhD student, Cassandra Koenig, developed a 2D hydro-thermal model to simulate the future runoff characteristics of high-altitude sites in the Chilean Andes under climate induced thawing of permafrost (with BGC Engineering).

In late 2023, the *Tipping points and resilience of mountain permafrost occurrence under increasing frequency of heat waves (TREAT)* project started with the University of Oslo (UiO), Universtity of Aachen, and TU Wien.

The *PERMA-XT* project, which aimed to understand heat exchange through the coarse debris mantle to predict the thermal evolution of underlying permafrost to climate change ended in 2023. PhD student, Julie Wee, researched glacier forefields in mountain permafrost environments. They characterize and analyse changes within these systems using photogrammetry, in-situ geophysics, and geodetic surveys. PhD student, Tamara Mathys, (re-)established monitoring of cryospheric-variables in central Asia, including a permafrost monitoring borehole in Kyrgyzstan with more planned in Kazakhstan and Tajikistan.

The Alpine Cryosphere and Geomorphology research group investigates the dynamics of permafrost related landforms in mountain environments and their geomorphic context. They survey >30 different landforms in the Swiss Alps using in-situ (differential GPS, permanent GNSS, and terrestrial lidar) and remote sensing techniques (InSAR, UAV-, air- and space-borne photogrammetry). It is part of the second phase of *ESA CCI Permafrost* which promotes the integration of mountain permafrost. The group leads *RoDynAlpS* and will host one postdoc on rock glacier dynamics modelling starting in autumn 2024. In 2024, the four-year *CRYO-SPIRIT: Understanding and preparing in a rapidly changing high-mountain environment - a collaborative scientific effort of two small mountain countries Bhutan and Switzerland* project will start; lead by SLF and the Royal University of Bhutan, with UTZh and EPFL.

For more information see:

- Del Siro, C., Antognini, M., and Scapozza, C. (2023). Il permafrost nelle Alpi Ticinesi (2019/2020, 2020/2021 e 2021/2022). Rapporto No. 6 del Gruppo Permafrost Ticino. Bollettino della Società ticinese di scienze naturali, 111.
- Del Siro, C., *et al.* (2023). Investigating the origin of solutes in rock glacier springs in the Swiss Alps: a conceptual model. *Frontiers in Earth Science*, 11. DOI: 10.3389/feart.2023.1056305.
- PERMOS (2023). Swiss Permafrost Bulletin 2022. Noetzli, J., and Pellet, C. (eds.). No. 4, DOI: 10.13093/permos-bull-23.

For more information contact Cécile Pellet (cecile.pellet@unifr.ch).

UNITED KINGDOM

BY JULIAN MURTON (UNIVERSITY OF SUSSEX)

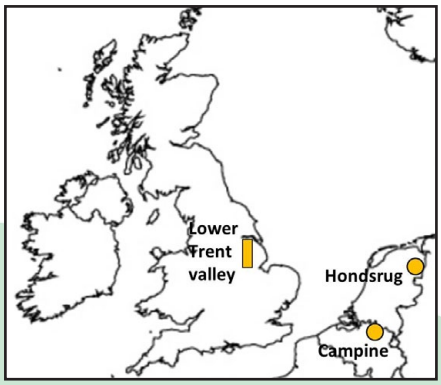
CAN THE FORMATION OF NEW SOIL ORGANIC MATTER OFFSET DECOMPOSITION LOSSES FROM THAWED PERMAFROST SOILS?

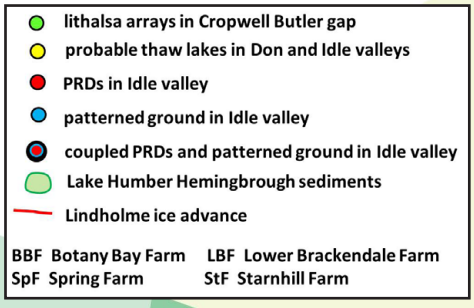
Thawing permafrost soils are predicted to release 10s of billions of tonnes of carbon by 2100. There is little potential for plant biomass gains to offset these losses, with plant biomass changes likely to be small. However, greater plant productivity and increased rooting depths may increase rates of C input into previously frozen soils and thus increase the formation of new soil organic matter (SOM). Alternatively, new inputs may stimulate, or 'prime', the decomposition of previously-frozen organic matter. Experiments on growing plants in contrasting permafrost soils under a ^{13}C-labelled atmosphere are directly measuring plant-induced priming for the first time, using a bespoke, climate-controlled growth and ^{13}C-labelling chamber. The experiments are being carried out at the University of Exeter by Nina Lindstrom-Friggens with Ian Hartley, Gareth Phoenix (Sheffield University), Julian Murton (Sussex University), Canadian collaborators Steve Kokelj (GNWT) and Fabrice Calmels (Yukon University), and Swedish collaborator Gustaf Hugelius (Stockholm University). The research project is funded by the UK's Natural Environmental Research Council (NERC).

COMPARISON OF PERIGLACIAL RAMPARTED DEPRESSIONS (RELICT LITHALSAS & PINGOS), UK EAST MIDLANDS & CONTINENTAL EUROPE

Investigations by Colin Baker (independent researcher) of historic Google Earth imagery have revealed widespread evidence of polygonised patterned ground in the UK Trent valley and surrounding areas indicative of relict thermal contraction within former continuous permafrost of Marine Isotope Stage (MIS) 2 age or earlier. Further work has located sites of potential periglacial ramparted depressions (PRDs) in contact with patterned ground. Comparisons should be drawn, not with PRDs in southern Ireland or south-west Wales (within the Last Glacial Maximum ice limit), but with those in East Anglia, the northern Netherlands and Belgium (outside the limit).

- Baker, C., Garton, D., and Ross, I. (2021). Widespread pre-Devensian and Devensian periglacial patterned ground in the East Midlands revealed in summer 2018 satellite imagery. *Mercian Geologist*, 20(2).





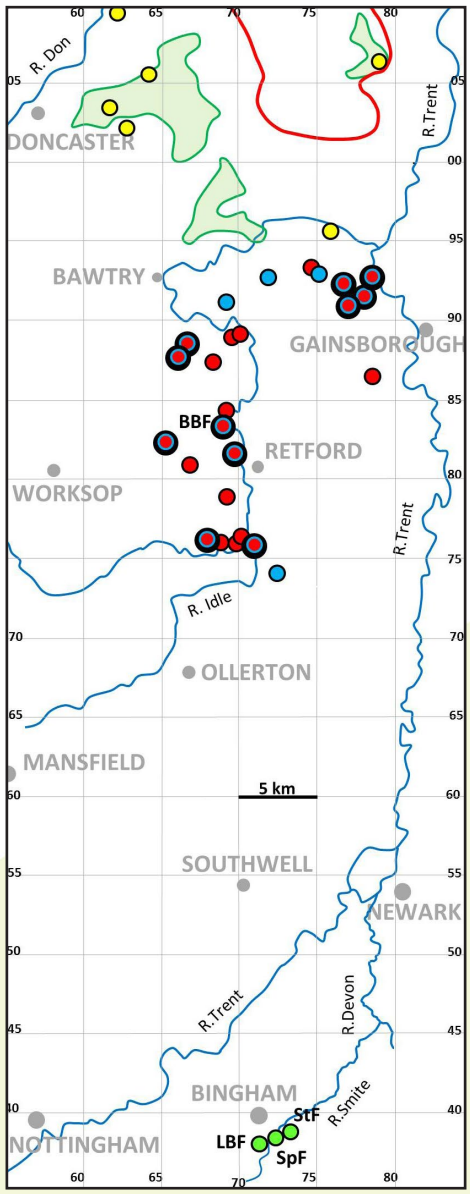


Fig 67. Periglacial phenomena identified in Google Earth imagery.

- Baker, C. (2022). Palaeodrainage reconstruction of the River Trent: new evidence from Google Earth imagery. *Quaternary Newsletter*, 157.
- Baker, C., Garton, D., and Ross, I. (2024). New evidence for periglacial ramparted depressions (relict lithalsas and pingos) in the East Midlands, UK. *Mercian Geologist*, 21(1), *in press*.

A dense field of suspected, small, relict lithalsas (2-5 m high, up to 13 m in diameter) occurs near Bingham (east of Nottingham) on a substrate of Mercia Mudstone Group dolomitic siltstone (Figs. 67, 68). These appear to have originated, firstly, as polygon-centred frost mounds, and, secondly, by localised ice segregation and intrusion at spring points on the siltstone dip slope. A two-phased approach here mirrors phased lithalsa formation in discontinuous permafrost of Younger Dryas age in the Hautes Fagnes, Belgium. Clusters of medium-sized relict lithalsas (40-50 m in diameter) also appear to have survived on similar dolomitic siltstones in the Idle Valley, again in contact with patterned ground (Fig. 67). Much larger PRDs (100-200 m in diameter) occur across the Chester Formation sandstone outcrop and River Idle first terrace sands and gravels. At Botany Bay Farm (Fig. 68) a clear polygonal horizon exists between two superimposed PRD features.

Comparable PRD structures were detected in the northern Netherlands (Hondsrug) and Belgium (Campine). These continental features are identifiable in satellite imagery as well-defined rampart margins, radial dilation cracks and, significantly, contact with polygonised patterned ground. Such criteria can be used to differentiate PRDs from deflation hollows, dolines, pits or other depressions of non-periglacial origin. In some cases polygonal networks overlie both rampart and central depression (Hondsrug); in others, interconnected dilation cracks create 3-way intersections and, running off the rampart slope, merge with surrounding relict frost-fissure polygons (Campine). These so-called "pingo ruins", long-recognised in the Netherlands, may be periglacial phenomena formed at the end of the Last Permafrost Maximum. Co-existence of these PRDs with polygonal patterns supports an interpretation of continuous permafrost. Open-system hydraulic pingo origin therefore seems a more likely scenario than lithalsa ice segregation. According to some Dutch researchers, the source of sub-permafrost groundwater flow for hydraulic pingos could have been driven by forebulging or salt-dome diapirism.

Some depressions – unusually large, deep and often rimless – may be regarded as relict gas emission

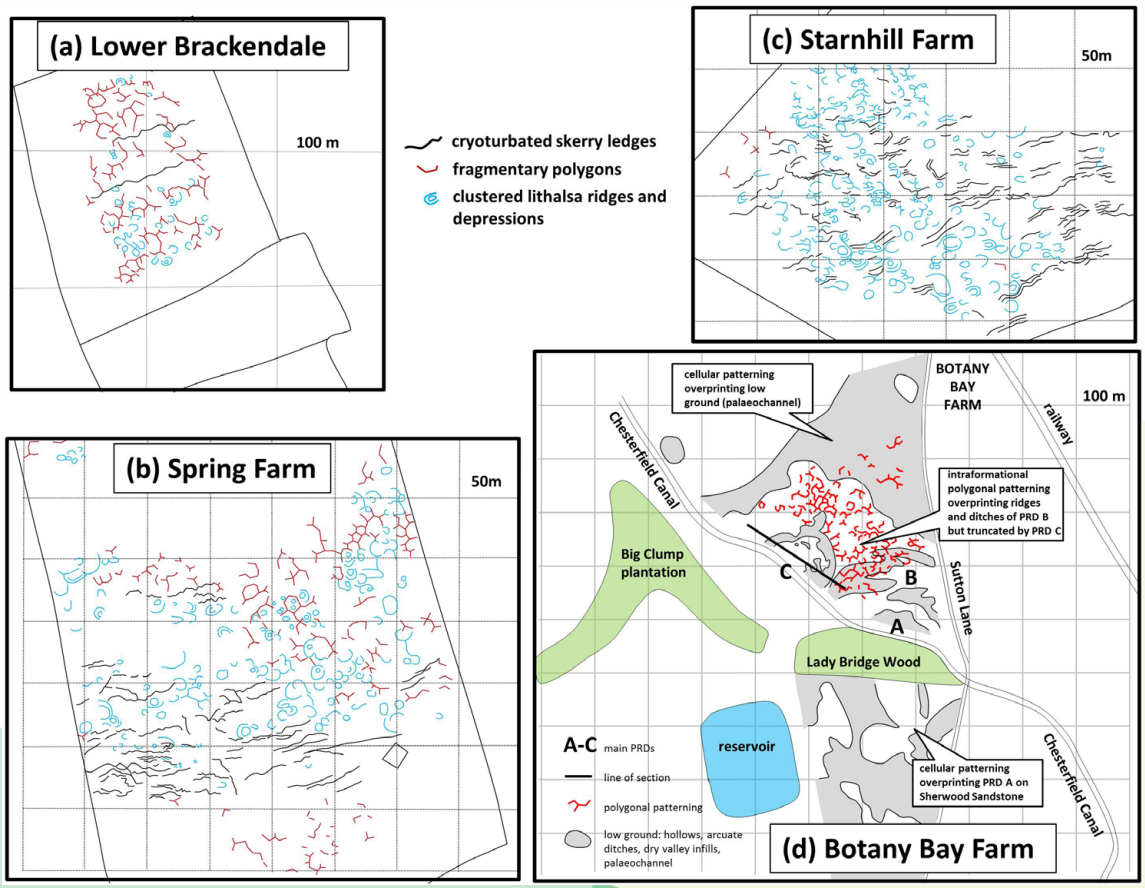


Fig. 68. Detailed outlines of PRDs and polygonal patterned ground at (a) Lower Brackendale Farm, Bingham (January 2010), (b) Spring Farm, Bingham (June 2018), (c) Starnhill Farm,Bingham (June 2018), and (d) Botany Bay Farm, Retford (July 2015).

craters during permafrost degradation (similar to those on the Yamal Peninsula) rather than shallow thaw lakes. Similar depressions in the UK have been cited, some within the Idle and Don valleys (Fig. 68); gas emission cratering could be an alternative working hypothesis.

In summary, comparable periglacial phenomena have been identified in Belgium, the Netherlands, and UK East Midlands. Recognition of former open-system pingos (continuous permafrost) and lithalsas (discontinuous permafrost) in contact with polygonal patterned ground contributes to our understanding of the Late Devensian periglacial record within the UK.

ROLE OF RETROGRESSIVE THAW SLUMPS IN RELEASE OF SULFUR INTO THE ENVIRONMENT & BIOSPHERE

Several processes during permafrost growth and thaw have been shown to influence sulfur isotopes in alternative settings. Retrogressive thaw slumps (RTS) are known to affect the hydrology and hydrochemistry of the catchments in which they occur and can be associated with significant release of sulfate into the environment. They thus represent an environment in which sulfur could be transferred from permafrost substrate to biosphere and thus a potential mechanism for (part of) the changes observed in the sulfur isotopes in late Quaternary fauna in Eurasia. In 2022, soil, vegetation, and water samples were collected from retrogressive thaw slumps formed in different substrates on a north–south transect across Canadian permafrost from the Arctic Ocean coast near Tuktoyaktuk, NT, to southern Yukon (Fig. 69). The samples are being analyzed for content and sulfur isotopic composition of extractable sulfate and sulfide and concentration and sulfur isotopic composition of surface drainage where present. The purpose is to determine the impact of thaw slumping on sulfur isotope release to the environment and biosphere. Additionally, samples of bone collagen of radiocarbon-dated Late Quaternary fauna from NW Canada are being analysed. The research is funded by The Leverhulme Trust and carried out by Rhiannon Stevens and Delphine Frémondeau (UCL), Simon Bottrell (University of Leeds), and Julian Murton (University of Sussex).

For more information contact Julian Murton (j.b.murton@sussex.ac.uk).

Fig 69. Sampling water and vegetation for sulfur isotope analysis at an RTS, Peel Plateau, NT, Canada (26 August 2022).

UNITED STATES OF AMERICA

BY U.S. PERMAFROST ASSOCIATION (USPA)

OVERVIEW

The purpose of the US Permafrost Association (USPA) is to encourage scientific and engineering investigations on permafrost and related topics and to disseminate results related to permafrost research. The position of the USPA is to encourage sharing knowledge and data in permafrost science. USPA provides strong support to early career researchers (ECRs) through the Permafrost Engineering Education Program (PEEP) and collaboratively through the USPA-PYRN Education Fund (UPEF) and, offering scholarships and travel grants, and advocating for career-enhancing opportunities.

THE YEAR IN REVIEW

Annual Meeting and Board Transitions

USPA held its Annual Meeting during the American Geophysical Union (AGU23) Fall Meeting in December 2023, in San Francisco. About 125 members participated, including Board members and committee chairs. President Anna Wagner (CRREL) announced the results of the Board of Directors elections for terms beginning in January 2024. Dr. Eva Stephani (USGS) is President-Elect and Ms. Wendy Presler (Shannon and Wilson) is the incoming Treasurer.

Dr. Ming Xiao (Penn State University) assumed the Presidency in 2024. New Board members are Dr. Victoria Herrmann (The Arctic Institute) and Dr. Vladimir Romanovsky (University of Alaska Fairbanks, UAF). Drs. Romanovsky and Hermann bring a wealth of experience and fresh ideas which we are eager to put to good use.

Dr. Anna Wagner serves as Past-President. Dr. Kevin Schaefer (NSIDC) continues as U.S. Representative to the IPA Council and 2022 President, John Thornley (WSP USA), serves as the second IPA representative. Edward Yarmak (Arctic Foundations Inc.) was elected to the IPA Executive Committee.

Drs. Jessica Ernakovich and Melissa Ward Jones continue their positions as general board members. Mr. Michael Lilly (Geo-Watershed Scientific) completed his term on the Board and his dedicated services, as well as those of past IPA Executive Council representative, Dr. Fritz Nelson (Emeritus, University of Delaware), are gratefully acknowledged.

PERMAFROST SCIENCE & ENGINEERING

Ongoing efforts

The USPA Diversity, Equity, and Inclusion (DEI) Committee is composed of seven USPA members and led by co-chairs Julian Dann (PhD candidate, UAF) and Shannon Dillard (University of Wisconsin). The committee kicked off 2023 with two well-attended workshops. *"Working with Arctic Indigenous Communities"* focused on best practices of working with local northern communities and featured speakers Kaare Sikuaq Erickson and Dr. Charleen Fisher. *"Field Safety"* talked through several scenarios with a senior researcher: car accidents, illness, visitors, wildlife, and conflict. At AGU23, the committee organized a mentorship lunch between USPA members at later career stages with early career members and graduate students. DEI is an energetic, creative group dedicated to welcoming everyone into the work of permafrost science. For more information or to join, contact Julian (jdann@alaska.edu) or Shannon (sdillard@wisc.edu).

PEEP, chaired by Dr. Ming Xiao, organized a STEM summer camp for middle school students in Utqiaġvik, AK, in June 2023 (Fig. 70). The National Science Foundation (NSF) funded the activity, and an enthusiastic group of Indigenous students learned some of the science about the ground beneath their feet. PEEP also awarded one early career student a travel grant to present at AGU23: Kaytan Kelkar (UAF).

New ventures

USPA Technical Training Webinar Series. A major activity by PEEP is helping professionals to stay up to date on measurement and analysis techniques.

Fig 70. Ming Xiao (second from right), Penn State students (Matthew Hallissey and Isabel Rubino), Mr. Simon Aina (Iḷisaġvik College), and a group of happy youngsters in Utqiagvik, AK.

The PEEP team with UPEF developed a list of key topics on permafrost engineering and science and found subject matter experts to give talks via Zoom. The program launched in October 2023 with a review of permafrost basics attended by 98 participants. November's topic was geotechnical subsurface exploration techniques, with 55 attendees. 18 participants earned professional development credits, and the series has already drawn interest from Canada, Russia, Germany, Peru, United Kingdom, and Finland. The series continues in 2024.

Family Care Program (FCP). When you're the parent of a young child or caregiver to an elder family member, field work or conference participation can be tough. Dr. Melissa Ward Jones (UAF), championed the USPA FCP to provide financial support ($500 USD) to cover costs associated with bringing kids along (a great way to initiate the next generation) or securing care back home. A successful fundraising effort ($4,000) will pay for the first two years of awards, and the program will continue to grow from here. This program started in April 2024 and fundraising efforts continue to ensure the longevity of the program. For more information or to donate, contact Melissa (mkwardjones@alaska.edu).

Advancing Science

A core mission of USPA is to support ECRs. This year, USPA gave five travel awards to Hailey Webb, Vasily Tolmanov, Katie Braun, and Leah Clayton (all UPEF-funded), and Kaytan Kelkar (PEEP-funded). Each winner recevied $600 for travel to AGU23. USPA awarded the Andrew Slater Memorial Award ($1,000) to Jon Wells for his outstanding work on permafrost modelling science (Figs. 71, 72). All the awardees presented posters or talks at the conference.

Fig 71. USPA award recipients.

Fig 72. Travel awardees and scholarship winner at the USPA Annual Meeting and Social (December 2023).

USPA members published dozens of papers in peer-reviewed journals, and presented posters and talks at conferences. At EUCOP6, President Anna Wagner, and Board members, Fritz Nelson, Melissa Ward Jones, John Thornley, and Ed Yarmak presented papers. AGU23 saw a host of activity by USPA's membership, with many, we are proud to say, by students.

Work Within the Organization

USPA combined the Communications and Membership Committees (CCOM and MCOM) into a single body, the Operations Committee (OpsCOM). This allows USPA to coordinate engagement with members and the larger permafrost community and to leverage the web platform more effectively.

Reviewing our filing system, website, and web platform for member management, we saw that we were sorely behind the times. It's 2023, and we knew we could do better. Thanks to our Treasurer, Eva Stephani, we opened a Google Workspace at no cost due to our status as a nonprofit. Several folks pitched in to move old files into the Google platform, organize them, and discard old files we no longer need.

We also know that our website can stand an upgrade to be more user-friendly and visually engaging. This project is just underway, so keep an eye on it as it evolves. Finally, we have a solid website for managing our members (MemberClicks), but we haven't used all its features to really understand what our demographics are and how we can use them. That's a priority for us going into 2024.

Membership

We began 2023 with 246 members and are closing with 283. We are proud that 27% of our individual members are students, and we certainly want to

increase our members in all categories. The revenue generated from member dues can be applied to travel awards for young researchers—a mainstay service for USPA—and to fund new, innovative programs such as those described above. Board member Kevin Schaefer is leading a membership drive with a goal of 550 members by 31 December 2024.

We are extremely grateful for the ongoing support of our institutional and corporate members. Our 18 corporate and institutional members contribute greatly to our fiscal status and offer sound collegial advice and support. We especially welcome our two new corporate members, Stantec and PND Engineers.

Institutional Members:

- American Geosciences Institute
- University of Colorado, National Snow and Ice Data Center
- University of Virginia, Dept. of Environmental Sciences
- U.S. Arctic Research Commission
- Woodwell Climate Research Center

Corporate Members:

- Alaska Ecoscience
- ABR, Inc.
- Arctic Foundations, Inc. (Life member)
- Syngen
- WSP
- GW Scientific, Inc
- PND Engineers, Inc.
- R&M Consultants Inc.
- Shannon & Wilson
- Stantec

The Year Ahead

It will be a busy year for USPA with our membership drive, website development, continued education and outreach activities, and ICOP2024.

In memoriam

Ronnie Daanen, 1972–2023. We were saddened to learn of the passing of Dr. Ronnie Daanen in a helicopter accident near Utqiagvik while he and others were conducting fieldwork. Ronnie was a much-loved, tremendously dedicated, and universally admired professional in the permafrost community. His work on cold-climate hydrology and slope stability will endure, and we will continue to hold his family in our thoughts.

Thomas Krzewinski, P.E., 1949-2023. A past president of USPA, Tom unexpectedly passed while on business in Canada last April. Mr. Krzewinski was an internationally recognized expert in cold regions geotechnical engineering. He started his career working on the design of the Trans Alaska Pipeline System right after graduating from the University of Minnesota and then worked on many, many projects. Tom received awards and accolades for his work and service to the profession including the prestigious Harold R. Peyton Award for Cold Regions Engineering from ASCE of which he was proudly the youngest recipient ever. His influence on the practice of engineering in cold regions will affect several generations of engineers well into the future.

For more information contact Kevin Schaefer (kevin.schaefer@colorado.edu) and John Thornley (john.thornley@wsp.com).