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Country Reports 2021

contact@ipa-permafrost.org
www.permafrost.org

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ARGENTINA with South American Partners and Mexico

BY DARIO TROMBOTTO LIAUDAT (IANIGLA-CRICYT-CONICET, ARGENTINA)

No Meeting was organized in 2021. The next meeting about Cryospheric Sciences in general is planned for March 2022, during the National Geological Congress in Puerto Madryn, Patagonia.

Joint Andean permafrost studies continued to be carried out in the Andes of San Juan, involving the Geocryology Unit of Mendoza (CONICET) and the National University of San Juan (Mag. Silvio Pastore).

Periglacial environments in Cuyo (Mendoza and San Juan) are being studied by PhD student, Martín Mendoza (Córdoba) and Dr. Tapia Baldis' under the project: *Rock glacier permafrost in the Central Andes of Argentina (PermArg): regional distribution ice content hydrological significance* (Deutsche-Forschungs-Gemeinschaft):

- Halla, C., *et al.* (2021). Ice content and interannual water storage changes of an active rock glacier in the dry Andes of Argentina. *The Cryosphere*, 15, 1187-1213. DOI: 10.5194/tc-15-1187-2021.
- Pecker Marcosig, I. and Trombotto Liaudat, D. (2021). Análisis de la dinámica de dos mallines de altura en Vallecitos, Cordón del Plata, Mendoza, Argentina en el periodo 2002-2019. *Acta Geológica Lilloana*, 33 (1), 1-24. DOI: 10.30550/j.agl/2021.33.1/2021-02-18.

In 2021, the Geocryology Unit of Mendoza worked with the Committee for the review of the inventory of rock glaciers in Perú. Dario Trombotto Liaudat was nominated and elected as member for the Permafrost Carbon Feedback (PCF) Action Group of the Canadian permafrost Association (CPA). He helped develop the PCF Intervention RoadMap and was collaborator and national representative for the Global Terrestrial Network for Permafrost (GTN-P).

At the 2021 Geological Society of America (GSA) meeting in Portland, OR, Amit Mushkin (Geological Survey of Israel) presented "A terrestrial brine-seepage analog for Martian slope streaks near Salar de Pedernales in the Atacama Desert, Chile". More hydrological basins with rock glaciers were incorporated into the periglacial maps, inventories and models carried out for permafrost and water studies (Fig. 1). Hydrogeological modelling is being carried out to determine the origin of the species dissolved in periglacial waters, causing the presence of heavy metals and their acidification. In 2021 new sampling sites between 3500-4800 m asl were added to the monitoring network in the Vallecitos river basin in Mendoza (Noelia Sileo). These add valuable information about the hydrochemical processes at the head of this main valley.

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

- Miller, L.A., *et al.* (2021). The Future? Big Questions about Feedbacks between Anthropogenic Change in the Cryosphere and Atmospheric Chemistry. In: P.B. Shepson, and F. Domine (eds.). *Chemistry in the Cryosphere*. World Scientific, 831-865. DOI: 10.1142/9789811230134_0017.

Fig. 1. Rock glacier intersecting with a regional small lake in the landscape of the Central Andes.

AUSTRIA

BY ANDREAS KELLERER-PIRKLBAUER (UNIVERSITY OF GRAZ)

GRAZ

In 2021, Viktor Kaufmann (Institute of Geodesy, Graz University of Technology) continued to monitor four rock glaciers in the Hohe Tauern Range (Dösen, Hinteres Langtalkar, Leibnitzkopf, and Tschadinhorn rock glaciers) using geodetic measurements (Fig. 2). In addition, UAV-based aerial surveys were carried out jointly with Gernot Seier (Institute of Geography and Regional Science, University of Graz) at the Tschadinhorn and Leibnitzkopf rock glaciers. The long-term movement behaviour of the Leibnitzkopf Rock Glacier was published in 2021:

- Kaufmann, V., Kellerer-Pirklbauer, A. and Seier, G. (2021). Conventional and UAV-based aerial surveys for long-term monitoring (1954–2020) of a highly active rock glacier in Austria. Frontiers in Remote Sensing, 2, 18 p. DOI: 10.3389/frsen.2021.732744.

Results of the annual geodetic measurements were also published and discussed in:

- Pellet, C., *et al.* (2021). Rock glacier kinematics. In: J. Blunden, and T. Boyer (eds.). *State of the Climate in 2020*. Bulletin of the American Meteorological Society, 102(8), S44-S45. DOI: 10.1175/2021BAMSStateoftheClimate.1.

Permafrost-related research by Andreas Kellerer-Pirklbauer, Gerhard Karl Lieb, Wolfgang Sulzer, Gernot Seier, Matthias Wecht (all 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 at the Graz University of Technology and the Zentralanstalt für Meteorologie und Geodynamik (ZAMG).

Fig. 2. Satellite-supported surveying of a fixed point in the vicinity of the Arthur-von-Schmidhaus (2281 m asl). View over the Dösen lake to the Dösener rock glacier. Photo: Viktor Kaufmann.

Permafrost monitoring in the Hohe Tauern Range was carried out in 2021 within the framework of two long-term project initiatives (*Permafrost monitoring in the Hohe Tauern National Park Carinthia 2019-2021* and *Long-term monitoring of ecosystem processes in the Hohe Tauern National Park – Modul 07*) coordinated by Andreas Kellerer-Pirklbauer and supported by 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 displacement data series, rockfall activities). In total, about 100 ground temperature data loggers measuring surface and deeper ground temperatures are operated.

Field work 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). First results from the latter site were presented during the (online) EGU conference in 2021:

- Kellerer-Pirklbauer, A. and Lieb, G.K. (2021). Ground thermal contrasts and variability at an alpine pyramidal peak in central Austria (Innerer Knorrkogel, Venediger Mountains). *vEGU General Assembly 2021*, EGU21-12588. DOI: 10.5194/egusphere-egu21-12588.

Philipp Krisch and Andreas Kellerer-Pirklbauer (University of Graz) measured the relative age of several rock glaciers and moraine ridges were in the Ankogel Mountains and compared their results with published ages from the same sites based on terrestrial cosmogenic nuclides (TCN) using the isotope Beryllium-10 (10Be). A related publication is in preparation.

As part of the INTERACT research project ACT-RG (An active rock glacier in West Greenland – Deciphering its structure and Landform evolution), a team of three (Andreas Kellerer-Pirklbauer, Jakob

Abermann and Felix Bernsteiner; all University of Graz) was able in July 2021 to study an exceptionally large rock glacier on the Greenland island of Bjørneø at latitude 64.5°N near Nuuk. This fieldwork was accomplished despite COVID-19 restrictions. The team used geophysics (electrical resistivity tomography and ground penetrating radar), differential GPS, relative surface dating, geomorphic mapping, clast form analysis, and ground, air, and water temperature monitoring (Fig. 3).

Fig. 3. GPR-campaign at the Bjørneø rock glacier, Greenland using a 100 MHZ RTA-antenna. Photo: Andreas Kellerer-Pirklbauer.

The Alpine Hydrogeology working group of the Institute of Earth Sciences at the University of Graz (Gerfried Winkler, Thomas Wagner, Simon Kainz) and its partners successfully completed the first year of their research project *RG-AlpCatch – Rock glaciers as groundwater storages in alpine catchments and their impact on downstream river systems with regard to climate change* (DaFNE-research project 101561). In five regions with variable rock glacier abundance but different meteorological conditions, test sites with various gauging stations have been installed. Meanwhile, within the PhD of Simon Kainz, discharge and isotopic data of the first year have been obtained to capture storage-discharge dynamics of individual rock glacier springs and their influence on downstream river systems. Based on the database of a previous research project, first research results due to liquid and solid water storage in rock glaciers related to glacier ice in the Austrian Alps were published jointly with colleagues from Innsbruck (Andrea Fischer, Kay Helfricht) and Vienna (Michael Avian):

- Wagner, T., *et al.* (2021a). Assessment of liquid and solid water storage in rock glaciers versus glacier ice in the Austrian Alps. *Science of The Total Environment*, 800, 14 p. DOI: 10.1016/j.scitotenv.2021.149593.

More knowledge on the quantification of the temporal variability of recharge and discharge components of an active rock glacier was obtained by combining results from natural and artificial tracer analyses and rainfall-runoff modelling:

- Wagner, T., *et al.* (2021b). Storage-discharge characteristics of an active rock glacier catchment in the Innere Ölgrube, Austrian Alps. *Hydrological Processes*, 35(5), 16 p. DOI: 10.1002/hyp.14210.

INNSBRUCK

The Institute for Interdisciplinary Mountain Research (Austrian Academy of Sciences) and the Verein Gletscher Klima continued and expanded their rock glacier monitoring programs. The long-term monitoring of the surface displacement at Äußeres Hochebenkar rock glacier (Andrea Fischer, Lea Hartl, Martin Stocker-Waldhuber) showed that the lower section of the rock glacier has accelerated again, resulting in rockfall onto the access road below. This rock glacier may be undergoing a process of destabilization and increasingly threatens the road. Additionally, geological mapping and analyses of rock glacier runoff are being carried out in the Futschöl valley, Silvretta, in collaboration with the University of Innsbruck to determine how temperature, conductivity and chemical components differ between active, inactive, and relict rock glaciers (Andrina Janicke, Andrea Fischer, Karl Krainer). Wagner *et al.* (2021a) highlighted the importance of permafrost bodies for water management by estimating water storage in rock glaciers.

- Hartl, L., Stocker-Waldhuber, M. and Abermann, J. (2021). Flow velocity records at Rock Glacier Outer Hochebenkar (Äußeres Hochebenkar), Ötztal, Tyrolian Alps, Austria, since 2016. *PANGAEA*. DOI: 10.1594/PANGAEA.928244.

SALZBURG

High-alpine permafrost monitoring was continued in 2021 at the Open-Air-Lab Kitzsteinhorn (OpAL), Hohe Tauern Range. The monitoring is operated by Ingo Hartmeyer and Markus Keuschnig (Georesearch). The maximum thickness of the active layer in 2021 (3.6 m) was less then 2020 (3.7 m), mainly due to an extremely cold spring season. Despite relatively cool conditions in 2021, the borehole data reveals a clear long-term warming trend. At several cirques (Sattelkar, Ofenkar, Mitterkar and Steinkar) in the Venediger Mountains, west of Kitzsteinhorn, ground-surface temperature is monitored at 30 sites by Georesearch supported by the Federal Province of Salzburg and the Hohe Tauern National Park authority.

The ZAMG regional office Salzburg focusses on permafrost-related research around the Hoher Sonnblick mountain, Hohe Tauern Range (see Vienna section).

VIENNA & KORNEUBURG NEAR VIENNA

Permafrost research activities by Michael Avian, Daniel Binder, Martina Frießenbichler, Anton Neureiter, Stefan Reisenhofer, Gernot Weyss, and Claudia Riedl (ZAMG) 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).

The project GCW-Permafrost long-term monitoring investigates the spatial distribution of permafrost in the Sonnblick region (3106 m asl). The project aim is to identify the driving permafrost parameters in the Sonnblick region, whereas geological, geomorphological, topographical and climatic parameters are evaluated. Since 2016 the rock temperature monitoring of the Sonnblick north face was continuously expanded with eight more shallow boreholes. These boreholes host temperature sensors at depths of 0, -20, -40, -60, -80 and -100 cm. Borehole temperatures are sampled every hour and automatically transmitted by a GSM transmitter. At the southern slope of the Hoher Sonnblick summit, services for 20 m deep boreholes were conducted in 2020. Currently, only the southernmost 20 m borehole (borehole 3) is still active. Boreholes 1 and 2 are no longer active due to technical problems and lightning damage. The active layer thickness in 2021 was 1.7 m at borehole 3 (no data is available for 2019 and 2020).

After the successful completion of the research project SeisRockHT in 2020 (established a rockfall monitoring by means of a local seismological monitoring and annual UAV surveys) the continuation of this initiative is assured by GCW-Permafrost and the ZAMG internal ASBO project. In doing so, four crackmeters were installed for the first time on the north face of the Hoher Sonnblick in 2021 (in cooperation with the geological company Furthmüller).

Rockfall monitoring at the Pasterze Glacier area has been carried out using TLS (since 2010) and UAV (since 2019). At Mittlerer Burgstall, analysis of the observation period 2019-2021 (in 2021 two measurements: July and September) reveal that a rockslide mass is displacing. Furthermore, UAV-based analysis gives clear evidence that the entire rock mass of the south-east ridge of Mittlerer Burgstall is undergoing an extensive slide affecting an area of about 43,000 m². In 2021, the monitoring of the rock glacier Hinteres Langtalkar (since 2001) was also carried out using UAVs (Fig. 4). The major advance of the lower part of the rock glacier continued in the in the observation period of 2019-2021 showing maximum displacement rates of 2.48 m per year at the rock glacier front. Both activities (Burgstall, Langtalkar) are funded by a project of the Hohe Tauern National Park authority and led by the University of Graz.

Fig. 4. Launch of a UAV by Gernot Weyss at about 2600 m asl used to survey the rock glacier in the Hinteres Langtalkar, Hohe Tauern Range. Photo: Michael Avian.

Permafrost and periglacial research at the University of Vienna is being conducted by Philipp Marr and Sabine Kraushaar. Within a postdoc fellowship of the German Academic Exchange Service (DAAD), Philipp Marr carried out field work in South Norway (in 2020) exploring the potential of boulder-dominated landforms of periglacial, paraglacial and related origin as a source of palaeoclimatic and morphodynamic information. The role of permafrost degradation in this context is expected to be one of the key drivers of the rock-slope failure and thawing permafrost following local deglaciation is assumed to have led to redistribution of sediment and the build-up of alluvial fans.

- Marr, P., *et al.* (2022). Age, origin and palaeoclimatic implications of peri- and paraglacial boulder-dominated landforms in Rondane, South Norway. *Geomorphology*, 408, 16 p. DOI: 10.1016/j.geomorph.2022.108251.

Sabine Kraushaar (University of Vienna) and Jan Blöthe (University of Freiburg, Germany) continued their work on the geomorphological and hydrological dynamics of the Kaiserberg rock glacier in the Kaunertal valley, Tyrol. Using a combination of hydro-chemical analyses, ground surface temperature analysis, UAV surveys and geophysical measurements, their project GeoHype aims to quantify the

relative contribution of active layer and permafrost body to the discharge from the rock glacier. In late summer 2021, a permanent exhibition on research activities within the Kaunertal (Austria) that also features the project GeoHype was opened.

The first phase of the ESA funded Climate Change Initiative project on permafrost has been completed. The b.geos team (Annett Bartsch, Georg Pointner, Aleksandra Efimova, Dan Jakober, Sarah Ley, Elin Högström) contributed specifically to the coordination of the documentation of the permafrost maps for the northern hemisphere spanning 1997-2019. Documentation includes validation based on GTN-P records and application examples. A use case carried out by the b.geos team focused on identification of infrastructure and general human impact in Arctic permafrost regions using satellite data. A circumpolar dataset has been released which includes man-made objects and permafrost properties of the surroundings (active layer thickness trends, ground temperature trends etc. from ESA CCI Permafrost). Field work for validation has been carried out on Svalbard (Fig. 5).

- Bartsch, A., *et al.* (2021). Expanding infrastructure and growing anthropogenic impacts along Arctic coasts. *Environmental Research Letters*, 16 115013. DOI: 10.1088/1748-9326/ac3176.
- Bartsch, A., Pointner, G., and Nitze, I. (2021). Sentinel-1/2 derived Arctic Coastal Human Impact dataset (SACHI) (Version 1) [Data set]. *Zenodo*. DOI: 10.5281/zenodo.4925911.

Fig. 5. Fieldwork around Longyearbyen, Svalbard, with a camera team in tow for outreach. Photo: Barbara Widhalm.

A new ESA funded networking initiative with focus on remote sensing and coastal erosion in permafrost regions has started in June 2021. It is coordinated by b.geos (Annett Bartsch), with contributions from AWI Potsdam, IGOT Lisbon and UAF. A strategy for the next generation of the Arctic Coastal Dynamics database will be developed.

The ERC Synergy project Q-Arctic (2021-2027; cooperation of b.geos with MPI-M and MPI-BGC) started in October 2021. The aim is the quantification of disturbance impacts on feedbacks between Arctic permafrost and global climate. Outreach on national level regarding Arctic permafrost has been organized through the Austrian Polar Research Institute. The work from b.geos was presented by A. Bartsch as part of the public “Polar Talks” series.

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

BELGIUM

BY HANNE HENDRICKX (GHENT UNIVERSITY) AND SOPHIE OPFERGELT (UNIVERSITÉ CATHOLIQUE DE LOUVAIN)

The goal of the Belgian Branch of the IPA is to foster the collaboration and an exchange between Belgian-based permafrost scientists in the broad sense (e.g. sharing of knowledge/data, collective fieldwork, sharing of samples, sharing of job opportunities and activities in Belgium related to permafrost research). For this purpose, the email list ipa_belgium@lists.ugent.be can be used by anyone who is a member. Please contact Hanne Hendrickx (hanne.hendrickx@ugent.be) if you want to added to this list.

As part of their PhD dissertation, Hanne Hendrickx published a paper on mountain permafrost in the Swiss Alps:

- Hendrickx, H., *et al.* (2022). Timing, volume and precursory indicators of rock- and cliff fall on a permafrost mountain ridge (Mattertal, Switzerland). *Earth Surface Processes and Landforms*, 47(6), 1532-1549. DOI: 10.1002/esp.5333.

Degradation of mountain permafrost can lead locally to enhanced rockfall activity by for example active layer thickening and the weakening of the rock-ice contact. In a heterogeneous mountain environment, this process is likely to be more complex than its theoretical understanding. This is also well illustrated by a recently published case study at Grosse Grabe (2600-2700 m a.s.l.), Mattertal in the Swiss Alps, led by Hanne Hendrickx from Ghent University, in collaboration with Swiss and French scientists (Fig. 6). We observed a rock wall destabilisation with an unprecedented level of detail, including a precursory deformation of the rock wall. The south exposure makes this densely fractured rock wall vulnerable for a thermally induced failure mechanism on different timescales, including thawing of deep bedrock permafrost. Although the elevation and the aspect of the rock face are not favourable for permafrost conditions, deep bedrock ice was exposed after large cliff falls (104-106 m^3) in the summer of 2019 and 2020. This exposure triggered a progressive failure of the rock wall due to thermal adjustment. Rock surface temperature estimates reveal that this deep bedrock permafrost has already been out of equilibrium with the surface temperature for three decades and probably dates back to the last glacial maximum. The collected high resolution temporal and spatial rockfall data provides a detailed insight in short-term rock wall destabilisation and therefore contributes to the understanding of high mountain geomorphology in a changing climate.

WEATHERINGEOCHEMISTRY

The research team includes Sophie Opfergelt (Principal Investigator), Catherine Hirst (Postdoctoral researcher), Elisabeth Mauclet, Arthur Monhonval, Maxime Thomas, Maëlle Villani, and Cécile Osy de Zegwaart-Favart (PhD students). The team are planning a two-month field campaign at Abisko, Sweden during the late shoulder season (14th September to 14th November 2022) (Fig. 7).

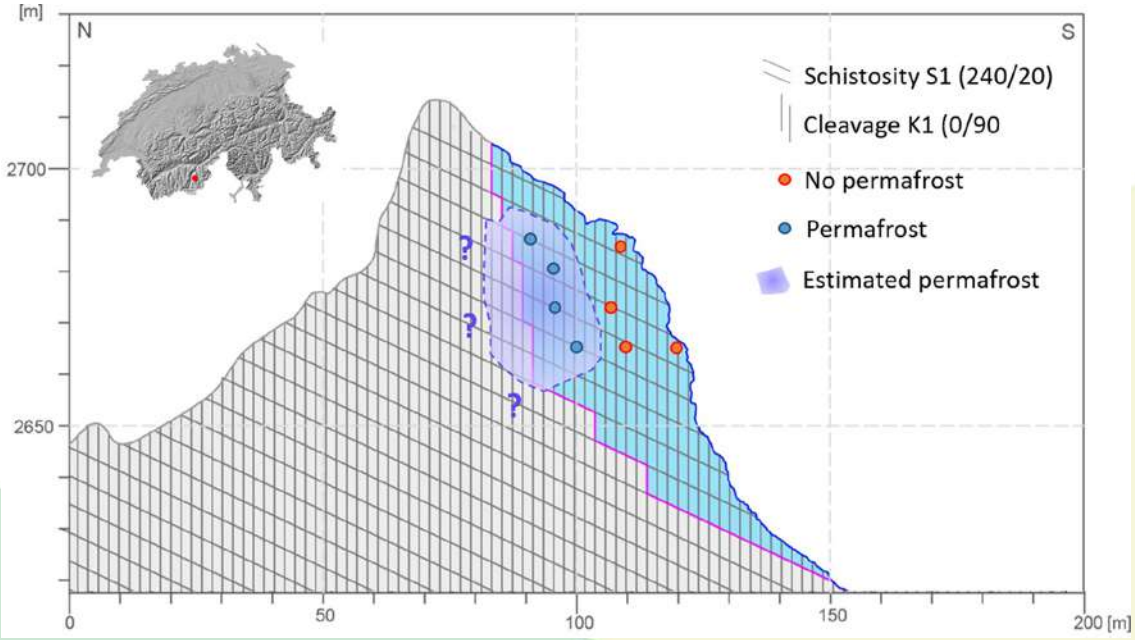


Fig. 6. Cross section of Grosse Grabe rock face, showing the total rockfall volume lost (light blue) and the estimated permafrost body (dark blue/purple). First small scale rock fall events (2017-2018) did not expose any ice in the fractures, while larger cliff falls (2019-2020) with deeper scar depths did expose deep bedrock permafrost (Hendrickx, *et al.*, 2022).

Fig. 7. Fieldwork campaign at the Stordalen Mire (Abisko, Sweden). Photo: Catherine Hirst (Oct. 2021).

Several research projects were also presented at the 7th International Geologica Belgica meeting in Tervuren, Belgium, 14-17 September 2021:

- Mauclet, E. *et al.* (2021). Influence of permafrost degradation on foliar mineral element cycling upon changing subarctic tundra vegetation.
- Villani, M., *et al.* (2021). Influence of permafrost degradation and shift in vegetation on litter and soil properties: case study in Central Alaska.
- Gilliot, A. *et al.* (2021). Evolution of iron-organic carbon interactions during abrupt thaw in ice-rich permafrost: case study in Siberia.
- Louis, J. *et al.* (2021). Influence of thermokarst formation on manganese-organic carbon interactions in ice-rich permafrost.

As well as the virtual American Geophysical Union (vAGU) meeting, 13-17 December 2021:

- Opfergelt, S., *et al.* (2021). Changing conditions for mineral-organic carbon interactions across the permafrost landscape: hot moments more than hot spots?

For more information contact Hanne Hendrickx (hanne.hendrickx@ugent.be) or Sophie Opfergelt (sophie.opfergelt@uclouvain.be) and see:

- Hatton, J.E., *et al.* (2020). Silicon isotopic composition of dry and wet-based glaciers in Antarctica. *Frontiers in Earth Science*, 8, 15 p. DOI: 10.3389/feart.2020.00286.
- Murphy, M.J., Hendry, K.R., and Opfergelt, S. (2021). Editorial: Novel isotope systems and biogeochemical cycling during cryospheric weathering in polar environments. *Frontiers in Earth Science*, 9, 3 p. DOI: 10.3389/feart.2021.660333.
- Monhonval, A., *et al.* (2021). Iron Redistribution upon Thermokarst Processes in the Yedoma Domain. *Frontiers in Earth Science*, 9, 18 p. DOI: 10.3389/feart.2021.703339.
- Monhonval, A., *et al.* (2021). Mineral Element Stocks in the Yedoma Domain: A Novel Method Applied to Ice-Rich Permafrost Regions. *Frontiers in Earth Science*, 9, 18 p. DOI: 10.3389/feart.2021.703304.
- Shmelev, D., *et al.* (2021). Reconstructing permafrost sedimentological characteristics and post-depositional processes of the Yedoma stratotype Duvanny Yar, Siberia. *Frontiers in Earth Science,* 9, 14 p. DOI: 10.3389/feart.2021.727315.
- Mauclet, E., *et al.* (2022). Changing sub-Arctic tundra vegetation upon permafrost degradation: impact on foliar mineral element cycling. *Biogeosciences*, 9(9), 2333-2351. DOI: 10.5194/bg-2021-263.
- 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), 24 p. DOI: 10.1029/2021GB007105.
- Villani, M., *et al.* (2022). Mineral element recycling in topsoil following permafrost degradation and a vegetation shift in sub-Arctic tundra. *Geoderma*, 421, 9 p. DOI: 10.1016/j.geoderma.2022.115915.

CANADA

BY SHARON SMITH (GEOLOGICAL SURVEY OF CANADA)

Travel restrictions to northern Canada were relaxed in 2021 and it was possible for Canadian permafrost scientists to conduct field work during the summer. Conferences and meetings were still largely virtual with permafrost sessions at the Canadian Permafrost Annual General Meeting held with NSERC PermafrostNet, ArcticNet Annual Science Meeting and the Yellowknife Geoscience Forum. A number of Canadian activities were highlighted in the 2021 edition of Frozen Ground. Additional activities are described below.

YUKON GEOLOGICAL SURVEY

Yukon Geological Survey (YGS) collaborated with YukonU Research Centre to characterize permafrost in the Greater Whitehorse area. Permafrost in this area is thin, warm and discontinuous and is limited to specific geological settings, including subalpine peat plateaus, north-facing slopes underlain by till, areas underlain by fine-grained glaciolacustrine sediment, and low-lying wetland areas. Seven case study sites representing these environments were investigated using a variety of techniques, including ERT geophysical surveys, ground temperature monitoring, borehole drilling and geotechnical analysis. This study included characterization of the rapidly developing Takhini River retrogressive thaw slump (Fig. 8), which threatens to damage the Alaska Highway in the near future.

- Roy, L.-P., *et al.* (2021). Greater Whitehorse area permafrost characterization. Yukon Geological Survey, Miscellaneous Report MR-22, 185 p., including appendices.

Fig. 8. The Takhini River thaw slump has been rapidly growing towards the Alaska Highway at rates of up to 11 m/yr since 2014 (5 Sept. 2019).

YGS launched the Yukon Permafrost Database web application which provides access to a wealth of geotechnical borehole data, ground temperature data, and spatially-referenced reports and other documents. Data may be explored using interactive online tools, or it may be downloaded for customized analysis. Over 15,000 geotechnical boreholes and 128 temperature monitoring sites are currently compiled. The database will be maintained and updated regularly, and YGS encourages ongoing data contributions from the permafrost community working in Yukon.

- Lipovsky, P.S., *et al.* (2022). Yukon Permafrost Database: A new baseline data resource. In: *Yukon Exploration and Geology 2021*. K.E. MacFarlane (ed.), Yukon Geological Survey, p. 37–49.

The permafrost capacity of YGS increased this year, with Derek Cronmiller filling a new Permafrost Geologist position. His work will focus on: expanding the YGS permafrost monitoring network; hazard mapping for communities and transportation corridors; developing a glacier monitoring program; and collaborating with various researchers. In 2021, Derek installed several new permafrost monitoring stations in Beaver Creek, Teslin, Carmacks, Mayo and along the Dempster Highway and updated instrumentation at several of YGS's older stations (Faro, Ross River and Watson Lake). Derek, in collaboration with Panya Lipovsky, is finalizing community hazard maps for Beaver Creek and Teslin, and will complete one for Haines Junction in 2022. Derek and Moya Painter are assessing thaw subsidence hazards along highway corridors and developing a glacier-monitoring program to track long term changes in glacier volume at selected glaciers. Also planned is establishment of a permafrost monitoring program in a portion of the Klondike Goldfields to examine the links between placer mining reclamation and the potential reestablishment of permafrost.

PERMAFROST MONITORING IN NUNAVUT

In 2008 and 2009, the Geological Survey of Canada (GSC) in collaboration with the Nunavut Government and communities, established permafrost monitoring sites in 10 communities as part of an International Polar Year Project. The first six years of ground temperature data were summarized in Ed-

nie and Smith (2015) and the continuous data collection facilitated assessment of trends and contributions to national and international assessments.

- Ednie, M., and Smith, S.L. (2015). Permafrost temperature data 2008-2014 from community based monitoring sites in Nunavut. Geological Survey of Canada Open File, 7784. DOI: 10.4095/296705.
- Smith, S.L., Duchesne, C., and Lewkowicz, A.G. (2019). Tracking changes in permafrost thermal state in Northern Canada. In: J.-P., Bilodeau, *et al.* (eds.). *Cold Regions Engineering 2019*. Proceedings of the 18th ICCRE and the 8th CPC, Québec City, QC, Canada, 18-22 August 2019. American Society of Civil Engineers (ASCE), 670-677. DOI: 10.1061/9780784482599.
- Smith, S.L., *et al.* (2021). Permafrost. In: M.L., Druckenmiller *et al.* (eds.). *State of the Climate in 2020*. Bulletin of the American Meteorological Society, 102(8), S293-S297. DOI: 10.1175/BAMS-D-21-0086.1.

In summer 2021, the Government of Nunavut, Department of Economic Development and Transportation, was able to travel to the communities through support received from Transport Canada's Northern Transportation Adaption Initiative (NTAI), and exchange pre-programmed data loggers provided by GSC with those installed at the sites. This enabled data acquisition from the eight monitoring sites that were still operating. Three to six community members participated in site visits and were trained on how to exchange the dataloggers. Meetings with local organizations were conducted to raise awareness of permafrost data available in their community and to bring forward local observations of permafrost change. These activities have facilitated increased agency of community members for data collection in their communities, increased local awareness of permafrost data available in their community, and has the potential for more regular data retrieval going forward by trained community members exchanging the pre-programmed dataloggers from GSC.

Updating of databases is currently in progress along with preparation of a report summarizing and presenting the ground temperature data. The continuous data collection and analysis of the extended time series will facilitate ongoing assessments in trends of permafrost temperature (Fig. 9).

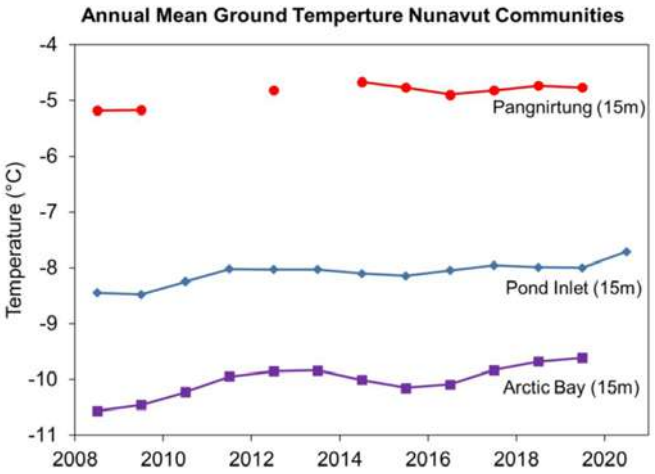


Fig. 9. Trends in permafrost temperature measured at 15 m depth for three communities in the Baffin region Nunavut. Updated from Smith *et al.* (2021).

MAPPING & INVESTIGATING PERMAFROST ALONG THE PROPOSED KIVALLIQ HYDRO-FIBRE LINK, NUNAVUT

The Kivalliq Hydro-Fibre Link (KHFL) project has the ambitious goal of providing several Arctic communities and mine sites in Nunavut with hydroelectricity and high-speed Internet. The project spans 1,200 km, extending from Gillam, MB, to Baker Lake, NU. Led by the Kivalliq Inuit Association (KIA), the KHFL will be Nunavut's first major infrastructure link to southern Canada.

Palmer has been contributing terrain/permafrost expertise to the advancement of the project since early 2020. Its team of geomorphologists and permafrost scientists, in a unique collaboration with researchers led by Dr. Pascale Roy-Léveillée of Université Laval, established a preliminary 1.2 km-wide corridor for the project based on the relative favourability of ground conditions for tower installation, interpreted from publicly available satellite imagery and pre-existing, regional-scale surficial geology and ground ice mapping. In 2021, 1:20,000-scale surficial geology mapping, with an emphasis on the identification of ground-ice indicators, was completed within the Nunavut portion of corridor based on stereo-interpretation of SPOT satellite imagery, archived aerial photography and the ArcticDEM.

Active participation of community members in multi-disciplinary field studies that help shape the project is a key priority for the KIA and its project team. Although COVID-19 has curtailed many in-person activities, field teams have still been able to conduct targeted field investigations with support from members of the Fox Lake Cree Nation as bear guards.

In 2021, the Palmer/Laval team conducted two helicopter-supported field investigations of terrain and permafrost along the KHFL corridor, building on initial reconnaissance and air/ground temperature installations completed the previous year (Fig. 10). In March, ground penetrating radar (GPR) lines were surveyed at several locations in Manitoba. In late August/early September, mapping was 'ground truthed' and additional investigations of permafrost were completed. Active layer thicknesses were measured using a frost probe, surficial deposits were examined in hand-dug test pits, and permafrost was cored and sampled up to ~2 m depth using a lightweight Talon drill. Initial ground temperature data was downloaded from sensors installed in Manitoba, and two additional sensors were installed in Nunavut.

Surficial deposits found to be sandy and gravelly (till, glaciofluvial and shallow-water glaciomarine deposits) tended to have relatively low ice contents and thick active layers. Fine-grained materials (fluvial and deep-water glaciomarine deposits) and wetlands had relatively high ice contents and thin active layers. This information, combined with the surficial geology mapping, is strengthening understanding of the diversity of ground conditions along the KHFL corridor and will ultimately inform route refinement and site-specific geotechnical investigations for tower installations.

Key results were presented at the 2021 Regional Conference on Permafrost (RCOP) and compiled into a paper for presentation at GeoCalgary 2022.

NSERC PERMAFROSTNET

NSERC PermafrostNet is midway through its five-year term with 28 graduate students and three postdoctoral research fellows currently conducting projects across Canada. Two theses have been completed: *A temporal deep learning approach to bedfast and floating thermokarst lake ice mapping using SAR imagery: Old Crow Flats, Yukon, Canada* (Maria Shaposhnikova); *Assessing a Geocell-supported railway embankment subjected to permafrost degradation and ponding water conditions using numerical modelling techniques* (Payam Sharifi).

Fieldwork resumed in 2021 (Fig. 11) with expeditions near Kelvin Camp, NT, in Chief Drygeese Territory, in the Norman Wells area in the Mackenzie Valley, NT, along the Alaska Highway from Beaver Creek, YT to Fort Nelson, BC, in the Mackenzie Mountains, NT, on the Dempster highway near Dawson City and near Mayo, YT, and in the Hudson Bay Lowlands, QC.

Network data scientist Nick Brown and post-doctoral research fellow Michel Paquette added additional permafrost-relevant terms to the CF standard

Fig. 10. Clockwise from upper left: soil pit with stadia tape measurements numbered in decimetres, community member ensuring safety from bears, downloading ground temperature data, augering and sampling with the Talon drill, logging frozen drill core, permafrost probing.

Fig. 11. Emilie Stewart-Jones gathering data for her research near Whitehorse, YT.

names list, that will be used as part of an initiative to publish interoperable datasets on PermafrostNet's ERDDAP server. The NSERC PermafrostNet Data Publication Handbook was produced and describes the steps and considerations for publishing permafrost data in a way that is open, and interoperable. It provides specific guidelines to publish permafrost data within the NSERC PermafrostNet program, with information on file formats, standards, and links to other resources. The network hosted a Permafrost Data Systems Workshop at RCOP2021 featuring invited speakers Ashley Rudy (Northwest Territories Geological Survey) and Jeanette Nötzli (Swiss Permafrost Monitoring Network, PERMOS).

The network ran the Science Communication Toolbox for Researchers in early 2021, a communication training course designed specifically for permafrost researchers with tailored made workshops including community engagement in the North and engaging with local policy makers. The network hosted a virtual AGM in November 2021 with the Canadian Permafrost Association. The three-day meeting, coordinated by Ryley Beddoe and Teddi Herring, included a special poster session on SpatialChat, keynote presentations and technical sessions. It also included a mentoring and career development session - Help Me, Help You, a strategy session, a Northern and Indigenous Engagement session and an awards ceremony (see also the Network News and Theme News on permafrost.ca website).

NORTHWEST TERRITORIES GEOLOGICAL SURVEY (NTGS)

In 2021, the Government of Northwest Territories (GNWT) significantly strengthened the Permafrost Science capacity to address increasing demands for permafrost information and advice. Territorial permafrost scientists now include Jennifer Humphries, Permafrost Specialist, at the Aurora Research Institute (ARI) and Tim Ensom, Geotechnical Advisor with the Department of Lands, and Dr. Steve Kokelj, Senior Permafrost Scientist; Alice Wilson, Permafrost Scientist; Dr. Neils Weiss, Permafrost Data Scientist; and Dr. Ashley Rudy, Permafrost Geohazard Scientist at the NWT Geological Survey (NTGS) (Fig. 12). This increased capacity allows the Northwest Territories (NWT) to lead and co-develop permafrost knowledge with government, academic, and Indigenous partners and mentor several graduate students. For example, the team developed a strong working relationship with Inuvialuit Environmental Monitors through regular data collection and training activities. To support the success of this growing team, the NTGS developed a strategic plan with the vision that *"The Northwest Territories has the permafrost science knowledge, expertise, capacity, and partnerships required to plan for and adapt to the impacts of changing permafrost conditions"*. It also provides a framework for the team to grow as scientists and work with collaborators and partners more effectively.

Fig. 12. NWT Permafrost Scientists. Shown left to right: Steve Kokelj, Seamus Daly (Permafrost Mapping Coordinator), Neils Weiss, Tim Ensom, Alice Wilson, Justin Kokoszka (NWT Summer student), Ashley Rudy.

The Dempster and Inuvik to Tuktoyaktuk Highway (ITH) corridors have been focal points of permafrost monitoring and research activities. The NTGS, in collaboration with Government, and academic partners, has implemented a state-of-the-art monitoring network to complement a legacy of geotechnical and mapping products. This applied regional permafrost research hub supports the training of students and Indigenous Environmental Monitors, advances research, and mobilizes knowledge through collaboration between ARI and Inuvik-based NTGS staff and by hosting PhD Student Emma Stockton. Projects include partnerships with Industry and Inuvialuit partners to examine the

effectiveness of snow compactions on disturbed and natural sites across the treeline, studying the growth mechanisms and distribution of Aufeis, and monitoring thaw-induced landslides using Remote Piloted Aircraft Systems and instrumentation to enable real-time monitoring of landslide risk. These initiatives, combined with a growing need to manage and make permafrost data available, have stimulated the development of an NWT Permafrost Database, which hosts permafrost geotechnical, and ground temperature data collected by the GNWT, industry, and academic partners. The permafrost datasets are now available as open reports, and soon through the database to support informed decision-making, climate change adaptation, risk management, and State of Environment Reporting.

The NWT Thermokarst Mapping Collective (TMC) project is a collaborative, northern-driven effort to inventory thaw-sensitive permafrost terrain across the NWT. The NTGS, with support from the Geological Survey of Canada and the GNWT-Wilfrid Laurier partnership, worked with academic partners to develop methods and train mappers across Canada. Using Sentinel-2 imagery, mappers attribute characteristics to a 7.5x7.5 km grid cell using a defined list of thermokarst and periglacial features or landscape types. The spatial data infrastructure accommodated a decentralized design enabling mapping progress throughout the COVID-19 pandemic. Preliminary outputs correspond well with high-resolution, independent datasets, and systematic aerial observations from the summers of 2020 and 2021. These were obtained from over 15,000 km of helicopter flight lines. Comparisons with national or global scale depictions of thermokarst or sensitive permafrost terrain indicate that the TMC significantly improves the understanding of thaw-sensitive terrain across the NWT. The dissemination of these spatial data products provides excellent opportunities to build collaborations with Indigenous partners and other research projects.

GEOLOGICAL SURVEY OF CANADA (GSC)

GSC scientists were able to conduct some fieldwork in 2021 in the Northwest Territories and Nunuvut. However, GSC were able to visit all field sites and collaboration and efforts of Territorial Government and academic partners were essential to data acquisition from several permafrost monitoring sites. In 2021, GSC research focused on regional permafrost feature mapping and ground ice modelling in the Slave-Grays Bay Corridor, assessment of talik occurrence in the Kivalliq region, national scale thermokarst modelling as well as contributions to international assessments of changes in permafrost conditions. The permafrost geoscience knowledge generated by this research supports adaptation to a changing climate and decisions regarding mineral resource development in northern Canada:

- LeBlanc, A.-M., Chartrand, J., and Smith, S.L. (2021). Estimation of maximum lake depth from the surrounding topography: towards a regional assessment of the occurrence of taliks below Arctic lakes. Geological Survey of Canada, Scientific Presentation 122. DOI: 10.4095/328242.
- Morse, P.D., Smith, S.L., and Parker, R.J. (2021). Periglacial landforms of the Grays Bay Road corridor region, Nunavut, and implications for climate-resilient infrastructure. Geological Survey of Canada, Scientific Presentation 123. DOI: 10.4095/328247.
- Oldenborger, G.A., Faucher, B., and LeBlanc, A.-M. (2021). Multispectral permafrost terrain classification, Rankin Inlet, Nunavut. Geological Survey of Canada, Open File 8824, 38 p. DOI: 10.4095/328869.
- Sladen, W.E., *et al.* (2021). Geomorphologic feature mapping along the Dempster Highway and Inuvik to Tuktoyaktuk Highway corridor, Yukon and Northwest Territories, Canada. Geological Survey of Canada, Scientific Presentation 124. DOI: 10.4095/328294.
- Sladen, W.E. *et al.* (2021). Geomorphologic feature mapping methodology developed for the Dempster Highway and Inuvik to Tuktoyaktuk Highway corridors; Geological Survey of Canada, Open File 8751. DOI: 10.4095/328181.
- Wolfe, S.A., O'Neill, H.B., and Duchesne, C. (2021). A ground ice atlas of Canada; Geological Survey of Canada, Open File 8770. DOI: 10.4095/328115.
- Wolfe, S.A., Morse, P.D., and Behnia, P. (2021). Spatial distribution of pingos in the Tuktoyaktuk coastlands and adjacent areas, Northwest Territories; Geological Survey of Canada, Open File 8787. DOI: 10.4095/328305.

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

FINLAND

BY JAN HORT (UNIVERSITY OF OULU)

FINNISH METEOROLOGICAL INSTITUTE (FMI)

Scientists at the FMI have developed methods to combine SMOS satellite data on soil freeze/thaw status with atmospheric inverse modeling. The atmospheric inverse model (Carbon Tracker Europe – CH4) was applied to estimate northern latitude wetland methane emissions, which are suppressed by the seasonal soil freezing. SMOS freeze/thaw data provides information on the temporal dynamics of soil freezing and thawing and can be utilized as a prior information in inversions.

- Tenkanen, M., *et al.* (2021). Utilizing Earth Observations of Soil Freeze/Thaw Data and Atmospheric Concentrations to Estimate Cold Season Methane Emissions in the Northern High Latitudes. *Remote Sensing*, 13(24), 27 p. DOI: 10.3390/rs13245059.

A team of scientist from FMI (Juha Aalto) and University of Helsinki (Miska Luoto, Pekka Niittynen and Henri Riihimäki) studied how cryogenic land surface processes (LSP) can constrain tundra biomass patterns. They conducted a comprehensive mapping of active geomorphological processes, such as cryoturbation and solifluction, over northern European tundra, and used spatial modeling techniques to relate LSP to satellite-derived aboveground biomass estimates. The results suggest that LSP significantly reduce tundra vegetation biomass with potentially important implications on future land surface changes and carbon cycling.

- Aalto, J., *et al.* (2021). Cryogenic land surface processes shape vegetation biomass patterns in northern European tundra. *Communications Earth & Environment*, 2, 10 p. DOI: 10.1038/s43247-021-00292-7.

UNIVERSITY OF HELSINKI

Collaborative projects were continued with the '*Arctic Avenue*' funding (a spearhead research projects between the University of Helsinki and Stockholm University). Minna Väliranta, Atte Korhola, and Teemu Juselius from the University of Helsinki are working on the project, *Permafrost peatlands under climate warming pressure*, which aims to increase our knowledge of ground thermal conditions in Fennoscandian permafrost peatlands along a climatic and topographic gradient, in order to project how future climate change will affect these environments. In 2021, these research sites were visited to collect the ground thermal data of the previous year (Fig. 13).

Fig. 13. Permafrost peatland in northwest Finland. A research site for ground thermal monitoring.

Modelling results incorporating measured greenhouse gas flux data and historical data, carried out in collaboration with scientists from the FMI and University of Eastern Finland, highlight the importance of Arctic peatlands in atmospheric greenhouse gas forcing both in the past and future. The study found out as a novel discovery that current bare peat surfaces in subarctic regions are probably remnants of permafrost initiation triggered bare peat areas. The initiation of permafrost by the late Holocene cooling paradoxically generated a short-term climate warming feedback.

- Väliranta, M., *et al.* (2021). Warming climate forcing impact from a sub-arctic peatland as a result of late Holocene permafrost aggradation and initiation of bare peat surfaces. *Quaternary Science Reviews*, 264, 10 p. DOI: 10.1016/j.quascirev.2021.107022.

Research following Minna Väliranta's previous project (ended 2020) *'Response of high-latitude peatlands to past and recent warming – predictions for future climate feedbacks'* was carried out based on the data collected for the project. The preliminary data shows habitat-type changes from wet to drier habitat conditions with Sphagna in permafrost peatlands of Fennoscandia and northwest European Russia. For more information, contact Minna Väliranta (minna.valiranta@helsinki.fi).

UNIVERSITY OF OULU

Studies on periglacial processes and landforms continued in the ArcticSHOC (*Spatial ensemble prediction of permafrost thaw, soil carbon and ground-ice in the Arctic*, Sep. 2018 - Aug. 2022) and HYPERISK (*Hybrid modelling for improved permafrost risk assessments*, Jan. 2021 - Dec. 2024) projects. In ArcticSHOC (Jan Hjort, Olli Karjalainen and Oona Könönen), the focus was on circumpolar modelling of ground ice content and palsas. In the HYPERISK project (Jan Hjort, Olli Karjalainen and Eirini Makopoulou), extensive data on slope features (retrogressive thaw slumps and active layer detachment slides) and environmental variables were compiled across the Northern Hemisphere's permafrost regions. Moreover, first spatial analysis of slope features was conducted. Next, the focus will be on hybrid modelling of mean annual ground temperatures.

Temperature monitoring and active layer thickness measurements (Jan Hjort) continued in palsa mires in northwest Finland (Kilpisjärvi, Peera).

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

FRANCE

BY ANTOINE SÉJOURNÉ (UNIVERSITÉ PARIS-SACLAY)

GÉOSCIENCES ENVIRONNEMENT TOULOUSE, UNIVERSITÉ PAUL SABATIER TOULOUSE

The HiPerBorea project which aims to simulate climate change impacts on permafrost using High Performance Computing, has extended its activities in 2021 thanks to the on-going PhD thesis of Simon Cazaurang at the Institut de Mécanique des Fluides de Toulouse (IMFT) and to the starting of the post-doc of Thibault Xavier at Géosciences Environnement Toulouse (GET). Simon Cazaurang studies the thermo-hydrological properties of boreal moss and lichen covers in Khanymey Research Station (INTERACT, Western Siberia) and Thibault Xavier uses permaFoam to forecast the permafrost status of permafrost at the Evenkian Field Station (INTERACT, Central Siberia). HiPerBorea has also been involved in research activities in Yakutia.

- Cazaurang, S., *et al.* (2021a). *Numerical estimation of effective hydraulic properties of sphagnum moss, lichen and peat from western siberian lowlands* [Conference Presentation]. 6th International Field Symposium "Western Siberian Peatlands and Carbon Cycle: Past and Present", 28 June - 7 July, Khanty-Mansiysk, Russia (Online).
- Cazaurang, S. *et al.* (2021b). Application of porous media study techniques on biological samples from Western Siberian Lowlands. In: *JEMP 2021 Biennial French InterPore Conference: Book of Abstracts*, 26-27 October 2021, Strasbourg, France, 114-115.
- Orgogozo L., *et al.* (2021a). Modeling of water fluxes in boreal peatlands: perspective offered by high-performance computing techniques [Conference Presentation]. 6th International Field Symposium "Western Siberian Peatlands and Carbon Cycle: Past and Present", 28 June - 7 July, Khanty-Mansiysk, Russia (Online).
- Orgogozo L., *et al.* (2021b). Applying high performance computing techniques to the simulation of heat and water transfers within permafrost. In: *JEMP 2021 Biennial French InterPore Conference: Book of Abstracts*, 26-27 October 2021, Strasbourg, France, 139-140.

Another research at the GET Laboratory (Toulouse) is focused on quantifying biogeochemical cycles of carbon (C), nutrients and metals in permafrost environments across the Arctic, from northeastern Europe to Eastern Siberia. We specifically focus on peat soils and soil porewaters and ice, thermokarst ponds and lakes, rivers, and atmospheric precipitates. We combine fieldwork, experimental modeling and mecosms approaches to reveal the physico-chemical and biological factors controlling fluxes and pools of C, nutrient and metals in artic and subarctic biomes of northeastern Europe and Siberia.

In particular, we demonstrated significant and previously underestimated role of inland waters of western Siberia in C emission to the atmosphere and we showed the dispersed ice which is present in peat below active layer represents highly labile reservoir of organic and inorganic nutrients which should be considered in permafrost thaw scenarios. The mesocosm experiments on thermokarst lakes of northeast European tundra showed the importance of ground vegetation such as mosses in providing the C and nutrients to the water column and controlling the C exchange fluxes between lake water and atmosphere.

- Karlsson, J. *et al.* (2021). Carbon emission from Western Siberian inland waters. *Nature Communications*, 12, 8 p. DOI: 10.1038/s41467-021-21054-1.
- Lim A.G., *et al.* (2021). Dispersed ground ice of permafrost peatlands: a non-accounted for source of C, nutrients and metals. *Chemosphere*, 226, 15 p. DOI: 10.1016/j.chemosphere.2020.128953.
- Lim A.G., Loiko, S.V., Pokrovsky, O.S. (2022). Sizeable pool of labile organic carbon in mineral soils of permafrost peatlands: an experimental approach. *Geoderma*, 409, 12 p. DOI: 10.1016/j.geoderma.2021.115601.
- Shirokova, L.S., *et al.* (2021). Lichen, moss and peat control of C, nutrient and trace metal regime in lakes of permafrost peatlands. *Science Total Environment*, 782, 14 p. DOI: 10.1016/j.scitotenv.2021.146737.

GÉOSCIENCES PARIS-SACLAY, UNIVERSITÉ PARIS-SACLAY

Unfortunately, the team from the laboratory Geosciences Paris Saclay could only conduct a short

field work in Central Yakutia (Eastern Siberia) in September 2021 due to the COVID-19 pandemic. The PRISMARCTYC project aims to better understand the impacts of permafrost thaw on soils, surface/groundwater fluxes (critical zone) and carbon cycle, as well as their controlling factors. The team in collaboration with colleagues of the Melnikov Permafrost Institute (MPI), Yakutsk, Russia, were able to collect data from a small watershed in Central Yakutia (100 km from Yakutsk) and in the Kolyma area. Different hydrological, geochemical, geomorphological, and microbiological data were collected to characterize the different hydrosystems (lakes, river, groundwater). During 2021, outreach activities about permafrost and climate change with primary schools in France and in Yakutia were still continuing.

However, the team published several papers, including a multi-proxy paleolimnological analysis of a sediment core sequence from Lake Malaya Chabyda in Central Yakutia (Eastern Siberia, Russia). This research investigated changes in lake processes, including lake development, sediment and organic carbon accumulation, and changes in primary productivity, within the context of Late Pleistocene and Holocene climate change. The maximum age of this sediment core was approximately 14 cal. kBP and three distinct sedimentary units were identified within the sediment core. Sedimentological and biogeochemical properties in the deepest section of the core (663-584 cm; 14.1-12.3 cal. kBP) suggests a lake environment mostly influenced by terrestrial vegetation. The middle section of the core (584–-76 cm; 12.3-9.0 cal. kBP) is characterized by higher primary productivity in the lake and higher sedimentation. Conditions in the upper section of the core suggest high primary productivity in the lake and high organic carbon (OC) accumulation rates with stable environmental conditions. Compact lake morphology and high sedimentation rates likely resulted in this lake acting as a significant OC sink since the Pleistocene-Holocene transition.

- Hughes-Allen, L., *et al.* (2021). 14,000-year Carbon Accumulation Dynamics in a Siberian Lake Reveal Catchment and Lake Productivity Changes. Frontiers in Earth Science. 9, 19 p. DOI: 10.3389/feart.2021.710257.

Another paper focused on the Lena River which is one of the largest fluvial hydrosystems within the thick and continuous permafrost zone. The Lena River and its tributaries are characterized by a large inter-annual variability with a thawing of the ice cover, inducing huge ice-jams and a fast rising of the water level, together with an active process of thermal and mechanical erosion. During spring floods, the islands along the Lena River channel are submerged and this induces an additional thermal imprint. Ten islands upstream of the city of Yakutsk have been monitored during two consecutive years (July 2009 to July 2011). We measured the frozen soil thermal regime and water temperatures of these islands on a daily basis using automated waterproof data loggers. Other sensors are used to estimate the height and duration of flooding. We examined the effect of repeated inundations and warm stream water on the thermal regime of frozen islands as well as the effect of the duration of the flood season. Our measurement campaigns revealed that the effect of island submersion at the time of break-up appears to have a relatively moderated impact on the frozen soil thermal profile at depth. The results also show that the Lena floodplain is thermally heterogeneous with islands composed of permafrost and others with only seasonally frozen ground. Our study shows that relatively young (< 30 years old) islands, composed of fine sand material appear less prone to permafrost formation compared to older islands with ice-rich silty material.

- Costard, F. *et al.* (2022). Thermal regime variability of frozen islands in the Lena River floodplain near Yakutsk, eastern Siberia. *Permafrost and Periglacial Processes*, 33(1), 18-31. DOI: 10.1002/ppp.2136.

LABORATOIRE DES SCIENCES DU CLIMAT ET DE L'ENVIRONNEMENT, UNIVERSITÉ PARIS-SACLAY

LSCE activities were still strongly altered from the 2021 confinements leading to the canceling of the experimental work in the cold room at GEOPS facility. Nevertheless, field study has been possible in September 2021 to collect data for the study of the thermal imprint of a small river on permafrost for the HiPerBorea project.

With great sadness, we announce the passing of Christophe Grenier in 2022.

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

Although the team could not conduct fieldwork in Eastern Siberia due to the COVID-pandemic, a number of actions were carried out in collabora-

tion with our Russian colleagues at MPI. A study conducted on the middle Lena analyzed the island dynamics for the last 50 years (1967 to 2017). The results identified several morphological changes that recently occurred: an increase in the number of islands, greater eroded surfaces and accelerated migration of islands. Furthermore, since 2008 the erosion of the islands with permafrost has suddenly increased. This evolution seems to be linked with the increasing duration of high water discharge and the number of flood peaks. The stream water temperature in May and August also has a major influence on permafrost islands (Fig. 14). Thus, the recent evolution in the Lena River proves that the global change deeply impacts periglacial rivers.

Fig. 14. Top: bank of an old island with permafrost (Lena River). Bottom: steep bank with a basal niche and collapsed frozen blocks. Photo: François Costard (July 2011).

Emmanuèle Gautier is also the leader of the thematic network *"Arctic: Issues for Environment and Societies"* which is supported by Centre National de la Recherche Scientifique (CNRS; INEE and INSHS). This network federates research on Arctic socio-ecosystems.

- Gautier, E., *et al.* (2021). Fifty-year dynamics of the Lena River islands (Russia): Spatio-temporal pattern of large periglacial anabranching river and influence of climate change. *Science of the Total Environment*, 783, 15 p. DOI: 10.1016/j.scitotenv.2021.147020.

LABORATOIRE ECOLOGIE FONCTIONNELLE ET ENVIRONNEMENT, INP-ENSAT, CASTANET TOLOSAN

In 2021, the LEFE laboratory published results on joint research conducted with MPI and the Sukachev Institute, Krasnoyarsk. Over three years the Russian and French teams installed and maintained high frequency in-situ monitoring of dissolved organic carbon (DOC) concentrations at the outlet of the Graviyka River, one of the northernmost tributary of the Yenisei River. The results highlight the seasonality of DOC transfer process and the potential important role of autumn floods in the annual exports.

In 2021, a new project has been funded by the ANR: *Impact of permafrost thaw on ARCTIC and Subarctic PEATland carbon dynamics - Arctic-PEAT*. This project will investigate the evolution of carbon stocks, carbon accumulation rates, microbial community structures and organic matter composition after permafrost, using chronosequences in Russia and Canada. The team includes researchers from France (LEFE, GET, LEGOS, LSCE, geosciences Rennes), Russia (MPI) and Canada (Geotop, Montreal).

- Gandois, L., *et al.* (2021). Seasonality of DOC Export From a Russian Subarctic Catchment Underlain by Discontinuous Permafrost, Highlighted by High-Frequency Monitoring. Journal of Geophysical Research: Biogeosciences, 126(10), 18 p. DOI: 10.1029/2020JG006152.

LABORATOIRE DE PLANÉTOLOGIE ET GÉOSCIENCES, UNIVERSITÉ DE NANTES

The PERMOLARDS project aims to understand how molards are linked with landslides and permafrost degradation, and if they can be used as accurate tracers for this degradation. LPG has three members involved in the project: Susan J. Conway (SJC), Axel Noblet (AN) and Meven Philippe (MP):

- Laboratory: we are conducting analogue experiments for modelling molards degradation. Preliminary experiments were conducted in Nantes with small models to explore the scientific relevance of several setups (MP);
- Field: fieldwork has been (and will be) conducted in Iceland (Fig. 15) and Greenland to study molards and permafrost degradation, and to bring samples back for particle size analyses (SJC, AN, MP);
- Orbit: molards are studied in their local geomorphological context on satellite imagery. For this purpose, we produced ~20 DTMs of various landslides around the world (AN, MP).

Fig. 15. Molard in Iceland. Florence Magnin drilling bedrock for installing temperature sensor at Holar site.

LABORATOIRE MORPHODYNAMIQUE CONTINENTALE ET CÔTIÈRE, UNIVERSITÉ DE CAEN NORMANDIE

The PERMOLARDS project aims to track the degradation of mountain permafrost with "molards" (cones of loose debris that result from thawing of blocks of ice-rich sediments mobilised by landslides in permafrost terrains). At the Laboratoire Morphodynamique Continentale et Côtière, eight members are involved in the project under the lead of Marianne Font-Ertlen with the focus on the experimental component of the project. The CryoEx cooling chambers are used to physically model the degradation of ice-cemented blocks into molards both in a continental and submerged environment. For initial downscaled experiments, 30 cm cube shaped blocks of frozen sediment are created and are left to thaw in under constant controlled forcings (Fig. 16). The blocks in the continental setup are thereby monitored by a timelapse photogrammetric system which was developed by the project collaborator at LPG Nantes. This allows us to create a 3D model of the molard formation process. Future experimental plans include variation in the initial block conditions such as the sediment composition and upscaling the block size, but also variing meteorological forcings by introducing seasonal cycles or precipitation.

ENVIRONNEMENTS, DYNAMIQUES ET TERRITOIRES DE MONTAGNE, UNIVERSITÉ SAVOIE MONT BLANC - LABORATOIRE DE SCIENCES SOCIALES, UNIVERSITÉ GRENOBLE ALPES

Since 2007, EDYTEM has been monitoring rockfalls (V >100 m³) in the Mont-Blanc massif in order to better understand the evolution of the frequency/volume of these phenomena in permafrost context in the Western Alps. In 2021, the database was updated for 2016-2021 (between 92 and 222 rockfalls per year). The data are currently being edited to be made available and analyzed to further investigate the permafrost-rockfall links. Where trajectory data are available, Maëva Cathala is modelling the path of small-sized rockfalls in glacial context as part of their PhD. These analyses are currently used to map potential release areas from permafrost rockwalls and potential runout distances. Suvrat Kaushik also continues to work on their PhD on ice aprons (IAs) (very small ice bodies of irregular outline, lying on permafrost slopes greater than 40°). 423 IAs have been identified in the Mont-Blanc massif and their current surface area (4.2 km²) has been reduced by more than 30% in two decades.

During the summer of 2021, two recently destabilized rockwall sites wee equipped with temperature sensors and surveyed with a drone. One of the sites, 3126 m asl in the Vallon d'Etache (Savoie) is west-facing and was affected by a c. 250 × 103 m³ rockfall in June 2020 (Fig. 17), after several days of intense precipitations. The other site, 3170 m asl at the Crête des Grangettes (Hautes Alpes), is north-facing and was affected by two successive rockfalls in September and October 2020. For both sites, ice and water marks were found in the scar. The collected data

Fig. 16. Analogue model of a degraded molard, around 30 cm in diameter.

will be used to build high resolution DEM in order to analyse their mobility patterns and model permafrost evolution to assess permafrost dynamics and evolution when failures occurred. Investigations are conducted in the frame of Maëva Cathala's PhD in collaboration with researchers from INRAE.

Finally, permafrost data collected in six boreholes 10-100 m depth in the French Alps since 2010 (three in the Mont Blanc massif at the Aiguille du Midi and three in les Ecrins massif at Les Deux Alpes), and three other boreholes 10-20 m depth equipped between 2017 and 2021 were analyzed to assess main permafrost distribution evolution patterns in the French Alps.

The Laboratoire EDYTEM has three members involved in the PERMOLARDS project: Costanza Morino, Florence Magnin, Philip Deline. Our team has been working on the geomorphological analyses of molards around the globe. We have used the dataset produced by LPG for analysing the morphometrics and distribution of molards in more than fifty landslides. We have performed fieldwork in Iceland in synchrony with the LPG team, where we made geomorphological observations of molards at four different sites, collected samples for labwork at M2C, and installed temperature sensors at three sites. The sensors were installed with the purpose of retrieving the data after one year (2nd season of fieldwork in July 2022) and perform permafrost modelling at local scale. Past variations in the state of permafrost will be modelled too. We have also been working on the morphometric analyses of candidate molards on Mars.

- Morino, C., *et al.* (2021). The impact of ground-ice thaw on landslide geomorphology and dynamics: two case studies in northern Iceland. *Landslides*, 18(8), 2785-2812. DOI: 10.1007/s10346-021-01661-1.
- Saemundsson, P., Morino, C., Conway, S. (2022). Mass-Movements in Cold and Polar Climates. In: J.F. Shroder (ed.). *Treatise on Geomorphology (Second Edition)*. Academic Press, 5, 350-370. DOI: 10.1016/B978-0-12-818234-5.00117-6.
- Morino, C., Coratza, P., and Soldati, M. (2022). Landslides, a Key Landform in the Global Geological Heritage. *Frontiers in Earth Science*, 10, 20 p. DOI: 10.3389/feart.2022.864760.

LITTORAL, ENVIRONNEMENT, TÉLÉDÉTECTION, GÉOMATIQUE, UNIVERSITÉ DE NANTES

The scientific actions carried out by the French CNRS lab LETG UMR6554 (Brest and Nantes) for the understanding of arctic and subarctic environments deal with (i) erosive dynamics of the rocky and sedimentary coasts in Iceland and associate storms, (ii) construction dynamics of coastal sedimentary landforms (coastal plains and deltas) in Svalbard, and (iii) dynamics of slopes in Nunavik (northern Quebec). These studies are supported by LabEx DRIIHM (Nunavik), and the French Polar Institute Paul-Emile Victor (IPEV – all projects).

Fig. 17. Rockfall that occurred in the Vallon d'Etache (Savoie) at c. 3100 m asl. Photo: L. Ravanel (June 2020).

The project EXTREMEVENT IPEV (Serge Suanez, Université de Bretagne Occidentale & LETG-Brest; Pierre Stéphan, CNRS, LETG-Brest; in collaboration with Jérôme Ammann, CNRS LGO UMR6538, Brest, Guillaume Marie, David Didier, Ronan Autret, UQAR, Sigurður Sigurðarson, Vegargerðin Íslands) studies the topo-morphological changes of the rocky and accumulation coasts in specific spots of Reykjanes Peninsula, Iceland. The results point out severe changes over short time periods (few years).

The project KONBHAS IPEV (Agnès Baltzer, Université de Nantes & LETG-Nantes, in collaboration with Hélène Howa, Université d'Angers, lab LGP-BIAF) studies the development of submarine prodeltas linked with the accelerating discharge of proglacial rivers in Kongsfjorden, Svalbard, revealing a notable development of fauna and flora in the prodeltas.

The projects MOVE – OHMi NUNAVIK/LabEx DRIIHM & DeSiGN IPEV (Armelle Decaulne, CNRS, LETG-Nantes, in collaboration with Najat Bhiry, Centre d'études Nordiques & université Laval, Québec) study the snow-avalanche regime over the last winters nearby Umiujaq, Nunavik, and the conducive meteorological conditions; recent researches have highlighted preferential long runout distance snow-avalanche paths close to the villages of Umiujaq and Kangiqsualujjuaq.

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

GERMANY

BY MICHAEL FRITZ (ALFRED WEGENER INSTITUTE, POTSDAM)

UNIVERSITY OF FREIBURG

Jan Blöthe (University of Freiburg) and Sabine Kraushaar (University of Vienna) continued their work on the geomorphological and hydrological dynamics of the Kaiserberg rock glacier in the Kaunertal Valley, Tyrol. Using a combination of hydro-chemical analyses, ground surface temperature analysis, UAV surveys and geophysical measurements, the project GeoHype *(Geomorphological and hydrological implications of permafrost degradation in the Alps)* aims to quantify the relative contribution of active layer and permafrost body to the discharge from the rock glacier. In late summer 2021, a permanent exhibition on research activities within the Kaunertal (Austria) that also features the project GeoHype was inaugurated.

For more information contact Jan Blöthe (jan.bloethe@geographie.uni-freiburg.de) and Sabine Kraushaar (sabine.kraushaar@univie.ac.at).

UNIVERSITY OF BAYREUTH

The Chair of Geomorphology continued their work in the German Research Foundation (DFG) funded project ClimRock (*Characterizing Rockwall Weathering from Microclimate, Rock Moisture and Rockfall Activity*, 2020-2023). The aim of the project is to quantify rock moisture and thermal regimes and their roles for frost and thermal weathering in alpine rockwalls. The project team consisting of Oliver Sass, Daniel Dräbing, Andrew Mitchell, and Till Mayer maintained rock moisture, temperature and kinematic loggers and repeated laserscanning campaigns at rockwalls at the Dachstein (Austria) (Fig. 18) and the Dammkar Valley (Germany).

In the framework of the DFG funded project Alpine Rock Slopes (*Predicting the effects of climate change on alpine rock slopes: Evaluation of paraglacial and periglacial drivers of rockfall in the European Alps*, 2016-2020), Daniel Dräbing published two manuscripts on topographic and geologic controls on frost weathering and resulting rock kinematics.

- Dräbing, D. and Mayer, T. (2021). Topographic and geologic controls on frost cracking in Alpine rockwalls. *Journal of Geophysical Research: Earth Surface*, 126(6), 23 p. DOI: 10.1029/2021JF006163.
- Dräbing, D. (2021). Identification of rock and fracture kinematics in high alpine rockwalls under the influence of elevation. Earth Surface Dynamics, 9(4), 977-994. DOI: 10.5194/esurf-9-977-2021.

A research team consisting of Jana Eichel (Utrecht University) and Daniel Dräbing maintained temperature loggers and repeated the annual monitoring of turf-banked solifluction lobes along a topographic gradient in the Turtmann Valley, Swiss Alps, using UAV and Structure-from-motion techniques.

For more information contact Oliver Sass (oliver.sass@uni-bayreuth.de) and Daniel Dräbing (d.draebing@uni-bayreuth.de).

Fig. 18. Laserscaning of the permafrost-affected Koppenkar rockwall in the Dachstein Massif. Photo: Daniel Dräbing).

TECHNICAL UNIVERSITY OF MUNICH

The Landslide Research Group of Michael Krautblatter investigated permafrost affected slopes in the European Alps (Germany, Austria, Switzerland) as well as in Norway, Canada and Ecuador.

Benjamin Jacobs co-authored a paper by Dr. Daniel Dräbing (University of Bayreuth) on alpine rockwall erosion patterns. The publication shows that paraglacial, frost cracking and permafrost processes jointly drive postglacial rockwall erosion and that all three processes are strongly conditioned by elevation. This provide a multi-process explanation for the increase of rockwall erosion rates with elevation across the European Alps.

- Dräbing, D. *et al.* (2022). Alpine rockwall erosion patterns follow elevation-dependent climate trajectories. *Communications Earth & Environment*, 3, 12 p. DOI: 10.1038/s43247-022-00348-2.

Benjamin and Johannes Leinauer contributed to an extensive publication with electrical resistivity surveys on the two Norwegian instable rock slopes Mannen and Gámanjunni-3. The detailed analysis of temperature, surface velocities and geophysical surveys gives new insights into the dynamics of big unstable rock slopes in permafrost regimes.

- Etzelmüller, B., *et al.* (2022). Permafrost in monitored unstable rock slopes in Norway – new insights from temperature and surface velocity measurements, geophysical surveying, and ground temperature modelling. *Earth Surface Dynamics*, 10, 97-129. DOI: 10.5194/esurf-10-97-2022.

As part of the BMBF-project RIESOS, Theresa Frimberger is investigating lahar hazards at the Cotopaxi (5897 m asl) and Chimborazo (6263 m asl) volcanos, Andean Highlands of Ecuador and recently affected by the unprecedented occurrence of periglacial lahars. She recently published a paper developing a generic Voellmy-Salm approach across different scales of high-magnitude lahars and showed how it can be used to anticipate future syneruptive lahars. Further on, geophysical measurements, orthophotographs and satellite images allowed to better understand these unique periglacial processes and elaborate a conceptual model for different trigger mechanisms of periglacial, secondary lahars.

- Frimberger, T., *et al.* (2021). Modelling future lahars controlled by different volcanic eruption scenarios at Cotopaxi (Ecuador) calibrated with the massively destructive 1877 lahar. *Earth Surface Processes and Landforms*, 46(3), 680-700. DOI: 10.1002/esp.5056.

ERT data collected at the permafrost-affected and unstable Steintaelli Ridge (3100 m asl, Matter Valley, Switzerland) in the last 13 years were inverted with a 3D time-lapse scheme in BERT. Thanks to the temperature-resistivity laboratory calibration of samples from the site, we propose for the first time a quantification of permafrost volumes inside the ridge and of its changes in the last decade. Riccardo Scandroglio recently published these results funded by the IGSSE and the DFG. He also continued the long-term ERT monitoring at the Zugspitze (2962 m asl, Germany, Fig. 19) and worked on new methods for monitoring the hydro-thermal state of permafrost, e.g. with relative gravimetry and induced polarization, in cooperation with the University of Bonn (Andreas Kemna) and the University Wien (Adrian Flores-Orozco).

- Scandroglio, R. *et al.* (2021). 4D quantification of alpine permafrost degradation in steep rock walls using a laboratory-calibrated electrical resistivity tomography approach. *Near Surface Geophysics*, 19(2), 241-260. DOI: 10.1002/nsg.12149.

Fig. 19. Permafrost monitoring on the Zugspitze Ridge.

Maike Offer joined the Research Group as a PhD student focusing on a quantitative imaging of water, ice, and air content in high-alpine permafrost-affected bedrock close to infrastructures. Her multimethod approach should help to improve the hazard potential assessment of foundations and anchroing in degrading permafrost. The Deutsche Bundesstiftung Umwelt (DBU) has approved funding for her research.

PhD candidate, Saskia Eppinger, worked on the data collected on Herschel Island, Canada, comparing past and present ERTs with own laboratory calibration, to detect decennial changes and gain a better understanding of the internal thermal behaviour.

PhD student, Philipp Mamot, completed his research with a stability assessment of degrading permafrost rock slopes based on a coupled thermo-mechanical model.

- Mamot, P., *et al.* (2021). A temperature-dependent mechanical model to assess the stability of degrading permafrost rock slopes. *Earth Surface Dynamics*, 9(5), 1125-1151. DOI: 10.5194/esurf-9-1125-2021.

The *AlpSenseRely* project (1.8M €), financed by the Bavarian State Ministry, aims at developing benchmark in-situ and remote sensing techniques for investigation of climate-change affected permafrost phenomena in the European Alps. These techniques are applied to active sites for real time monitoring and early warning of hazards.

For more information contact Michael Krautblatter (m.krautblatter@tum.de).

UNIVERSITY OF BONN

Geomorphology and Environmental Systems Research Group (Lothar Schrott)

Many watersheds in the semiarid Andes of Argentina are not at all glacierized (ice glacier) but generate numerous creeks and small rivers, particularly in areas above 4000 m asl where large blockslopes, taluses and rock glaciers are abundant (IANIGLA-CONICET, 2018). The DFG research project, *Spatial occurrence and hydrological significance of Andean permafrost, Agua Negra, Argentina (HyPerm)*, investigates the spatial distribution, geomorphic characteristics and hydrological significance of Andean mountain permafrost in blockslopes and taluses (including protalus ramparts) (Fig. 20).

Findings from our previous DFG project, *PermArg*, on rock glaciers will be integrated and extended through mapping, remote sensing (UAV), statistical modelling, soil temperature monitoring, and extensive geophysical (incl. four-phase modelling) and hydrological surveys.

- Halla, C., *et al.* (2021). Ice content and interannual water storage changes of an active rock glacier in the dry Andes of Argentina. *The Cryosphere*, 15, 1187-1213. DOI: 10.5194/tc-15-1187-2021.

To distinguish between different glacial and periglacial runoff contributors and their hydrological significance, continuous discharge measurements have been initiated at six gauging stations along the longitudinal profile of the Agua Negra river starting

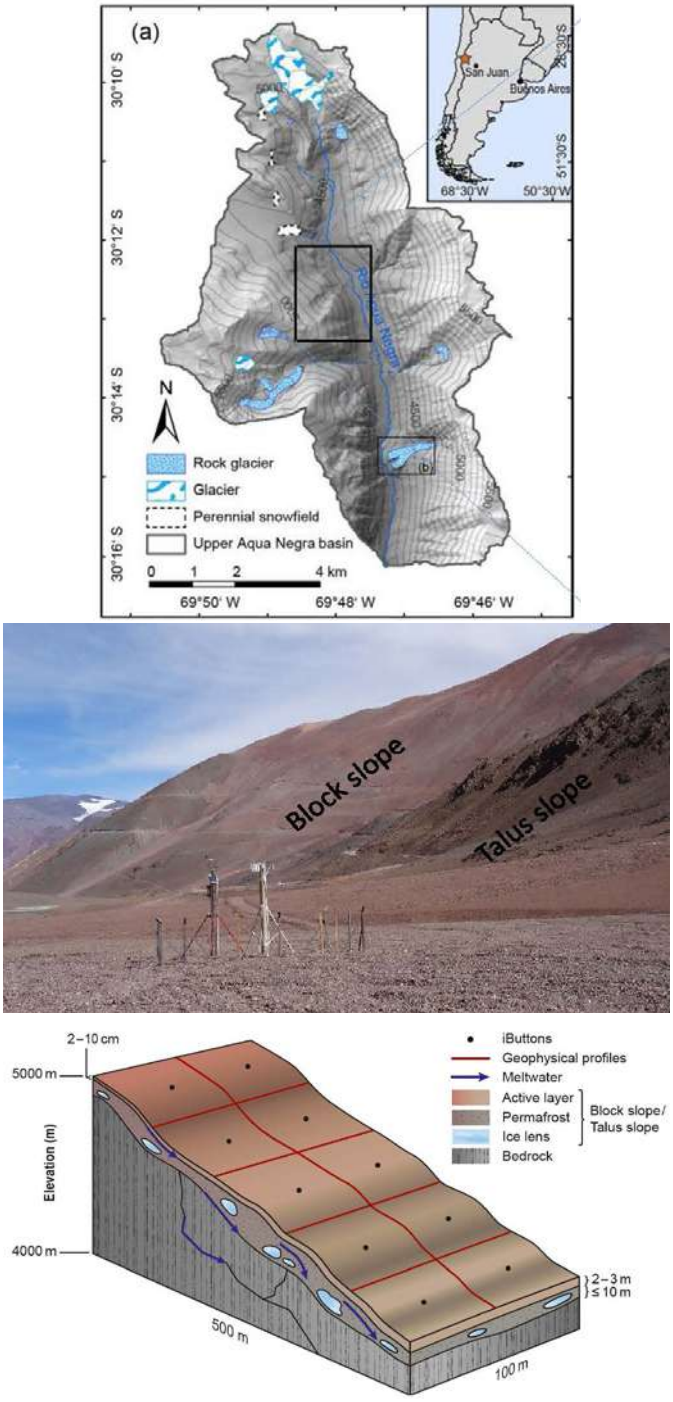


Fig. 20. Top & middle: predominant blockslopes and talus slopes in the upper Agua Negra catchment, where geophysical surveys will be carried out. Bottom: the blockslope has a vertical extension of >800 m asl. Photo: Lothar Schrott (March 2019).

in February 2022. Bucket measurements on small permafrost springs, water sampling for isotopic composition and hydrochemical analyses as well as hydrograph separations will enable us to decipher the runoff contribution from the different water sources (snowmelt, glacier melt, meltwater from active layer) and tributaries. In addition, we are monitoring rock glaciers and ice debris complexes by obtained DEMs from remote sensing (unmanned aerial vehicle and satellite based).

Since permafrost bodies show a delayed reaction to changing climatic conditions compared to glaciers, the hydrological significance of landforms affected by permafrost will become even more relevant in the future, especially in arid high mountain regions. This project will address a significant research gap and further allow determining with greater precision the distribution and hydrological significance of permafrost in the dry Andes and the influence of climatic, topographic and lithological parameters on the permafrost conditions of these landforms.

For more information contact Lothar Schrott (lothar.schrott@uni-bonn.de), Christian Halla (christian.halla@uni-bonn.de), and Jan Blöthe (jan.bloethe@geographie.uni-freiburg.de).

HELMHOLTZ CENTER HEREON (GEESTACHT)

The British-German Changing Arctic Ocean (CAO) Program of the BMBF and NERC ended in 2021. The projects *CACOON* (Changing Arctic Carbon cycle in the cOastal Ocean Near-shore) and *EISPAC* (Effects of ice stressors and pollutants on the Arctic marine cryosphere) conducted fieldwork in the Lena Delta in 2019 to investigate the transport of organic matter, including carbon and nitrogen from the permafrost within the Delta to the nearshore Laptev Sea. A dataset was published in ESSD and several publications were featured in the special issue, *"A changing Arctic Ocean"*, of the journal Ambio:

- Mann, P.J., *et al.* (2021). Degrading permafrost river catchments and their impact on Arctic Ocean nearshore processes. *Ambio*, 51, 439-455. DOI: 10.1007/s13280-021-01666-z.
- Townhill, B.L., *et al.* (2021). Pollution in the Arctic Ocean: An overview of multiple pressures and implications for ecosystem services. *Ambio*, 51, 471-483. DOI: 10.1007/s13280-021-01657-0.
- Tuerena, R.E., *et al.* (2021). Nutrient pathways and their susceptibility to past and future change in the Eurasian Arctic Ocean. *Ambio*, 51, 355-369. DOI: 10.1007/s13280-021-01673-0.
- Sanders, T., *et al.* (2021). Seasonal nitrogen fluxes of the Lena River Delta. *Ambio*, 51, 423-438. DOI: 10.1007/s13280-021-01665-0.
- Fuchs, M. *et al.* (2022). High-resolution bathymetry models for the Lena Delta and Kolyma Gulf coastal zones. *Earth System Science Data*, 14, 2279-2301. DOI: 10.5194/essd-14-2279-2022.

For more information contact Jens Strauss (jens.strauss@awi.de) and Tina Sanders (tina.sanders@hereon.de).

HELMHOLTZ CENTER FOR POLAR & MARINE RESEARCH ALFRED WEGENER INSTITUTE (AWI)

FluxWin

Our newly set up automated flux chambers along with this year's manual flux measurements, soil water samples, dissolved gas samples and lab incubations of soil samples from the Siikaneva wetland complex in Southern Finland will greatly help us to monitor and understand the processes involved in the C- and N-cycles in boreal wetlands on an annual timescale as part of the *FluxWIN* project.

For more information contact Clair Treat (claire.treat@awi.de) and Lona van Delden (lona.van.delden@awi.de).

P2C2 Arctic Coastal Wetlands

In the framework of the project, Palaeo perspectives on Climate Change (P2C2), fieldwork was conducted on the Kenai Peninsula, Alaska, to measure greenhouse gas emissions from Arctic coastal wetlands. The aim is to understand the role of coastal wetlands within the carbon cycle in the Northern high-latitudes and how sea level rise in the past and present affects methane (CH_4) emissions from these areas. The fieldwork was a collaboration of AWI Potsdam, U.S. Geological Survey (Reston, VA), University of New Hampshire, and University of Alaska Fairbanks.

For more information contact Clair Treat (claire.treat@awi.de) and Matthias Fuchs (matthias.fuchs@awi.de).

MOSES

Fieldwork on rapid permafrost thaw along the Inuvik-Tuktoyaktuk Highway (NWT, Canada) took place in September 2021 as part of the Helmholtz Association infrastructure project, *Modular Observation Solutions for Earth Systems (MOSES)*. Greenhouse gas fluxes and permafrost thaw beneath water bodies, such as thermokarst lakes, methane seep sites in the Mackenzie Delta and in the coastal offshore zone, were investigated using a suite of mobile, modular instruments, to help us understand how ongoing permafrost thaw is tied to climate warming.

For more information contact Julia Boike (Julia.Boike@awi.de).

PermaRisk

The BMBF young investigators group PermaRisk (Moritz Langer) aims to study the impact of permafrost degradation on infrastructure and ecosystem functions in the Arctic using numerical models and remote sensing. In 2021, numerous studies were published on model development, change detection based on high-resolution remote sensing, and climate change impacts on mobility in the terrestrial Arctic. A novel BMBF-funded Citizen Science project (UnderCoverEisagenten) was launched in 2021 and will start with field campaigns in the Mackenzie Delta (Canada) in 2022. As part of a joint HGF project with the GFZ, another focus was on modeling the development of Arctic river deltas with special attention to the role of cryospheric processes.

For more information contact Moritz Langer (moritz.langer@awi.de).

UndercoverEisAgenten (UndercoverIceAgents)

In July 2021, a team from AWI, DLR and HeiGIT started the BMBF citizen science project, *UndercoverEisAgenten*. The 3.5 years project invites school kids in Germany and NW-Canada to collect data on visible landscape disturbances in the Canadian Arctic to gain better insights into the extent and rate of permafrost thaw. While teachers and school kids become drone pilots and collect high-resolution aerial photographs from the areas of their interest and biggest concern, school kids in Germany will test and apply a newly developed smartphone mapping application to support the image processing. The citizen scientists will create a unique reference dataset that will be of great use to improve the quality of remote sensing-based monitoring and prediction of permafrost thaw.

For more information contact Josfine Lenz (Josefine.Lenz@awi.de) and undercovereisagenten@awi.de.

Permafrost im Wandel (Permafrost Change)

In 2021, our small team at AWI Potsdam finalized the national outreach project, *Permafrost im Wandel*. While we developed further outreach materials like flipped postcards, 3D prints of permafrost landscapes, infographics and VR tours through Canadian, Siberian and Scandinavian tundra, we used all possibilities to test our materials and thaw experiments with school kids with visiting classes and at public events, like the Science Festival in Bremen or during the WWF School Academy. We very look forward to a much for a wider application of experience and materials in the coming years when the pandemic is easing.

For more information contact Josfine Lenz (Josefine.Lenz@awi.de).

Nunataryuk

The 2021 highlights from the EU H2020 project, Nunataryuk, include a risk framework for Arctic coastal communities with co-production of risk management solutions with local stakeholders as a central component, a novel AI enhanced Arctic Coastal Human Impact (SACHI) satellite dataset highlighting communities and infrastructure at risk over the next 30 years and a study examining adaptive capacity for managing permafrost degradation in Northwest Greenland.

For more information contact Hugues Lantuit (Hugues.Lantuit@awi.de) and Michael Fritz (Michael.Fritz@awi.de).

GTN-P

The GTN-P Office, formerly funded by Nunataryuk, is now part of the EU H2020 project, *Arctic PASSION*. The GTN-P held its first virtual General Assembly in November 2021. With more than 40 participants from all over the world and presentations on permafrost temperature and active layer thickness from 15 countries it was a great success. The virtual GTN-P General Assembly will now be a yearly recurring event. A major milestone was reached with publishing the new GTN-P Strategy and Implementation Plan (2021-2024) and the supplementing document on GTN-P Measurement and Monitoring Guidelines. The guidelines serve as an interim document until the WMO Permafrost Best Practices will be released in 2023.

For more information contact Anna Irrgang (anna.irrgang@awi.de).

Permafrost Carbon Stabilization by Recreating a Herbivore-Driven Ecosystem (PeCHEc)

We finalized analysis of soil samples from northeastern Siberia and northern Finland and related the total organic carbon (TOC) content to local grazing intensity. The project hypothesis of grazing increasing soil carbon storage as well as first findings, referring to the Siberian samples, were presented at the Siberian Permafrost Symposium and at RCOP.

For more information contact Torben Windirsch (Torben.Windirsch@awi.de).

Permafrost Carbon on the Beaufort Shelf (PeCaBeau)

The PeCaBeau project was funded under the Horizon2020 project, ARICE – *Arctic Research Icebreaker Consortium*. PeCaBeau aims to track the movement and transformation of material from permafrost thaw along the land-to-ocean continuum. This multi-disciplinary effort investigates the sediment column between subsea permafrost and the seafloor, the water column, the atmosphere and the interfaces between these three units in the Beaufort Sea. By studying the sources, quantities and the quality of organic matter in the water column and in sediments, we aim to improve assessments of the Beaufort shelf as a carbon source or sink, and place these outcomes in the context of the Holocene paleo-environment and transgressed permafrost. Sampling operations took place in September and October 2021 on the Canadian icebreaker CCGS Amundsen (Fig. 21). The project is led by Jorien Vonk (Vrije Universiteit Amsterdam, The Netherlands).

- Bröder, L., *et al.* (2022). The Permafrost Carbon in the Beaufort Sea (PeCaBeau) Expedition of the Research Vessel CCGS AMUNDSEN (AMD2104) in 2021. Reports on Polar and Marine Research, Alfred-Wegener-Institut, Helmholtz-Zentrum für Polar- und Meeresforschung, 759, 120 p. DOI: 10.48433/BzPM_0759_2022.

For more information contact Michael Fritz (Michael.Fritz@awi.de) and Paul Overduin (Paul.Overduin@awi.de).

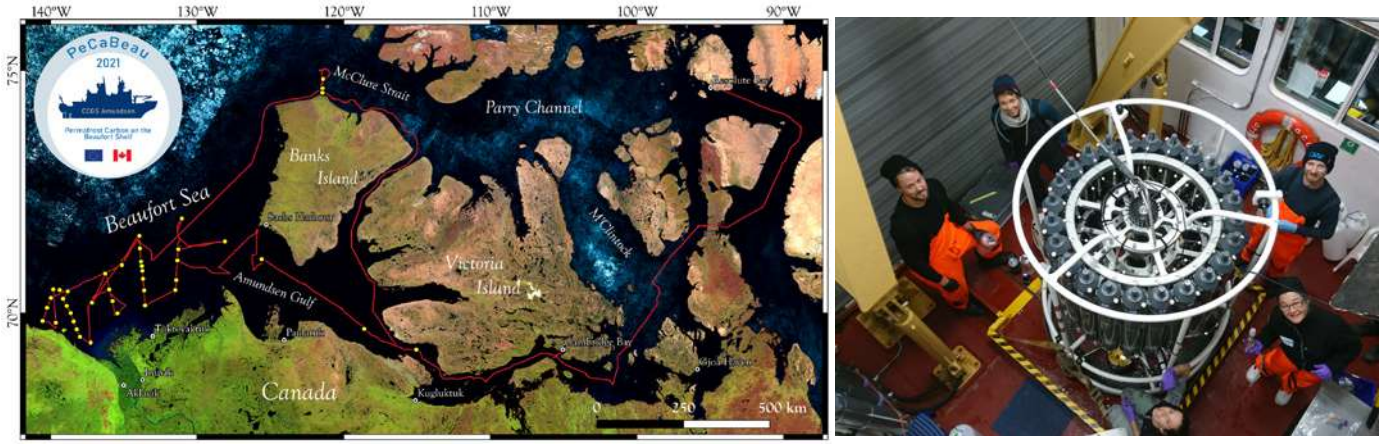


Fig. 21. Left: full cruise track of 4300 nautical miles and our 41 stations along the way. Right: the Water group empties the rosette bottles once it is back on deck.

ITALY

BY RENATO R. COLUCCI & ANDREA SECURO (INSTITUTE OF POLAR SCIENCES, ITALIAN NATIONAL RESEARCH COUNCIL), UMBERTO MORRA DI CELLA (ARPA VALLE D'AOSTA), LUCA PARO (ARPA PIEMONTE), & MAURO GUGLIELMIN (INSUBRIA UNIVERSITY)

Besides the usual activities normally carried out by the permafrost scientific community in the polar environment, we highlight here some aspects of alpine permafrost studies and monitoring with contributions from Valle d'Aosta, Piemonte, Lombardia and Friuli Venezia Giulia regions.

POLAR ENVIRONMENT

The Cryosphere Research Group at Insubria University, led by Mauro Guglielmin, in Lombardia is still going on the long term permafrost monitoring in Svalbard in cooperation with Institute of Polar Sciences of the National Research Council (CNR-ISP), and above all in Antarctica. The permafrost network includes eight boreholes below the depth of zero annual amplitude (ZAA; five in Antarctica, and one in Svalbard). In addition the group still manages three CALM grids (one in Svalbard and two in Antarctica) for active layer measurements and a dozen shallow boreholes in other parts of Antarctica.

ALPS – PERMAFROST & GROUND TEMPERATURE MONITORING

In 2021, the Environmental Protection Agency (ARPA) in Valle d'Aosta (Umberto Morra di Cella and Edoardo Cremonese) revisited their long-term permafrost monitoring sites at Cime Bianche (high mountain plateau, 3100 m asl) and Matterhorn - Carrel Hut (steep rockwall, 3800 m asl). The hydrological year 2021 was slightly colder with respect to the previous years mainly due to a winter season with less snow insulating the ground and a colder than usual summer, especially in July and August. The active layer thickness was 6 m at Cime Bianche (6.7 m in 2020) and 2.4 m at Carrel Hut (2.9 m in 2020). A long term warming trend of about +0.2 °C per decade is documented at Cime Bianche (30 m depth).

ARPA in Piemonte (Fig. 22) manages a permafrost monitoring regional network in the Piemonte region, consisting of six stations (boreholes 5-100 m deep at 2500-3020 m asl), and the geotechnical-thermal station of Mount Rocciamelone (borehole 30 m deep at 3150 m asl). Periglacial and permafrost studies and monitoring in Piemonte region are carried out

Fig. 22. Maintenance of the permafrost station at Salati Pass (ARPA Piemonte).

by the Natural and Environmental Risks Dept. of ARPA Piemonte (Luca Paro), within the specific institutional topic named *"B3.19 – Monitoraggio del permafrost"* (permafrost monitoring). These activities started in 2006 and developed significantly thanks to the partnership in EU Interreg projects (Alpine Space project *"PermaNET - Permafrost long-term monitoring Network"*, 2008-2011; Italy-France project *"PrévRiskHauteMontagne"*, 2016-2017; Italy-Switzerland project *"ReservAqua"*, 2019-2023).

In Friuli Venezia Giulia Region, the CNR-ISP continues to monitor the ground thermal regime in the Italian Eastern Alps at Mount Canin (Julian Alps).

ALPS - ROCK GLACIERS

The Cryosphere Research Group at Insubria University continue geophysical investigations (ERT and GPR in cooperation with the Trieste University Group led by Emanuele Forte) with tomographic surveys by land and UAV on some rock glaciers in the Upper Valtellina (Foscagno, Stelvio and Livigno areas) as well as on some protalus ramparts and other periglacial landforms and the related vegetation.

ARPA in Piemonte region performed a rockglacier surveys by using GPR, ERT, and passive seismic (HVSR) approaches with the University of Pisa (Adriano Ribolini in collaboration with Simone Sartini) at the rock glaciers of Vej del Bouc, Le Caldaie and Punta Sabbia. GNSS and UAV photogrammetry surveys were conducted at the first two sites in

collaboration with ARPA of Valle d'Aosta (Umberto Morra di Cella and Stefano Drigo).

In Valle d'Aosta, ARPA conducted the 3rd season of hydrological studies (Fig. 23) at the Gran Sometta rock glacier, located in the Cervinia basin at 2600 m asl. This activity started in 2020 within the *Interreg project Reservaqua* (2019-2023). The main goal of this project is the quantification of the water outflow (direct observations and modeling) relating it with the surface volume variations (detected by UAV surveys) and the hydro-chemical footprint (collab. with DISAFA-UniTO, Nicola Colombo).

At Gran Sometta ARPA cooperates with several research groups: i) the Geoscience Department of the University of Fribourg (Prof. Christian Hauck and Reynald Delaloye) and TU-Wien (Prof. Adrian Flores-Orozco and Theresa Maierhofer) for the geophysical and geomorphological aspects; ii) the GlacierLab of the Technical University of Turin (Prof. Alberto Godio) for a pilot-study on rock glacier movements with passive seismic. In January 2022 an informal meeting with all the involved subjects was held online to take stock of the current activities and define the lines of collaboration for the next future.

In the central Italian Alps we had other three shallow boreholes (Foscagno valley).

Fig. 23. Water sampling at Schiantalà rock glacier (ARPA Piemonte.

ALPS - ICE DEPOSITS IN CAVES & GROUND ICE

In 2021 the project CryoKarst Cryosphere in the Karstic environments of Friuli Venezia Giulia was launched thanks to an operational agreement between the CNR-ISP and the Geological Service of the Autonomous Region Friuli Venezia Giulia.

The project focuses on studying climate-cryosphere interactions in high alpine underground environments of the Eatsern Alps, with a focus in the Canin-

Fig. 24. Firn and ice deposits in a karstic cave in the eastern Alps, Mount Canin (Friuli Venezia Giulia). Photo: Andrea Securo.

Kanin massif (Julian Alps) (Fig. 24). The project objectives are to i) monitor climate, paleoclimate, geomorphology and permafrost evolution of the underground cryosphere; ii) develop innovative 3D surveying techniques for detecting and quantifying volume changes in underground glacial environments (Structure from Motion and Multi View Stero + Light Detection and Ranging); iii) implement the regional speleological inventory introducing a specific section on ground ice, improving present speleological surveying protocols placing a major relevance to ice deposits in caves.

Management and development of GST monitoring regional network (14 sites) and of temperature monitoring in ice caves (5 sites, in collaboration with Techincal University of Torino, Bartolomeo Vigna) are also carried out by ARPA in Piemonte. New sites for temperature monitoring of rock, air, snow and infiltration water have been installed in Bossea cave's entrance, Mount Malanotte and Turbiglie sinkhole.

OTHERS

Management of cold springs monitoring to develop a hydrogeological model in periglacial and permafrost environment is being carried out by ARPA in Piemonte. This includes, water sampling for chemical analysis (in collaboration with CNR-IRSA, Michela Rogora and Gabriele Tartari) at five sites in the Piedmont Alps and laboratory inter-comparison for water sampling and analysis (Gran Sometta) at ARPAs Piemonte and Valle d'Aosta and CNR-IRSA Verbania.

In collaboration with INRIM – Italian Institute for Metrological Research (Andrea Merlone and Francesca Sanna), ARPA Piemonte organized a webinar titled *"Metrological contribution to monitoring of*

permafrost, air temperature and precipitation" (1-3 Dec. 2021) in the framework of the Interreg Italy-Switzerland project *ReservAqua*.

The Insubria Group continues to monitor thermokarst in the Stelvio area and monitor the relations between different vegetation and landforms, and snow in the Foscagno Valley, Stelvio Valley (two sites) through UAV surveys.

For more information contact Renato R. Colucci (renato.colucci@isp.cnr.it) and see:

- Etzelmüller B., *et al.* (2020). Twenty years of European mountain permafrost dynamics-the PACE legacy. 2020. *Environmental Research Letters*, 15(10), 14p. DOI: 10.1088/1748-9326/abae9d.
- Guglielmin M., *et al.* (2021). Recent thermokarst evolution in the Italian Central Alps. *Permafrost and Periglacial Processes*, 32(2), 299-317. DOI: 10.1002/ppp.2099.
- Pintaldi E., *et al.* (2021). Hidden soils and their carbon stocks at high-elevation in the European Alps (North-West Italy). *Catena*, 198, 13 p. DOI: 10.1016/j.catena.2020.105044.
- 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*, 46(3), 422-440. DOI: 10.1177/03091333211065123.
- Tarca G., *et al.* (2022). Small-scale spatial-temporal variability in snow cover and relationships with vegetation and climate in maritime Antarctica. *Catena*, 208, 14 p. DOI: 10.1016/j.catena.2021.105739.
- Giordano, F., *et al.* (2021). *Rapporto sugli indicatori di impatto dei cambiamenti climatici*. Sistema Nazionale per la Protezione dell'Ambiente, Doc. No. 112/21, 246 p.

JAPAN

BY KAZUYUKI SAITO (JAMSTEC)

In 2021, members of the Japanese Permafrost Association (JPA) include one student and 30 regular members with the president, Kazuyuki Saito (JAMSTEC) and the Secretary, Atsushi Ikeda (University of Tsukuba).

ARCTIC CHALLENGE FOR SUSTAINABILITY II (ARCS II) PROJECT

It was the 2nd year of Japan's five-year national Arctic research project, ArCS II *(Arctic Challenge for Sustainability II)*, which aims to promote research on the present and future status of climate and environmental changes in the Arctic, and to assess the impact of rapid changes on society. Despite limitations and difficulties with field activities caused by the COVID-19 pandemic and consequent travel restrictions some observations were carried out.

Biogeochemical Cycling in the Terrestrial Arctic

The research activities of ArCS II's terrestrial research program in 2021 included a short field campaign, sample/data analysis, and some modelling works. A two-week field campaign in the Alaskan range was carried out as the first field activity in the project. This campaign targets the GHG monitoring at the forefield of several glaciers and a palsa mound, as well as sampling for the mercury analysis. Analysis using the existing samples was also continued, getting more comprehensive data covering the several sampling sites in northern Alaska (Tetsuo Sueyoshi, JAMSTEC).

Research activities in the Human Society Research Program in ArCS II

The *"Human Security, Energy and Food in the Arctic under Climate Change"*, one of the Research Programs of the ArCS II project, focuses on the social impacts of permafrost degradation in Eastern Siberia. In situations where field surveys have been difficult, novel analysis methods are applied using satellite data and deep learning. Interferometric (InSAR) analysis using synthetic aperture radar satellite images (ALOS series) was conducted for the Batagay region in the Verkhoyansk Mountains and the middle basin of the Lena River in Eastern Siberia. In the Churapcha and Mayya area in the central basin of the Lena River, we proceeded with the temporal and spatial distribution analysis of the relationship between the estimated subsidence of landforms in response to the development of thermokarst caused by permafrost thawing and the history of human activities (the process of abandonment of agricultural and deforested lands). The results have been published in a Yedoma special issue of Frontier in Earth Science. The detection of gully development and topographic subsidence associated with the thawing of frozen soil after forest fires in the Batagay region, including seasonal freezing and subsidence, has also shown the possibility of detecting the degradation process by using InSAR analyses (see also below). In addition, as the visualization and regional assessment of the effects of permafrost degradation, we further developed an identification model on thermokarst subsidence landform by applying the Chopped Picture Method, an image analysis method based on deep learning (Yoshihiro Iijima, Mie University).

- Iijima, Y., *et al.* (2021). Thermokarst Landscape Development detected by Multiple Geospatial Data in Churapcha, Eastern Siberia. *Frontiers in Earth Science*, 9, 13 p. DOI: 10.3389/feart.2021.750298.

OVERSEAS RESEARCH ACTIVITIES

Climatic assessment of circum-Arctic permafrost zonation since the Last Interglacial

An assessment of permafrost zonation of the circum-Arctic environment for the past 122 kyr was attempted with a revised classification employing freezing and thawing indices to gain a climatic understanding of the spatiotemporal variability of frozen ground under different climate conditions (Fig. 25). Temporal variations were constructed from a Greenland ice core, and the spatial ones from the present-day reanalysis climatology, together with a glacial isostatic adjustment model. Permafrost zones over exposed land north of 50°N varied between 9.11 million km² (interglacial) and 26.7 million km² (glacial); the maximum extent of subsea and subglacial permafrost was estimated at 7.7 million km² and 0.5 million km², respectively. The climatic sensitivity of its areal extent showed a decrease by 4.3 million km² for 1°C warming of the global mean annual temperature (Kazuyuki Saito, JAMSTEC).

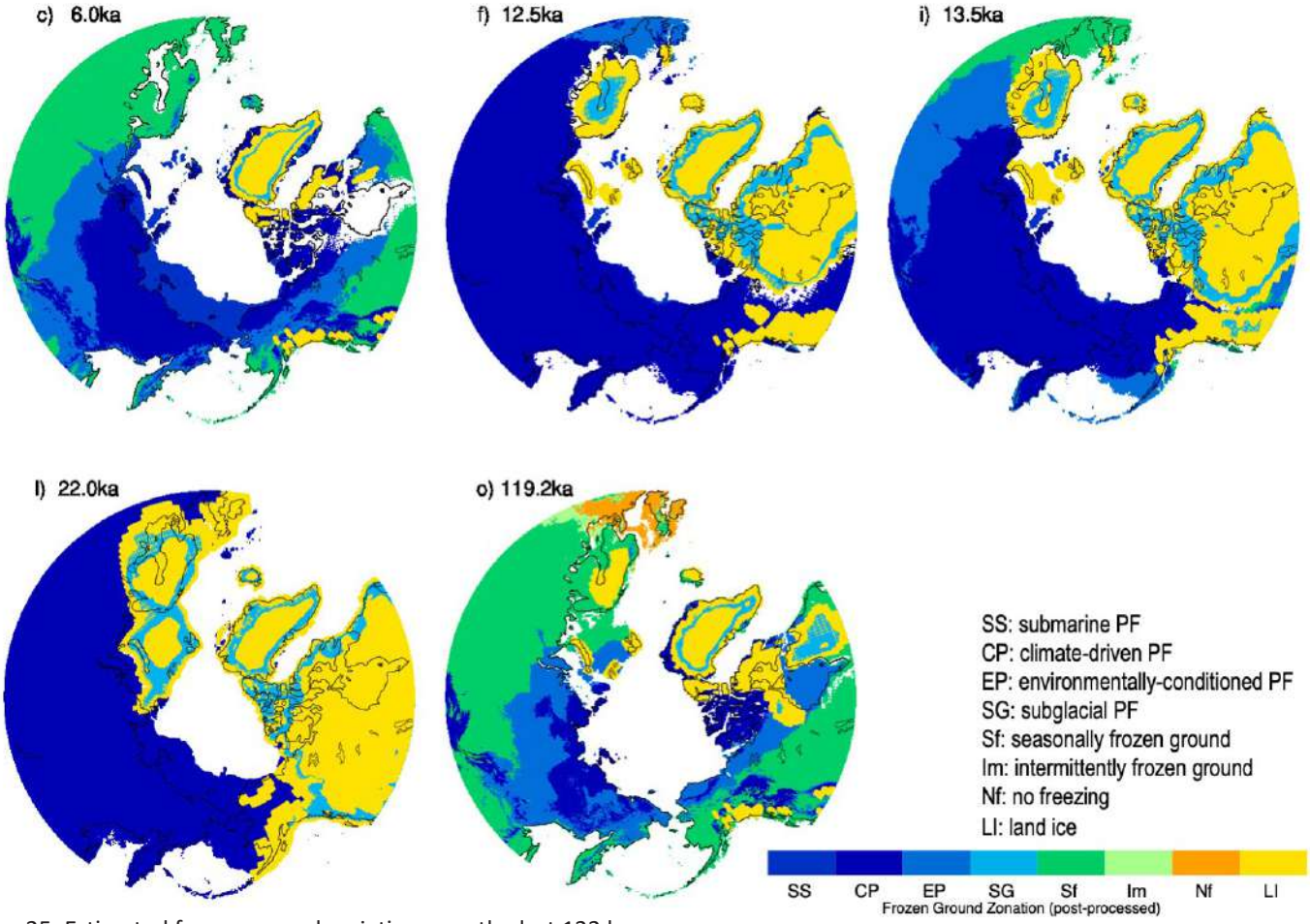


Fig. 25. Estimated frozen ground variation over the last 122 kyr.

- Saito, K. *et al.* (2022). Climatic assessment of circum-Arctic permafrost zonation over the last 122 kyr. *Polar Science*, 31, 17 p. DOI: 10.1016/j.polar.2021.100765.

Field observation & InSAR image analysis near Batagaika megaslump, Siberia

Kazuki Yanagiya (Hokkaido University; now Japan Aerospace Exploration Agency/JAXA), Masato Furuya (Hokkaido University), Go Iwahana (University of Alaska Fairbanks), Nikolai Fedorov (Seoul National University), Petr Danilov (North-Eastern Federal University), and Alexander Fedorov (Melnikov Permafrost Institute) continued with field observations at fire scars near Batagaika megaslump, Northeastern Siberia. The main objective is to reveal the process of post-fire permafrost thawing and ground deformation. In September 2021, this team measured thaw depth and soil water content within the fire scars to verify satellite data. They also took the annual data of relative elevation and air/soil temperature to compare the burned and unburned sites. They will continue to monitor the thawing and recovering processes at the fire scars by combining InSAR image analysis and field observation (Kazuki Yanagiya, JAXA).

2nd International Workshop on "Food Life History of the North"

The 2nd International Open Workshop on *"Food Life History of the North"* was held in October 2021 in a hybrid format at the RIHN conference room, Kyoto, Japan with 35 inter- and trans-disciplinary attendants from Siberia, Alaska, and Japan (Kazuyuki Saito, Go Iwahana, and Nikolai Fedorov). The workshop focused on the life, culture, and food sovereignty associated with the underground storage practices using the natural frozen energy. Preliminary surveys on the current use and situations of "ice cellars" conducted in summer 2021 in interior Siberia and northwestern Alaska were reported, as well as the panel discussion on *"Research of Global Issues in Local Communities"* by six researchers of diverse disciplinary (anthropology, geography, climatologist, economy/sociology) and geographic (Indigenous Alaska, Sakha, Japan, USA, Russia) background and gender, and a session on *"Ethics in Research with Indigenous Communities"* (Kazuyuki Saito, JAMSTEC).

DOMESTIC RESEARCH ACTIVITIES

The Daisetsu Mountains

A reduction in areas of suitable climatic conditions to sustain permafrost in the Daisetsu Mountain, Hokkaido is predicted in the 21st century as diagnosed by a classification using the freezing and thawing indices, and future projections simulated by five earth system models (Go Iwahana, UAF).

- Yokohata, T. *et al.* (2021). Projections of surface air temperature required to sustain permafrost and importance of adaptation to climate change in the Daisetsu Mountains, Japan. *Scientific Reports*, 11, 14 p. DOI: 10.1038/s41598-021-94222-4.

Field observation and Interferometric Synthetic Aperture Radar (InSAR) analyses were conducted to detect seasonal thaw subsidence in the Daisetsu Mountains, Hokkaido, which are considered to have the widest mountainous permafrost in Japan. A field observation carried out during the snow-free season in 2020 showed more than 2 cm of seasonal subsidence from the end of May through June, followed by more than 0.5 cm in subsidence through the end of August. InSAR results have shown that spatial variation in subsidence coincided with that of wind-swept terrains with almost no vegetation and have the same tendency for change as the field observation data, confirming the effectiveness of InSAR. However, the magnitude of seasonal thaw subsidence in May-June by InSAR was less than 1 cm, smaller than the field observation. This difference is considered to result from the difference in spatial representativeness between the leveling survey and InSAR (Takahiro Abe, Mie University).

- Abe, T. *et al.* (2022). Surface displacement induced by seasonal ground thaw, measured by synthetic aperture radar in the Daisetsu Mountains, Japan. *Sepyo,* 84(1), 13-27. DOI: 10.5331/seppyo.84.1_13.

Mount Yōtei

Mean annual air temperature (MAAT) on the summit of Mount Yōtei (1898 m asl) is about -2 °C. Ground temperature monitoring started to confirm the existence of permafrost (Fig. 26) (Iida K., Takayuki Shiraiwa, and Teruo Sone, Hokkaido University).

Monitoring on Mount Fuji

Using data on freeze-thaw on the western flank of Mt. Fuji researchers at the University of Tsukuba discussed thresholds of rainfall triggering debris flows. Seasonal ground freezing at the high altitudes lowered the thresholds because the ground became less permeable. Such a geomorphological process is unique to Mt. Fuji in Japan, where the other mountains are located mostly below the forest line (Atsushi Ikeda, University of Tsukuba).

Fig. 26. Drilling on the summit area of Mt.Yotei, Hokkaido.

- Imaizumi, F., *et al.* (2021). Temporal changes in the debris flow threshold under the effects of ground freezing and sediment storage on Mt. Fuji. *Earth Surface Dynamics*, 9, 1381–1398. DOI: 10.5194/esurf-9-1381-2021.

PUBLICATION AND OUTREACH ACTIVITIES

Nikkei Business series: "Permafrost Changes in the Arctic: Knowing the Past and Future of the Earth"

There are not many commentaries for the public in Japanese that provide a comprehensive and easy-to-understand overview of the recent changes in the permafrost environment occurring in the Arctic region based on scientific knowledge. Thus, this series of articles brings together a diverse group of researchers from the natural and social sciences to cover a wide range of environmental changes in the Arctic region and their societal impacts, with a focus on "permafrost thawing". A total of 10 articles were published on the Nikkei Business Website from October 2021 to March 2022, to organize the findings of each expert and communicate them in a visually appealing and easy-to-understand manner. In March 2022, we also published a booklet version of this series of articles (Fig. 27). We highly appreciate Dr. Jens Strauss and Dr. Lutz Schirrmeister (Alfred Wegener Institute, Germany) for providing wonderful photos of permafrost features for the series (Yoshihiro Iijima, Mie University).

Fig. 27. Cover picture of the booklet compiled from the permafrost series articles.

Exhibition material for public museums

Satoshi Akagawa (National Museum of Nature and Science) published a report on the history and development of frozen ground engineering technology in Japan *"Systematic Survey on Frozen Ground Engineering Technology"* (currently Japanese version only. English version to be released shortly) as a series of Survey Reports on the Systemization of Technologies, compiled by the Center of the History of Japanese Industrial Technology, National Museum of Nature and Science (Satoshi Akagawa, Cryosphere Engineering Laboratory).

Measuring frost depth in Japan

Since November 2011, the *"Frost tube in Japan"* project has been conducted in collaboration with the *"Permafrost Outreach Programs"* project, operated by Kenji Yoshikawa (WERC, INE, UAF). As an outreach program, frost tubes were installed at 38 schools in the Hokkaido area, northern Japan, and measured by children and teachers during the 2021-2021 winter season (Koichiro Harada, Miyagi University).

For more information contact Kazuyuki Saito (ksaito@jamstec.go.jp).

KYRGYZSTAN

BY TAMARA MATHYS, MARTIN HOELZLE, CHRISTIN HILBICH, ERIC POHL & TOMAS SAKS (UNIVERSITY OF FRIBOURG, SWITZERLAND), SERGEY MARCHENKO (UNIVERSITY OF ALASKA FAIRBANKS, USA), JEANNETTE NOETZLI & JOEL FIDDES (WSL INSTITUT FOR SNOW AND AVALANCHE RESEARCH SLF, SWITZERLAND), ANDI HASLER (SENSALPIN, SWITZERLAND), MURATALY DUISHONAKUNOV (KYRGYZ NATIONAL UNIVERSITY, KYRGYZSTAN), AND RYSKUL USUBALIEV (CENTRAL ASIAN INSTITUTE FOR APPLIED GEOSCIENCES, CAIAG, KYRGYZSTAN)

In 2021, we started to establish a permafrost monitoring network in Kyrgyzstan in the framework of the CROMO-ADAPT *(Cryospheric Observations and Modelling for improved Adaptation in Central Asia)* project, funded by the SDC (Swiss agency for Development and Cooperation), University of Fribourg (Switzerland), and WSL Institute for Snow and Avalanche Research SLF. The monitoring network will consist of new boreholes and the re-establishment of old boreholes, distributed ground surface temperature (GST) loggers, and repeated geophysical measurements using Electrical Resistivity Tomography (ERT), and Refraction Seismic Tomography (RST), and potentially also rock glacier kinematics. The overall goal of this new project is to inform policy makers, and planning and implementation of adaptation measures in the water and risk management sectors of Central Asia based on high quality cryospheric data (permafrost, glaciers and snow). Such data, especially on permafrost, is lacking in this region.

In July, August and September 2021, we conducted the first extensive ERT measurements at four different sites in the Tien Shan and Pamir Alay of Kyrgyzstan (Fig. 28). The measurements covered a variety of different landforms such as rock glaciers, moraines, talus slopes, and vegetated plains. The results point to frozen (high-resistivity layers) and potentially ice-rich conditions in many of the sampled landforms. Fig. 29 shows the ERT tomogram of one of the measurements done in the Pamir Alay as an example result. In 2022, the ERT measurements will be complemented by RST measurements in order to have a basis for ground ice content modelling. Furthermore, we also installed GST loggers at the different sites, and re-discovered an old borehole

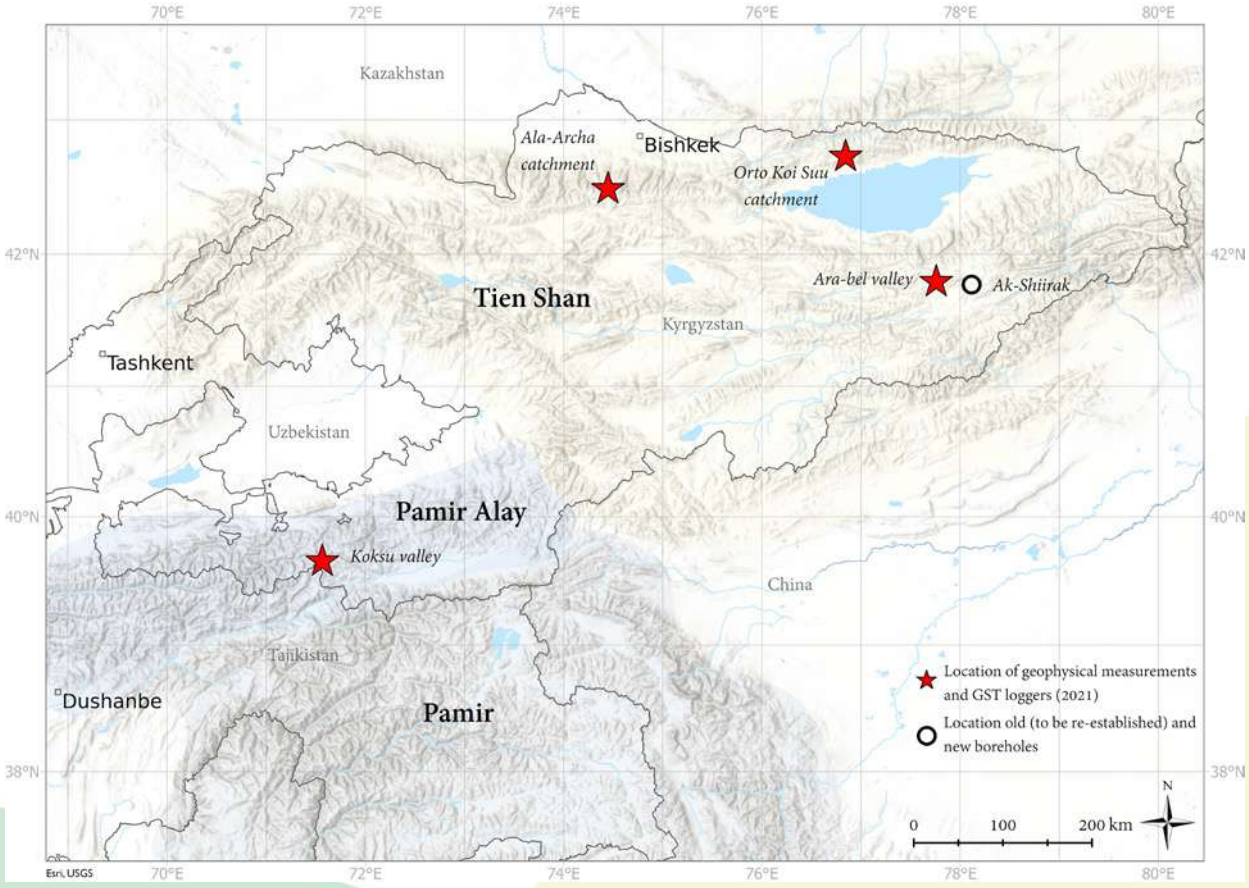


Fig. 28. Study sites where ERT measurements were conducted and GST loggers were distributed in summer 2021. The old and planned new boreholes are also shown. Shaded areas are approximate areas of the mountain ranges (Tien Shan, Pamir Alay, Pamir).

which is going to be reequipped with a thermistor chain in fall 2022. In addition, we will also drill one new borehole in the Ak-Shiirak region (approximate location of the new borehole marked in Fig. 28).

Another important goal of the CROMO-ADAPT project is the education and capacity building of local scientists and students, which will make the permafrost monitoring network sustainable in the future. Some insights to the capacity building activities during field work in the remote study sites are shown in Fig. 30.

The permafrost team currently working for the CROMO-ADAPT activities in Kyrgyzstan consists of Tamara Mathys, Martin Hoelzle, Christin Hilbich, Eric Pohl, Tomas Saks, Joel Fiddes, Ryskul Usubaliev, Murataly Duishonakunov, Sergey Marchenko, with logistic help of Jeannette Noetzli and Andreas Hasler.

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

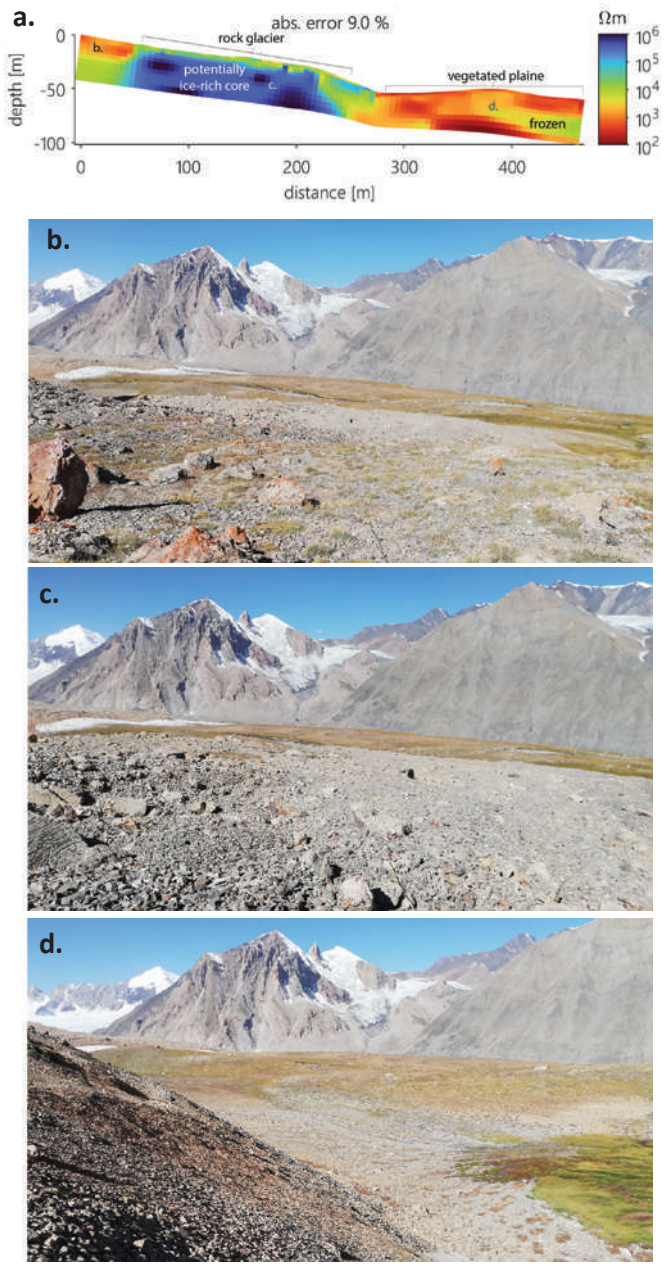


Fig. 29. a: ERT tomogram of a rock glacier and vegetated sediments, Pamir Alay. High-resistivity layers point to frozen and potentially ice-rich conditions; b-d: photos showing the different parts of the profile (marked in the tomogram).

Fig. 30. Capacity building in the field.

MONGOLIA

BY YAMKHIN JAMBALJAV (MONGOLIAN ACADEMY OF SCIENCES)

GENERAL GEOCRYOLOGICAL ACTIVITIES

In 2021, Sharhuu Natsagdorj, Avirmed Dashtseren (Institute of Geography and Geoecology) and the National Agency for Metrology and Environmental Monitoring continued long-monitoring of permafrost. The research team from the Institute of Geography and Geoecology traveled approximately 15,000 km across the permafrost region of Mongolia and collected data from over 80 borehole sites. The team installed four automatic weather stations (AWSs) in the Hangai, Hovsgol, and Altai ranges, which aims to draw micro-climate conditions of local permafrost existence. AWSs were also installed at high altitudes to understand the current climate of glaciers (Fig. 31).

Fig. 31. The Institute of Geography and Geoecology team with an AWS installed near a glacier.

Anarmaa Sharkhuu established new research sites near Ulaanbaatar and re-established a research site on the eastern shore of Hovsgol Lake as part of the University of Oslo's *permafrost4life* project. The research site on the eastern shore of Hovsgol Lake was established in early 2000 as part of the Biodiversity and Permafrost Thawing Project.

ENGINEERING PERMAFROST ACTIVITIES

We (lead by Yamkhin Jambaljav) have been working in collaboration with the project coordinator of Western Regional Road Corridor, ACT Good Consulting LLC and China Huashi JSC to identify the causes of road damage and develop methods, and recommendations to prevent permafrost thawing by conducting geophysical ERT, drilling, core sampling, and borehole temperature measurements were carried out between 18 June and 15 July 2021 at Buraat pass in Tolbo soum, Bayn-Ulgii province, a part of AH4 road between Khovd and Ulgii. This road project is financed by Asian Development Bank. As results of this study the permafrost thaw on each strip took place under the asphalt-concrete pavement, as well as under the shoulder beneath of drainage. In other words, thawing process happened due to increase in conductive heat flow under the asphalt-concrete pavement, also increase in convective heat flow on both sides of the road. Detailed measurements, drilling and coring were performed at the permafrost thawing parts, and each strip differs in the amount of superapermafrost water, ice, thawing subsidence and soil particle composition. The main purposes of the study are to identify the causes of damage on road surface, to develop preventative methods from damage, and recommendations. We recommend using combined methods to prevent permafrost from thawing. Combined methods include two phase thermosyphon and revetment crushed rocks, and looped thermosyphon and revetment crushed rocks (Fig. 32).

Fig. 32. Thermosyphons installed along a roadway to prevent thawing permafrost and settlement of the road surface.

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

THE NETHERLANDS

BY JORIEN VONK (VRIJE UNIVERSITEIT AMSTERDAM), RÚNA MAGNÚSSON & MONIQUE HEIJMANS (WAGENINGEN UNIVERSITY)

INVITED REVIEW FOR *NATURE REVIEWS EARTH & ENVIRONMENT* SPECIAL EDITION

Tundra vegetation productivity and composition are responding rapidly to climatic changes in the Arctic. Such changes can in turn mitigate or amplify permafrost thaw. In this invited review, lead author Monique Heijmans collated and analyzed field and remote sensing observations of tundra vegetation changes and associated changes to the soil thermal regime, and reviewed recent literature on tundra vegetation changes and impacts on permafrost thaw. Permafrost ice content was found to be an important control on local vegetation changes; woody vegetation generally increased in ice-poor uplands, whereas replacement of woody vegetation by (aquatic) graminoids following abrupt permafrost thaw was more frequently observed in ice-rich Arctic lowlands. These locally observed vegetation changes contributed more or less equally to regional satellite-observed greening trends. Increased vegetation cover and height were generally reported to mitigate permafrost thaw in summer but increased annual soil temperatures through snow-related winter soil warming effects (Fig. 33). Strong vegetation–soil feedbacks likely currently alleviate the consequences of thaw-related disturbances and rapid establishment of vegetation may take place on sites disturbed by permafrost degradation. However, if the increasing scale and frequency of disturbances in a warming Arctic exceeds the capacity for vegetation and permafrost recovery, changes to Arctic ecosystems could be irreversible. The authors conclude that ecological field studies remain crucial to better disentangle vegetation–soil–permafrost interactions, but require better integration with geophysical assessments. For more information see:

- Heijmans, M.M.P.D., *et al.* (2022). Tundra vegetation change and impacts on permafrost. *Nature Reviews Earth & Environment*, 3, 68-84. DOI: 10.1038/s43017-021-00233-0.

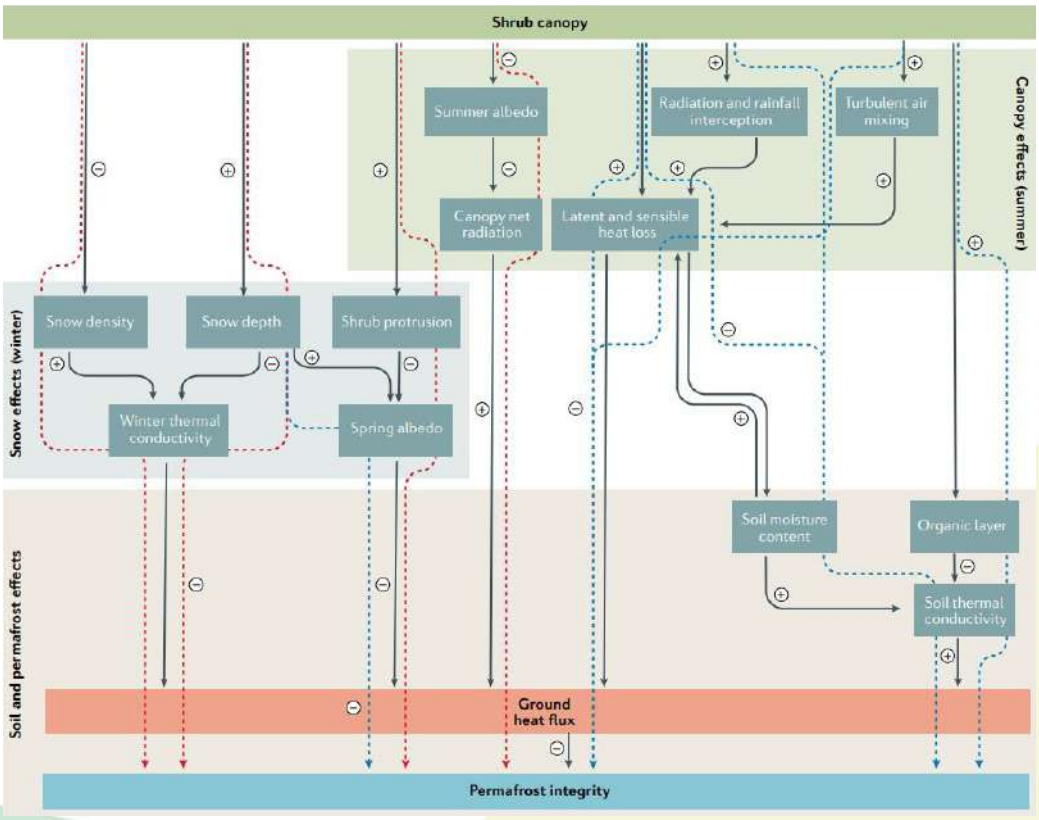


Fig. 33. Effects of shrub canopies on permafrost thaw depth. Black arrows indicate effects related to vegetation, snow and soil (+ for positive, − for negative). Dashed arrows indicate net effects across causal dependencies, where blue indicates positive net effects on permafrost integrity and red negative net effects.

FIELD EXPERIMENT AND MODEL ANALYSIS OF EFFECTS OF EXTREME SUMMER RAINFALL ON PERMAFROST THAW DEPTH IN THE SIBERIAN LOWLAND TUNDRA

Apart from temperatures, precipitation is increasing throughout the Arctic. With simultaneous warming, an increasing proportion of this precipitation will fall as rain rather than snow. With year-to-year variability in summer rainfall also increasing, extreme summer rainfall events are projected to become more common across the Arctic. Such rainfall extremes have been proposed to increase permafrost thaw, but the magnitude and duration of this effect were still poorly understood. From 2018 to 2021 we worked on an experimental study supported by soil thermal-hydrological modelling. We supplied plots of dwarf birch dominated tundra with an extremely high amount of summer rainfall in 2018, relative to control plots which received no additional rainfall. We found that a single extremely wet summer (+100 mm; 120% increase relative to average June–August rainfall) enhanced thaw depth by up to 35% in this ice-rich Siberian tundra site (see Fig. 1 in Magnússon, *et al.*, 2022). This effect persisted over two subsequent summers, demonstrating a carry-over effect of extremely wet summers. Using soil thermal hydrological modelling, we show that rainfall extremes delayed autumn freeze-up and rainfall-induced increases in thaw were most pronounced for warm summers with mid-summer precipitation rainfall extremes. Our results suggest that, with rainfall and temperature both increasing in the Arctic, permafrost will likely degrade and disappear faster than anticipated based on projected increases in air temperatures alone. The authors recommend extension of this experiment across diverse Arctic tundra ecosystems is recommended to gain insight into effects of rainfall extremes on a pan-Arctic level. For more information see:

- Magnússon, R.Í., *et al.* (2022). Extremely wet summer events enhance permafrost thaw for multiple years in Siberian tundra. *Nature Communications*, 13, 10 p. DOI: 10.1038/s41467-022-29248-x.

DEGRADATION ESTIMATES OF FLUVIAL PARTICULATE MATTER IN ONE OF THE LARGEST ARCTIC RIVERS

Major Arctic rivers are undergoing changes due to climate warming with higher discharge and increased amounts of solutes and organic carbon (OC) draining into rivers and coastal seas. Permafrost thaw mobilizes previously frozen OC to the fluvial network where it can be degraded into greenhouse gases and emitted to the atmosphere. Degradation of OC during downstream transport, especially of the particulate OC (POC), is however poorly characterized. Here, we quantified POC degradation in the Kolyma River, the largest river system underlain with continuous permafrost, during 9–15 d whole-water incubations (containing POC and dissolved OC—DOC) during two seasons: spring freshet (early June) and late summer (end of July) (Fig. 34).

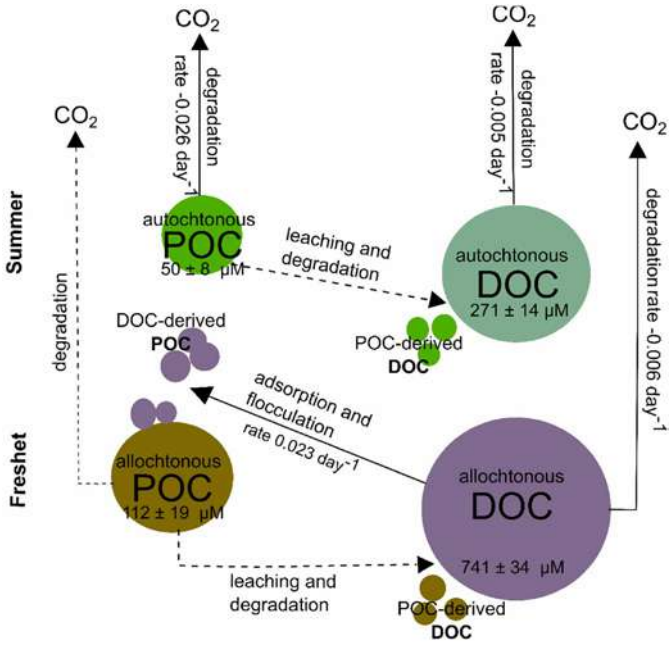


Fig. 34. Concept of the dominating pathways of POC and DOC loss and interactions of POC and DOC during freshet and summer conditions. Note: 'degradation rate' is used for the combined losses from microbial and mechanical breakdown and is temperature-corrected for *in situ* river temperatures.

Furthermore, we examined interactions between dissolved and particulate phases using parallel incubations of filtered water (only DOC). We measured OC concentrations and carbon isotopes ($\delta^{13}C$, $\Delta^{14}C$) to define carbon losses and to characterize OC composition, respectively. We found that both POC composition and biodegradability differs greatly between seasons. During summer, POC was predominantly autochthonous (47%–95%) and degraded rapidly (~33% loss) whereas freshet POC was largely of allochthonous origin (77%–96%) and less degradable. Gains in POC concentrations (up to 31%) were observed in freshet waters that could be attributed to flocculation and adsorption of DOC to particles. The demonstrated DOC flocculation and adsorption to POC indicates that the fate and dynamics of the substantially-sized DOC pool may shift from degradation

to settling, depending on season and POC concentrations—the latter potentially acting to attenuate greenhouse gas emissions from fluvial systems. We finally note that DOC incubations without POC present may yield degradation estimates that do not reflect degradation in the in situ river conditions, and that interaction between dissolved and particulate phases may be important to consider when determining fluvial carbon dynamics and feedbacks under a changing climate. For more information see:

- Keskitalo, K.H., *et al.* (2022). Seasonal variability in particulate organic carbon degradation in the Kolyma River, Siberia. *Environmental Research Letters,* 17(3), 15 p. DOI: 10.1088/1748-9326/ac4f8d.

CO_2 PRODUCTION PATHWAYS OF ERODING COASTAL PERMAFROST

Warming air and sea temperatures, longer open-water seasons and sea-level rise collectively promote the erosion of permafrost coasts in the Arctic, which profoundly impacts organic matter pathways. Although estimates on organic carbon (OC) fluxes from erosion exist for some parts of the Arctic, little is known about how much OC is transformed into greenhouse gases (GHGs). In this study we investigated two different coastal erosion scenarios on Qikiqtaruk – Herschel Island (Canada) and estimate the potential for GHG formation. We distinguished between a delayed release represented by mud debris draining a coastal thermos-erosional feature and a direct release represented by cliff debris at a low collapsing bluff. Carbon dioxide (CO_2) production was measured during incubations at 4°C under aerobic conditions for two months and were modeled for four months and a full year. Our incubation results show that mud debris and cliff debris lost a considerable amount of OC as CO_2 (2.5 ± 0.2 and 1.6 ± 0.3% of OC, respectively). Although relative OC losses were highest in mineral mud debris, higher initial OC content and fresh organic matter in cliff debris resulted in a abot three times higher cumulative CO_2 release (4.0 ± 0.9 compared to 1.4 ± 0.1 mg CO_2 gdw^{-1}), which was further increased by the addition of seawater. After four months, modeled OC losses were 4.9 ± 0.1 and 3.2 ± 0.3% in set-ups without seawater and 14.3 ± 0.1 and 7.3 ± 0.8% in set-ups with seawater. The results indicate that a delayed release may support substantial cycling of OC at relatively low CO_2 production rates during long transit times onshore during the Arctic warm season. By contrast, direct erosion may result in a single CO_2 pulse and less substantial OC cycling onshore as transfer times are short. Once eroded sediments are deposited in the nearshore, highest OC losses can be expected. We conclude that the release of CO_2 from eroding permafrost coasts varies considerably between erosion types and residence time onshore. We emphasize the importance of a more comprehensive understanding of OC degradation during the coastal erosion process to improve thawed carbon trajectories and models (Fig. 35). For more information see:

- Tanski, G., *et al.* (2021). Permafrost carbon and CO_2 pathways differ at contrasting coastal erosion sites in the Canadian Arctic. *Frontiers in Earth Science*, 9, 20 p. DOI: 10.3389/feart.2021.630493.

PECABEAU EXPEDITION ONBOARD THE AMUNDSEN ICEBREAKER, FUNDED BY ARICE

A large international team of scientists from Europe, together with a few close Canadian collaborators, took part in the PeCaBeau Expedition (Permafrost Carbon in the Beaufort Sea). They sailed onboard the CCGS Amundsen (AMD2104) from Resolute Bay to Cambridge Bay, Canada, from 9 September to 10

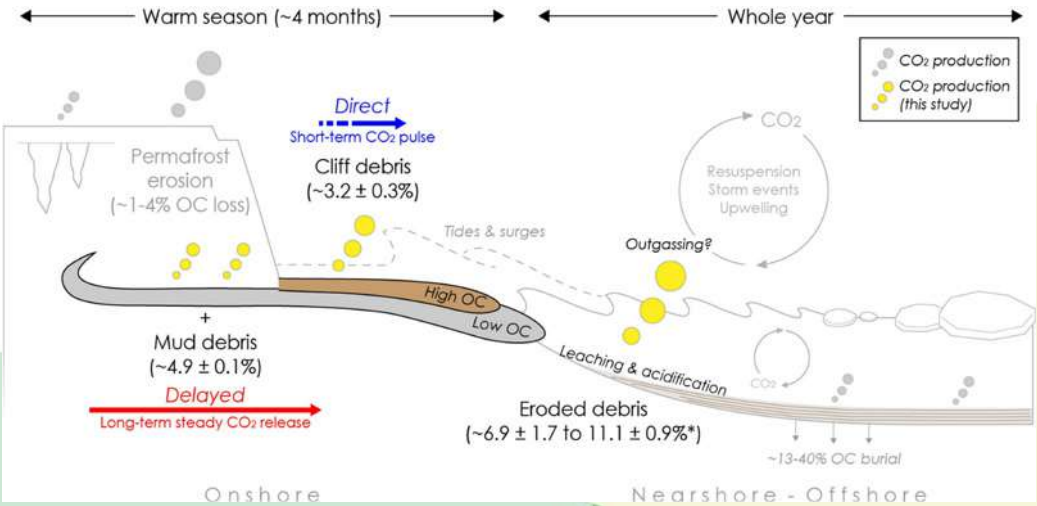


Fig. 35. Infographic summarizing potential organic carbon loss (%OC as CO_2) during coastal erosion processes from different erosion types in an Arctic warm season and entire year upon erosion in the sea. The magnitude of absolute carbon dioxide (mg CO_2 gdw) release is indicated by the size of yellow bubbles.

October 2021. The PeCaBeau project aims to track the movement and transformation of material from permafrost thaw along the land-to-ocean continuum. This multi-disciplinary effort investigates the sediment column between subsea permafrost and the seafloor, the water column, the atmosphere and the interfaces between these three units. By studying the sources, quantities and the quality of organic matter in the water column and in sediments, we aim to improve assessments of the Beaufort shelf as a carbon source or sink, and place these outcomes in the context of the Holocene paleoenvironment and transgressed permafrost. Sampling operations took place in the Southern Beaufort Sea with five major across-shelf transects. Mapping surveys were conducted during the entire cruise, radiometry measurements were performed under way and at 18 locations, water-column profiling and sediment sampling were conducted at 35 and 27 stations, respectively. For more information see:

- Bröder, L., *et al.* (2022). *The Permafrost Carbon in the Beaufort Sea (PeCaBeau) Expedition of the Research Vessel CCGS AMUNDSEN (AMD2104) in 2021*. Berichte zur Polar- und Meeresforschung = Reports on Polar and Marine Research, 759, 120 p. DOI: 10.48433/BzPM_0759_2022.

PLANS FOR 2022

Rúna Magnússon & Monique Heijmans - The research of Wageningen University in the Siberian lowland tundra has been and continues to be heavily impacted by restrictions on travel and collaboration. It is currently unlikely that we will receive any data or samples from Russia this year and envisioned longer-term monitoring of impacts of extreme rainfall on the tundra ecosystem in Siberia is not possible. Current research relies on previously sampled vegetation and remote sensing data to assess climate change impacts on shrub growth and tundra greening. New experimental research of Wageningen University is being set up on Svalbard (integrated permafrost and vegetation monitoring following experimental rainfall extremes) and we collaborate with researchers at Stockholm University and NOAA on literature review and modelling studies of rainfall impacts on permafrost soil thermal regime.

Jorien Vonk & colleagues – Planned fieldwork on the Siberian lowland tundra site has for us also been cancelled. As a replacement, we have organised multiple field campaigns to Churchill in Manitoba (Canada) to study lake sediment dynamics (methane production potential; via ebullition measurements and incubations) (Geert Hensgens and student), microbial composition and its boundary conditions in permafrost (Jeremy Emmett), and lateral organic matter transport within soil pore water and streams (Melanie Martyn Rosco and student). Furthermore, we will continue our coastal work in the Canadian Beaufort Sea based from Tuktoyaktuk, where we look at the fate of organic matter from eroding permafrost using hydrodynamic fractionation techniques (Fleur van Crimpen) as well as the impacts of increased sedimentation on Tuktoyaktuk Harbour (Lina Madaj) in collaboration with Dustin Whalen from NRCan. We also will participate in the SEES2022 expedition in July onboard the Ortelius to travel to Edgeøya in SE Spitsbergen that is organised by the Arctic Centre in Groningen together with Oceanwide Expeditions and subsidised by the Dutch Research Council.

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

NEW ZEALAND

BY TANYA O'NEILL (UNIVERSITY OF WAIKATO), ESME ROBINSON (ANTARTICA NEW ZEALAND), AND MARJOLAINE VERRET (VICTORIA UNIVERSITY OF WELLINGTON)

ANTARCTIC RESEARCH CENTRE, VICTORIA UNIVERSITY OF WELLINGTON

Marjolaine Verret was awarded an Early Career Researcher Seed Grant from the New Zealand Antarctic Research Institute (NZARI) to conduct research on ancient and modern microbial life in Antarctic permafrost. Using near-surface cores from the 2016/17 Friis Hills Drilling Project, this project aims to use lipid biomarkers to document the shift from a mid-Miocene tundra-dominated landscape to a modern bacteria-dominated one. From October to December 2021, Marjolaine also joined a team of scientists from the SETI Institute and the University of Ottawa, Canada, working in the Untersee Oasis, East Antarctica. Part of the field season involved reconnaissance work in the ice-free areas of the oasis and installing ground temperature monitoring stations to investigate the dry permafrost (*i.e.,* ice-free permafrost) (Fig. 36).

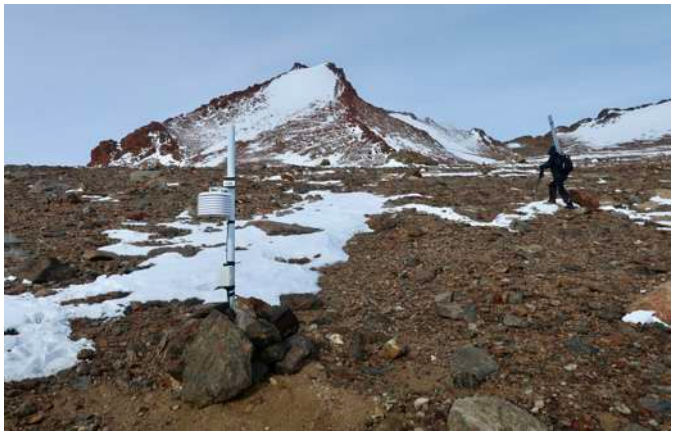


Fig. 36. Installing new ground temperature monitoring stations in the Untersee Oasis, East Antarctica - a project in collaboration with Dale Andersen (SETI Institute) and Denis Lacelle (University of Ottawa). Photo: Marjolaine Verret.

ANTARCTICA NEW ZEALAND

Scott Base redevelopment

Work on the Scott Base Redevelopment (Fig. 37) continued during the 2021/22 Antarctic summer season. Geotechnical investigations were undertaken at the Ross Island site to inform foundation design for the new station infrastructure, and inform plans for new wind turbines that will provide power to the Ross Island Wind Energy grid (which includes Scott Base and the United States Antarctic Program's McMurdo station). The new soil climate station installed by Tanya O'Neill (University of Waikato) and Pete Wilson (University of Canterbury), in 2020/21, is halfway through its data overlap period, and continues to function well (Fig. 38). The existing soil climate station (since 1999) will be impacted by the base rebuild, and the new installation will allow a two-year overlap of data before earthworks for the new base begin.

Fig. 37. Design image of the proposed New Zealand Antarctic Programme Scott Base. Photo supplied by: Esme Robinson.

Fig. 38. The Scott Base soil climate station (installed in 2020/21), Crater Hill and the wind farm in the background. Photo: Tanya O'Neill.

GEOLOGICAL & NUCLEAR SCIENCES, UNIVERSITY OF OTAGO & INSTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

A collaborative research programme from New Zealand (GNS Science, University of Otago) and Italy (National Institute of Geophysics and Volcanology, Instituto Nazionale di Geofisica e Vulcanologia) completed their third season of Antarctic fieldwork during 2021/22. The team carried out a series of electrical resistivity surveys, and downloaded, ser-

viced and relocated a network of year-round soil gas probes. The research aims to identify the origin and flux rates of greenhouse gases (primarily CO_2 and CH_4), and determine the subsurface structure and distribution of permafrost and linked subsurface fluids. The target sites for the field surveys are the lower Wright and lower Taylor valleys in the McMurdo Dry Valleys. Both are known to contain thick sedimentary sequences and thick permafrost layers. The research is funded by the Italian Antarctic Research Programme, PNRA (Programma Nazionale di Ricerche in Antartide), and supported by Antarctica New Zealand.

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) travelled

Fig. 39. Pete Wilson at the Victoria soil climate station in the McMurdo Dry Valleys.

to Antarctica late November 2021 to undertake the annual maintenance and data download (Fig. 39). Pete also downloaded the two 30 m borehole temperature strings which are run in collaboration with Mauro Guglielmin from Italy. The data contribute to the CALM (circum-polar active layer monitoring) programme as well as to the GTNP (Global Temperature Network-Permafrost).

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

NORWAY

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

UNIVERSITY OF OSLO, DEPT. OF GEOSCIENCES

We conducted a one-week campaign to Ny-Ålesund on Svalbard to continue our investigation of the thermal regime of rockwalls at and close to the sea. We downloaded data from iButton temperature loggers in cliffs from the inner parts of Kongsfjorden to the tip of Brøgger Peninsula, at elevations from sea level to about 250 m asl. Furthermore, we conducted dGPS measurements along the coastline of Brøgger Peninsula. Participants: Juditha Aga, Sebastian Westermann, Robin B. Zweigel; Funding: Research Council of Norway. Finally, we were able to download logger data in our permafrost observatories both in southern and northern Norway, including most rock wall loggers and loggers in palsa mires. Participants: Bernd Etzelmüller, Juditha Aga, Cas Renette.

GEOLOGICAL SURVEY OF NORWAY (NGU)

NGU is carrying out mapping of unstable rock slopes for hazard and risk assessment over Norway and in Isfjorden on Svalbard, the last in a cooperation with the Federal Institute for Geosciences and Natural Resources, Germany as part of the Norwegian landslide hazard mapping program financed and supervised by the Norwegian Water and Energy Directorate. Within this activity, mapping of unstable rock slopes was carried out in 2021 in permafrost environment as well as in areas not affected by permafrost. In 2021 NGU compared the database for unstable rock slopes that contains more than 500 unstable slopes distributed over Norway against existing permafrost and permafrost in rock wall maps. Results indicate that in northern Norway (north of the polar circle) most of the known rock slope instabilities lie in sporadic to discontinuous permafrost environment, while this number is much lower in the south. Both in northern and southern Norway lie the most active rock slope instabilities (highest deformation rates) in sporadic or discontinuous permafrost while the number of rock slope instabilities that do not show deformation today lie on slopes not affected by permafrost. Participants: Ivanna Penna, Reginald Hermanns, Martina Bøhme, Pierrick Nicolet, Marie Bredal, François Noél, Jose Pullaruello.

UNIVERSITY CENTRE IN SVALBARD (UNIS)

Still in 2021 UNIS had to cancel all master courses in the spring semester due to COVID-19. This, unfortunately, meant that the new course *AG-352 "Geohazards and geotechnics in high Arctic permafrost regions"* could also not be run in 2021. This was developed during 2019 as part of the INTPART Norwegian Research Council funded project *"Landscape & infrastructure dynamics of frozen environments undergoing climate change in Canada, Norway and Svalbard"*, which started in 2018 and planned to end in 2021. Due to the COVID-19 pandemic the project now has been extended to the end of 2022, and the AG-352 will run for the first time in 2022.

The permafrost group at UNIS were able to perform the last major winter drilling season to establish new boreholes as part of the SIOS InfraNOR project, delayed with one year by COVID-19. A 100 m borehole was drilled using the UNIS permafrost drill rigg operated by Kolibri Geo Services and instrumented in late autumn. This is the first deep borehole drilled in lowlands in Svalbard that almost penetrated the permafrost (Fig. 40).

The UNIS Strategic Pilot Project *"Developing a permafrost and meteorological climate change response system to build resilience in Arctic communities"* (PermaMeteoCommunity) started in 2021. This is a project led by UNIS and with local authorities and several national partners. A new PhD student Knut Tveit is studying in this interdisciplinary geoscientific research and educational project. A drilling campaign was performed in September and October to map the extent of sediment filling Longyearbyen valley and determine its permafrost content and type. Also, an inclined borehole to record temperatures below the Kulturhuset building centrally in Longyearbyen was done.

Fig. 40. The 100 m deep SIOS InfraNOR borehole in Endalen. It was instrumented during the polar night in mid-November 2021 by Kolibri Geo Services run by Ulrich Neuman (left) and assisted by PhD student Knut Tveit (right).

The ClimaGas Norwegian Research Council funded project, sampled methane gas from pingos and springs all over central Svalbard, focussing on mapping and understanding the dynamics and amount of GHG that is emitted from permafrost this way. The project also included modelling.

NORCE NORWEGIAN RESEARCH CENTRE

In 2021, research on satellite remote sensing applied to mountain and lowland permafrost science has continued at NORCE Energy & Technology, as part of the FrostInSAR project (Research Council of Norway Grant 263005) and the ESA CCN2 Climate Change Initiative (CCI) Permafrost. In Northern Norway and Svalbard, Synthetic Aperture Radar Interferometry (InSAR) has been used to study the spatial distribution and temporal variability of ground movement associated with rock glacier creep and active layer freeze and thaw. We showed the potential of InSAR to map the timing of the seasonal thaw subsidence maxima and indirectly document the active layer thermal regime at the landscape-scale (Fig. 41).

- Rouyet, L. *et al.* (2021). Seasonal InSAR Displacements Documenting the Active Layer Freeze and Thaw Progression in Central-Western Spitsbergen, Svalbard. *Remote Sensing*, 13(15), 30 p. DOI: 10.3390/rs13152977.

The INTPART project PRISM led by NORCE Environment & Climate started in 2021 with the main objective to create a multidisciplinary dialogue to improve understanding of the risks of permafrost thaw to nature and society. In 2021, the project organised a range of training and network activities: some were held online, such as the Cryogrid workshop organised by UiO; others like a summer school in Iceland had to be delayed to 2022 due to travel restrictions. A website has been established to provide updates and information on these activities.

NTNU TRONDHEIM - GEOGRAPHY

NTNU Geography conducted fieldwork at three field sites on Svalbard (blockfield at Platåberget) and in Southern Norway (Tron summit blockfield in Østerdalen and Gamlemsveten blockfield close to Ålesund). The team downloaded about 100 miniature temperature dataloggers in different near-surface settings in late summer/fall and measured snow depths and density in spring at the dataloggers. This is connected to a PhD project on periglacial erosion

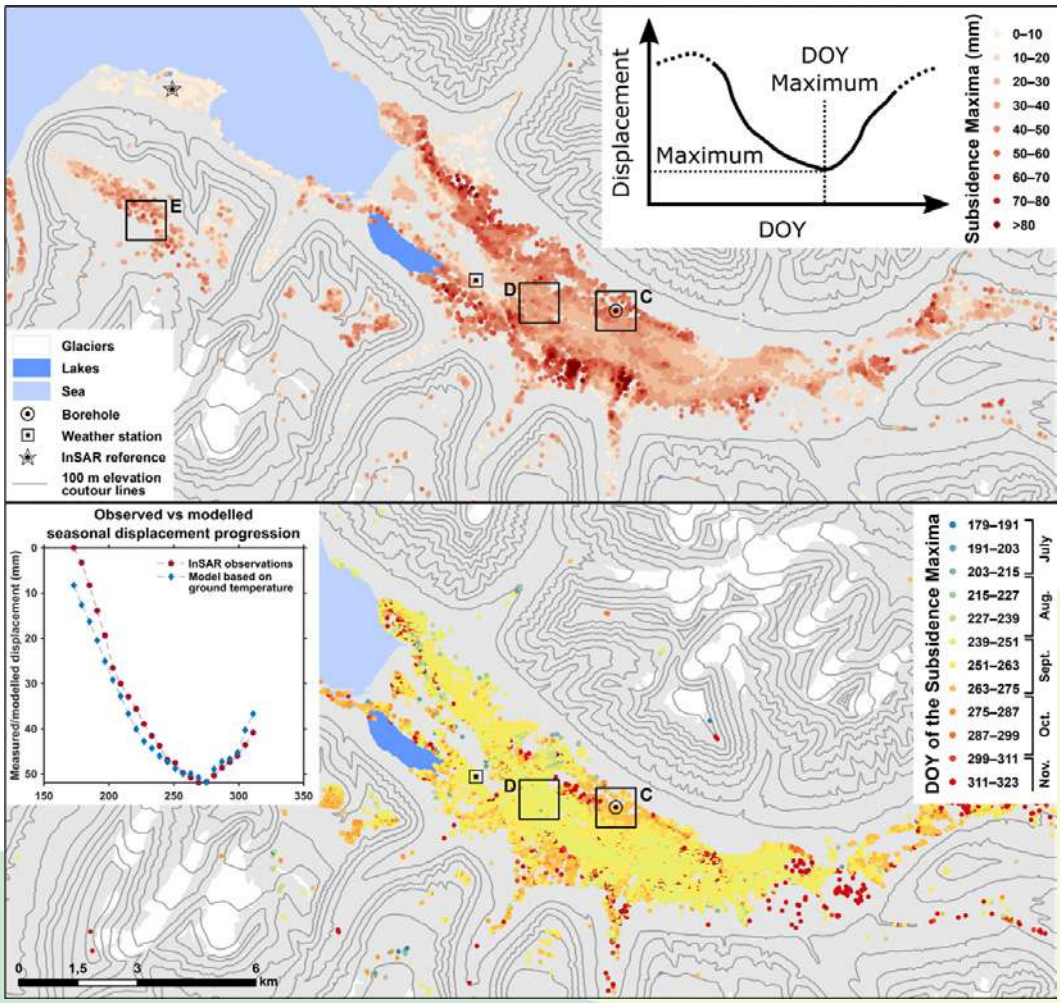


Fig. 41. InSAR-based products documenting the seasonal active layer freeze and thaw progression in Adventalen, Svalbard. Top: subsidence maxima based on seasonal displacement time series. Bottom: timing (Day of Year: DOY) of the subsidence maxima. The good match between InSAR results and model based on temperature (left inset) shows that the subsidence-heave displacements are well representative of the active layer thermal regime (Rouyet *et al.*, 2021).

modeling and landscape evolution of high elevation-low relief surfaces. Chantel Nixon, Ola Fredin (NTNU) and Bernd Etzelmüller (UiO) are supervising the thesis. Furthermore, samples and data from sorted ground at Brøggerhalvøya and Isfjordflya, Svalbard, were collected in August/September in connection to an Arctic Field Grant from the Norwegian Research Council/Svalbard Science Forum.

NORWEGIAN METEOROLOGICAL INSTITUTE (MET NORWAY)

In 2021 three new operational permafrost monitoring sites were established at remote locations on Svalbard in the high-Arctic (Fig. 42) as part of the Climate-ecological Observatory for Arctic Tundra (COAT) and Svalbard Integrated Arctic Earth Observing System (SIOS) projects. The establishment and installations was led by MET Norway in collaboration with the Norwegian Polar Institute and The University Centre in Svalbard. The boreholes were drilled by Ullrich Neumann (Kolibri Geo Services) and his drill crew. A digital temperature cable with 27 sensors down to a depth of 30 m was installed and connected to the automatic weather station (AWS) at the three sites. The new permafrost stations provides real-time data, and data transfer and storage takes place through MET Norway operational systems. Access to the latest products showing the current state of permafrost at these sites are available for free at Cryo and Frost API.

SINTEF-TRONDHEIM

In 2022, monitoring of ground surface temperatures in Longyearbyen and Ny-Ålesund, as part of the *"Polar Climate and Cultural Heritage – Preservation and Restoration Management"* (PCCH-Arctic). This began with installation of an array of i-Buttons along the system of cableway posts in Longyearbyen, and selected historical structures in Longyearbyen (the old cableway centre in Longyearbyen, the old cableway station in Hiorthhamn, station, the Titan crane), and Ny-Ålesund (the Green Harbor House, the White house, the airship mast). This data will be used as an input parameter for modelling of permafrost degradation at those locations. Permafrost modelling will be based on the next version of CryoGrid (currently under development in University of Oslo), which be powered by the next generation climate projections (currently under development at MET Norway).

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

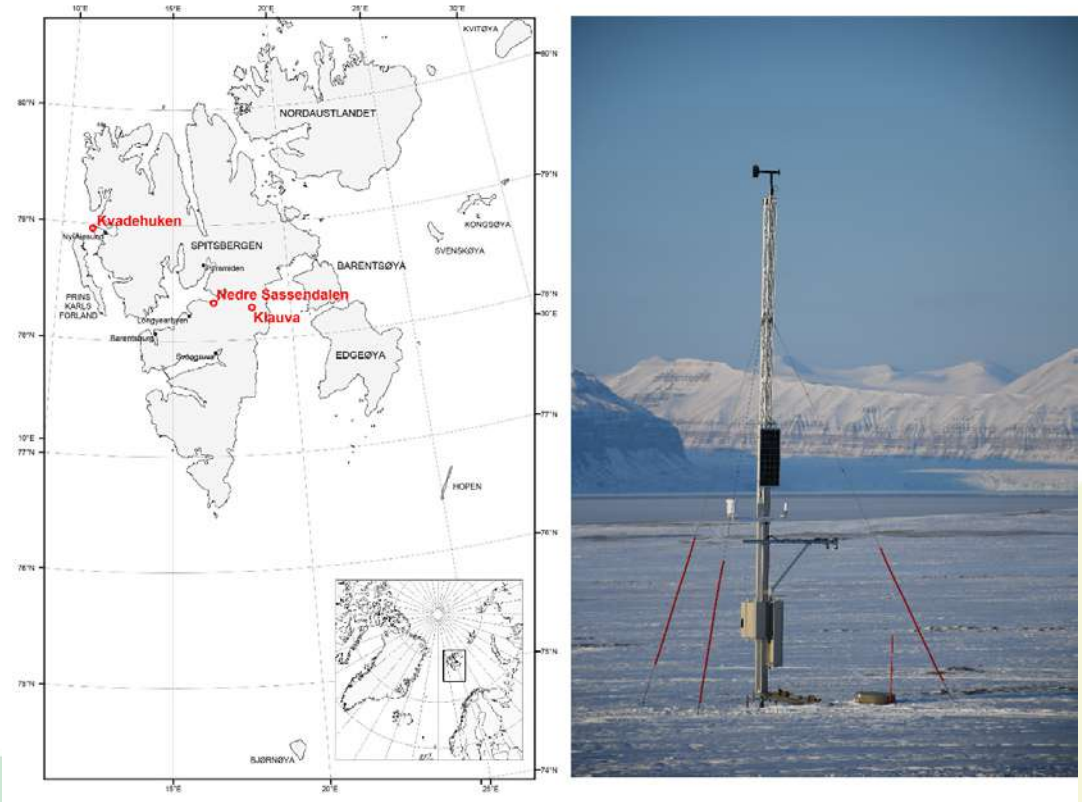


Fig. 42. Left: map of the three new remote permafrost monitoring sites at Kvadehuken, Nedre Sassendalen and Klauva on Svalbard. Right: photo of the Nedre Sassendalen weather and permafrost monitoring station. Photo: Ketil Isaksen.

POLAND

BY RAJMUND PRZYBYLAK (UNIWERSYTET MIKOŁAJA KOPERNIKA)

ADAM MICKIEWICZ UNIVERSITY IN POZNAŃ

At Adam Mickiewicz University Polar Station in Petuniabukta (central Spitsbergen, Svalbard), permafrost research continued at selected sites where ground temperature and humidity loggers are installed. Pandemic restrictions limited monitoring to data downloading and equipment maintenance at the end of the melting season. Measurement results include the permafrost active layer temperature profile and subsurface temperature and humidity used for assessing the adaptation of tundra plant habitats and aeolian processes.

INSTITUTE OF GEOPHYSICS, POLISH ACADEMY OF SCIENCES

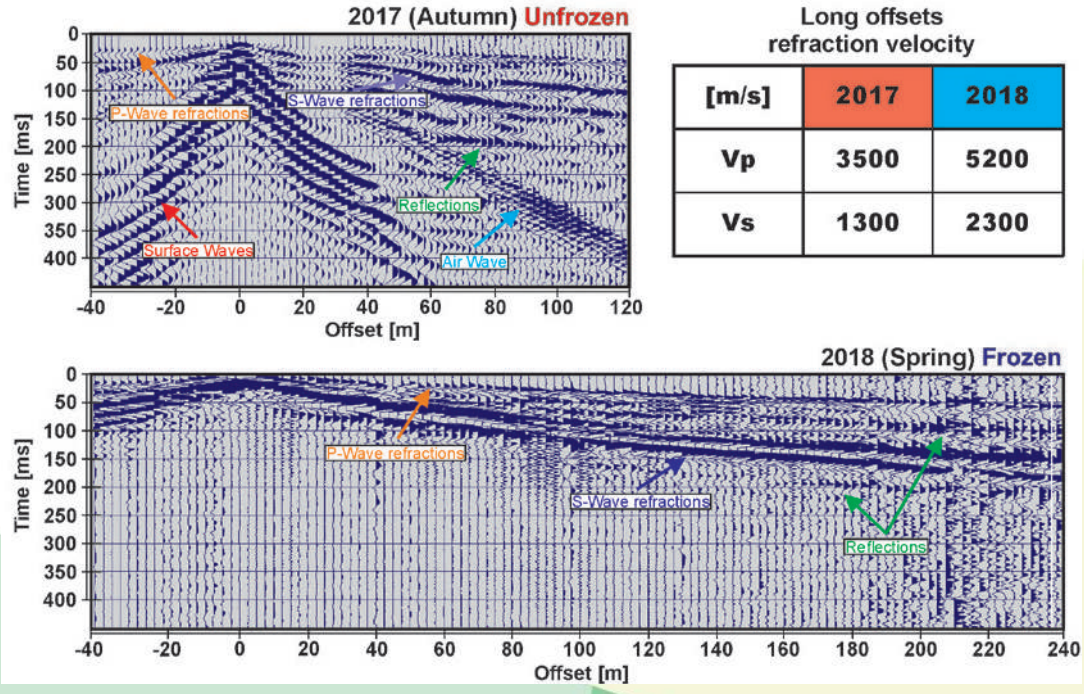
Results from seismic studies conducted in 2017 and 2019, as part of a project funded by the National Science Centre, Poland (NCN), Grant UMO-2015/21/B/ST10/02509, were published in *Permafrost and Periglacial Processes*. A second article was accepted to the *Journal of Polish Polar Research*. The study reveals that seasonal changes are affecting the permafrost and leading hydrological changes at the study site. As a result, the observed changes in physical parameters reach much deeper than previously believed, to even 40 m bgl (Fig. 43). The multimethod approach presented in the study allowed for precise separation between geological structures and thermal seasonal effects affecting the subsurface of the Svalbard area (Fig. 44). Additionally, complicated structures of the Fugglebekken catchment and the Hans Glacier forefield were geophysically imaged, revealing a complicated geological construction with multiple periglacial landforms.

- 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* (early view). DOI: 10.1002/ppp.2147.

GDAŃSK UNIVERSITY OF TECHNOLOGY

This year we analyzed samples taken in various locations in Svalbard (Arctic) and on the western shore of Admiralty Bay (Maritime Antarctica).

The water and sediment from the Arctic location was tested for ions, metals, non-metals, and TOC concentrations. The shaping of surface water chemistry in the Svalbard Archipelago (Bellsund, Hornsund) is strongly dependent on the geology of the catchment and the process of long-range transport of atmospheric pollutants (LRTAP). It was observed that increases in air temperature and rain, which resulted in increased water discharge, caused intense transport of the trace elements load. Moreover, the results of the precipitation sensitivity coef-



Long offsets refraction velocity

[m/s]	2017	2018
Vp	3500	5200
Vs	1300	2300

Fig. 43. Seasonal changes in velocity observed on shot gathers for autumn and spring conditions (maximal thawing and freezing effect) (Majdański *et al.*, 2022).

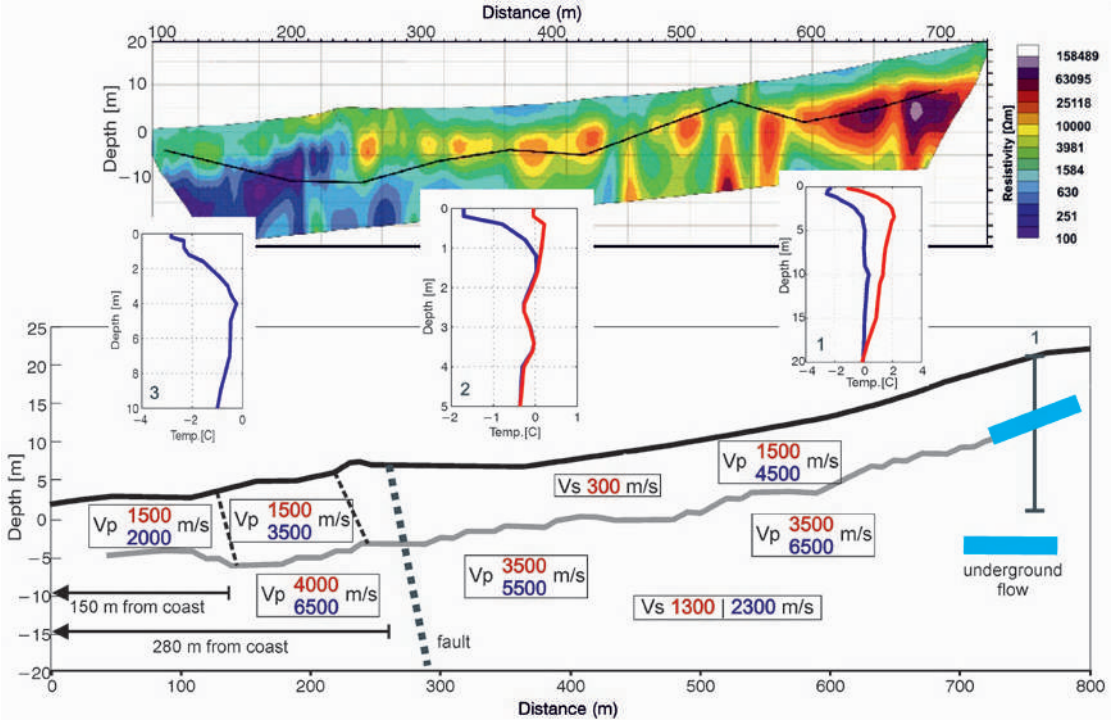


Fig. 44. Interpretation image, based on multimethod approach. The seasonal variations in velocity were identified (Majdański *et al.*, 2022).

ficient factor (CF) proved that precipitation affected the occurrence of metals in the Arctic River. Metals and metalloids in snow on glaciers, depending on the season of deposition, may come from various sources: local rock dust (erosion of the geological substratum), marine aerosols, local human activity (e.g., impurities in combusted fuel and waste incineration), and long-range atmospheric transport. At the study site, snow was up to six times more efficient in bringing metal pollution into the terrestrial environment than was rain.

The water and sediment from the Antarctic location (the Warszawa Icefield area) was tested for PAHs, metals, non-metals and TOC concentrations, showing the importance of rock weathering on the elemental fluxes in river waters impacted by increased snowmelt. A slight increase in PAHs and heavy-metal concentrations was observed at the marginal parts of the icefield, which suggests the impact of scientific stations. This work was carried out in cooperation with the Kazimierz Wielki University in Bydgoszcz, Institute of Earth Sciences, University of Silesia, Sosnowiec, Maria Sklodowska-Curie University in Lublin, Adam Mickiewicz University and Bremen University.

NICOLAUS COPERNICUS UNIVERSITY IN TORUŃ

In 2021, monitoring of active-layer thickness continued at a few fixed measurement points on the Kaffiøyra Plain around the Nicolaus Copernicus University Polar Station. These research points are part of the CALM programme network and are among the few points located in the High Arctic region. The measurement points represent typical Kaffiøyra sites: sandy beach, tundra plain and moraine embankment. The amount of ground thawing and thickness of the active layer have been measured every 7-10 days since 1996. Active layer (ground) temperatures were measured. For this purpose, automatic temperature loggers were installed at various depths (max. 150 cm) at measurement points. Temperatures have been recorded continuously, year-round at the measurement points on the moraine (since 2006), the beach (since 2012) and the tundra (since 2006). A summary of permafrost research in Kaffiøyra was published in:

- Sobota, I. (2021). Permafrost of Kaffiøyra. In: I. Sobota (ed.). *Atlas of changes in the glaciers of Kaffiøyra (Svalbard, the Arctic)*. Wydawnictwo Naukowe Uniwersytetu Mikołaja Kopernika, 101-107 pp.

UNIVERSITY OF SILESIA

Another of last year's initiatives was the editing of a special volume of Geosciences under the slogan "Permafrost and Glaciers: Perspectives for the Earth and Planetary Sciences". It contains six original papers that are briefly characterized in:

- Dobiński, W. and Kneisel, C. (2021). Permafrost and Glaciers: Perspectives for the Earth and Planetary Sciences—Another Step Forward. *Geosciences*, 11(2), 2p. DOI: 10.3390/geosciences11020068.

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

- Barbaro, E., *et al.* (2021). Measurement report: Spatial variations in ionic chemistry and water-stable isotopes in the snowpack on glaciers across Svalbard during the 2015-2016 snow accumulation season. *Atmospheric Chemistry and Physics*, 21, 3163-3180. DOI: 10.5194/acp-21-3163-2021.
- Kozioł, K., *et al.* (2021). Seasonal and spatial differences in metal and metalloid concentrations in the snow cover of Hansbreen, Svalbard. *Frontiers in Earth Science*, 8, 1-9. DOI: 10.3389/feart.2020.538762.
- Lehmann-Konera, S., *et al.* (2021). Effects of biotransport and hydro-meteorological conditions on transport of trace elements in the Scott River (Bellsund, Spitsbergen). *PeerJ*, 9, 21 p. DOI: 10.7717/peerj.11477.
- Pawlak, F., Kozioł, K. and Polkowska, Ż. (2021). Chemical hazard in glacial melt? The glacial system as a secondary source of POPs (in the Northern Hemisphere). A systematic review. *Science of the Total Environment*, 778, 18 p. DOI: 10.1016/j.scitotenv.2021.145244.
- Ruman, M., *et al.* (2021). A High-Arctic flow-through lake system hydrochemical changes: Revvatnet, southwestern Svalbard (years 2010–2018). *Chemosphere*, 275, 13 p. DOI: 10.1016/j.chemosphere.2021.
- Spolaor, A., *et al.* (2021). Investigation on the Sources and Impact of Trace Elements in the Annual Snowpack and the Firn in the Hansbreen (Southwest Spitsbergen). *Frontiers in Earth Science*, 8, 10 p. DOI: 10.3389/feart.2020.536036.
- Szumińska, D., *et al.* (2021). Sources and composition of chemical pollution in Maritime Antarctica (King George Island), part 2: Organic and inorganic chemicals in snow cover at the Warszawa Icefield. *Science of the Total Environment*, 796, 13 p. DOI: 10.1016/j.scitotenv.2021.149054.
- Zdanowicz, C., *et al.* (2021). Elemental and water-insoluble organic carbon in Svalbard snow: a synthesis of observations during 2007-2018. *Atmospheric Chemistry and Physics*, 21, 3035-3057. DOI: 10.5194/acp-21-3035-2021.

PORTUGAL

BY GONÇALO VIEIRA (UNIVERSIDADE DE LISBOA)

Portuguese activities on permafrost research were severely affected by the COVID-19 pandemic in 2021, with all field activities cancelled, both in the Arctic and Antarctic. This limited the contributions received to this annual report.

Research at CEG/IGOT continued in the Western Antarctic Peninsula, mainly focusing in 2021 on ground surface temperature modelling in Barton Peninsula (King George Island). The collection of data from the PERMANTAR Observatories in the Antarctic Peninsula (Gonçalo Vieira, Universidade de Lisboa) was performed through international cooperation with the University of Alcalá de Henares for Deception and Livingston Islands, with the Bulgarian Antarctic Institute in Livingston Island, with the Korean Polar Research Institute for Barton Peninsula and with US Antarctic Program – Palmer station for the borehole in Amsler Island. Unfortunately, it was not possible to access the Primavera borehole. The two Automatic Electrical Resistivity Tomography sites associated with the boreholes in Hurd Peninsula and Deception Island were also maintained by the University of Alcalá de Henares. These systems have been developed by a team from IDL – Universidade de Lisboa and INIAV in the framework of the project ANTERMON (Mohammad Farzamian, INIAV). The PERMANTAR observatories currently include 9 boreholes and 2 boreholes in cooperation with Spain. The support from our partners was essential for the maintenance of the data series and is warmly appreciated! Joana Baptista started her PhD targeting at modelling permafrost temperatures in the Antarctic Peninsula.

The CEG/IGOT – Universidade de Lisboa was also able to continue the remote sensing research in northern Canada, although no field data has been collected. The project THAWPOND (Carla Mora, Universidade de Lisboa) focuses on the dynamics of permafrost thaw lakes and ponds in Nunavik, Northern Quebec. The activities have focused on studying the effects of vegetation shadow casts on water spectral properties by using UAVs and remote sensing imagery. The objective is to analyse the spatial and temporal variability of water color in thermokarst lakes and ponds along two transects, one in Northern Quebec and another one in the Mackenzie river delta. This is the research topic of Pedro Freitas' PhD project and is a collaboration with the CEN/Université Laval and CQE/IST. The activities of CEG/IGOT at the project Nunataryuk (Gonçalo Vieira) continued targeting at monitoring coastal erosion in the Canadian Beaufort Sea using remote sensing data (UAV, Very high resolution multispectral imagery and SAR). Although field work was not possible, new very high resolution satellite imagery has been acquired, including from the SAR satellites TerraSAR-X (DLR) and PAZ (HisdeSAT), which are allowing important insight at very high resolution into the intraseasonal coastal dynamics. These activities are a collaboration with NRCAN/GSC, AWI, CQE/IST and UC. A new project funded by the European Space Agency, "Earth Observation for Permafrost Arctic Coasts (EO4PAC)", led by bGeos and partnered with AWI and IGOT, started in 2021. This project will allow the consolidation and improvement of the Arctic Coastal Dynamics Database, as well as generating new coastal erosion and infrastructure data, with extensive validation. EO4PAC counts also with partnerships with the University of Alaska in Fairbanks, the University of Edinburgh and Natural Resources Canada.

The CQE/IST developed activities in the Canadian Arctic in two research areas related with the biogeochemistry of permafrost thaw lakes (João Canário, Universidade de Lisboa). One of those is assessing the chemical composition of dissolved organic matter (DOM) and its role on carbon availability and consequently on GHG release. For this purpose, several structural analytical techniques (e.g. FTIR-ATR, NMR, HPLC-TOF-MS) have been used in parallel with classical optical measurements, which allowed to identify the composition of DOM in terms of great functional groups and to identify their mobility, lability and source in thaw lake waters. This research frames the PhD of Diogo Folhas. The other project is related with mercury (Hg) biogeochemistry speciation and fate in the same lakes. CQE/IST has been used Hg stable isotope techniques to track this processes and to estimate Hg methylation and methyl-Hg demethylation rates in the lake systems. Both of the projects result from the scientific cooperation between, CQE/IST, CEG/IGOT and the Universities Laval and Trent in Canada.

The main activities developed at the Universidade

de Coimbra (IA, Department of Earth Sciences), in close collaboration with the University of Lisbon (CERENA, IST), are based on the synergistic use of remote sensing to map and characterise vegetation and patterned ground in the South Shetlands and the Antarctic Peninsula. All the activities in 2021 were developed at computing laboratories, due to the COVID-19 pandemics and the impossibility of developing a field campaign. The mapping of the vegetation within the project VEGETANTAR (Pedro Pina, Universidade de Coimbra) is based on a novel approach to classify Landsat series images, the only satellite datasets that allow large-scale mapping for about five decades, though with a spatial resolution (30 m) often below the size of the sparse and vegetation patches in the Antarctic Peninsula. A methodology is under development, based on image analysis and machine learning, to classify the Landsat images (30 m) through the integration of multiscale imagery of Sentinel2 (10 m), WorldView or similar (1-2 m) and UAV-Unmanned Aerial Vehicles (0.005-0.05 m). This is the PhD research topic of Vasco Miranda. Understanding how the vegetation patterns change and mix with other surfaces with the decrease of the spatial scale was the main challenge addressed in 2021 to design and calibrate adequate classifiers. Sorted stone circles have been analysed through ultra-high resolution datasets (mm-cm resolutions) obtained UAV surveys in Barton Peninsula, King George Island. The use of image mosaics and digital elevation models, built after structure-from-motion techniques, allowed delineating accurately each sorted stone circle and extract 2D and 3D morphometric features. These characteristics of nearly 3000 circles were analysed along an altitudinal gradient in the peninsula (from 65 to 245 m asl) and their relation to the vegetation were analysed in detail. MSc and PhD students, presenting and preparing their theses on these subjects, were also involved.

For more information contact Gonçalo Vieira (vieira@campus.ul.pt).

RUSSIA

BY DMITRY S. DROZDOV (RUSSIAN ACADEMY OF SCIENCES)

EARTH CRYOSPHERE INSTITUTE, TYUMEN SCIENTIFIC CENTRE, SIBERIAN BRANCH, RUSSIAN ACADEMY OF SCIENCE (ECI TYUMEN SCIENTIFIC CENTRE SB RAS)

In May 2021, the Earth Cryosphere Institute (ECI SB RAS) celebrates its 30th anniversary. Creation of this institute in Tyumen back in 1991 was an event marking an important stage in the development of cryology:

- Melnikov, V.P., *et al.* (2021). To the anniversary of the Earth Cryosphere Institute, Tyumen Scientific Centre SB RAS. *Earth's Cryosphere*, 2, 68-72.

Important results from programs at the ECI SB RAS and others Institutes and organizations specializing in permafrost/cryosphere research are presented in the journal *Earth's Cryosphere* (*Kriosfera Zemli*). It has been translated into English since 2014.

MELNIKOV PERMAFROST INSTITUTE, SIBERIAN BRANCH, RUSSIAN ACADEMY OF SCIENCE (MPI SB RAS, YAKUTSK)

In 2021, MPI initiated a new long-term project on *"The Evolution of Permafrost and Glacial Deposits and the Pleistocene Chronostratigraphy of Northeast Siberia"* in collaboration with the Arctic Research Center, Sakha Academy of Sciences (Yakutsk), the Institute of Geography, RAS (Moscow), the Faculty of Geography, Moscow State University (Moscow), the Institute of Earth Crust (Irkutsk) and the Department of Geoscience, Aarhus University (Denmark). The project, led by Dr. Alexey Galanin (MPI), commenced with four expeditions carried out during the summer of 2021 in the Yana, Kolyma and Lena basins. The Lena expedition (Fig. 45) focused on Pleistocene periglacial features and Verkhoyansk morainic complexes along the Undulyung River and Point Mavra near Zhigansk, as well as on reference sections at Ust-Buotama and Diring sites near Yakutsk. Samples were collected for radiocarbon, optically stimulated luminescence, and cosmogenic isotope dating.

Fig. 45. Field party riding up the Undulyung River (July 2021).

An expedition to the northern Tien-Shan (Kazakhstan) was conducted in July 2021 by a team of MPI's hydrogeologists led by Nadezhda Pavlova. It included field measurements and sampling in the Ozernaya River basin near the Kirgizia border to characterize stream runoff and water chemistry, as well as the influence of rock-glacier discharge on river systems (Fig. 46).

Fig. 46. Measuring stream discharge, northern Tien-Shan (July 2021).

The Sixth Forum for Young Permafrost Scientists was held at MPI from 29 June o 13 July 2021, commemorating the 100th birthday of two prominent figures in Russian permafrost science, Evgeny M. Katasonov and Nina P. Anisimova. The Forum program included a four-day conference with in-person and online attendance of about 140 people from Russian and foreign universities, research centers and companies. The conference was followed by a field trip featuring cold deserts of central Yakutia (Fig. 47). The trip participants took part in field studies of the D'Olkuma Formation exposure at Ust-Buotama, the active Saamys-Kumaga Dune Field and the Lena Dune. In the Makhatta and Kysyl-Syr sand fields, ground and surface water sampling and groundwater discharge measurements were conducted. Results will be compared with historical data taken in 1974-1975 to assess water resource changes over the last 50 years.

Fig. 47. Examining cover sand stratigraphy, Makhatta Tukulan dune field (July 2021).

Mikhail Grigoriev, Deputy Director of MPI, and Hans-Wolfgang Hubberten, former Director of the Alfred Wegener Institute's Potsdam Unit, received the Officer's Cross of the Order of Merit of the Federal Republic of Germany in recognition of significant contributions to research cooperation between Germany and Russia. Ceremonies of bestowal were held in Yakutsk on October 6, 2021 (Fig. 48) and in Potsdam on November 29, 2021.

Fig. 48. Consul General of the Federal Republic of Germany in Novosibirsk, Bernd Finke (left) presents the Officer's Cross of the Order of Merit to Mikhail Grigoriev (right) in Yakutsk (Oct. 2021).

SERGEEV INSTITUTE OF ENVIRONMENTAL GEOSCIENCE RAS (IGE RAS, MOSCOW)

The Institute of the Earth's Crust SB RAS, together with the Sergeev Institute of Environmental Geoscience RAS, continued the regular geocryological observations in the southern geocryological zone adjacent to the shores of Lake Baikal (Fig. 49). Areas with significant changes in landscapes associated with long-term thawing of permafrost have been identified. In spite of a variable epidemiological situation in Russia during summer 2021, the regular geocryological observations following GTN-P program was realized (Fig. 50). Permafrost temperatures decreased, which is explained by a cold winter with little snow in 2020-2021.

Fig. 49. Observation of coastal processes in the southern geocryological zone (western shore of Baikal Lake). Photo: M.G. Mnushkin.

Fig. 50. Moscow State University educational geocryological practice in Vorkuta. Study of the ground temperature regime and the activity of geocryological processes. Photo: A.P. Bezdelova.

INSTITUTE OF PHYSICOCHEMICAL & BIOLOGICAL PROBLEMS IN SOIL SCIENCE, RAS (SOIL CRYOLOGY LABORATORY) (PUSHCHINO, RUSSIA)

The survival of an obligate parthenogenetic bdelloid rotifer (Fig. 51), recovered from northeastern Siberian permafrost radiocarbon-dated to ~24,000 years BP was reported. This constitutes the longest reported case of rotifer survival in a frozen state. We confirmed the finding by identifying rotifer actin gene sequences in a metagenome obtained from the same sample. By morphological and molecular markers, the discovered rotifer belongs to the genus Adineta, and aligns with a contemporary Adineta vaga isolate collected in Belgium. Experiments demonstrated that the ancient rotifer withstands slow cooling and freezing (~1°C min^{-1}) for at least seven days. We also show that a clonal culture can continuously reproduce in the laboratory by parthenogenesis.

- Shmakova, L., *et al.* (2021). A living bdelloid rotifer from 24,000-year-old Arctic permafrost. *Current Biology*, 31(11), R712-R713. DOI: 10.1016/j.cub.2021.04.077.

Fig. 51. Strain Ad01 (SCL-15-7) frozen deposits (Shmakova et al. 2021). A: whole animal, B: head side view, C: inner jaw.

Metagenomic studies of permafrost biodiversity are continuing. Analysis of the geological structure of the reference sections of ancient permafrost in the Arctic showed the possibility of continuous existence of permafrost here during the last 1-1.4 million years. This, in turn, coincides with the maximum retention time of viable microorganisms in these deposits. Such long-term preservation of viable cells makes it possible to search for answers to both fundamental biological questions, and is also important in the astrobiological aspects.

- Abramov, A., Vishnivetskaya T., Rivkina E. (2021). Are permafrost microorganisms as old as permafrost? *FEMS Microbiology Ecology*, 97(2). DOI: 10.1093/femsec/fiaa260.
- Sipes K., *et al.* (2021). Eight Metagenome-Assembled Genomes Provide Evidence for Microbial Adaptation in 20,000- to 1,000,000-Year-Old Siberian Permafrost. *Applied and Environmental Microbiology*, 87(19), 17 p. DOI: 10.1128/AEM.00972-21.
- Liang, R., *et al.* (2021). Genomic reconstruction of fossil and living microorganisms in ancient Siberian permafrost. *Microbiome*, 9(1), 1-20. DOI: 10.1186/s40168-021-01057-2.

Lake change trend analysis for a 44,500 km² region of the Kolyma Lowland using Landsat imagery in conjunction with TanDEM-X digital elevation model and Quaternary Geology map data was reported. Comparison of drained lake basin area with thermokarst lake extents reveal the overall limnicity decrease by 80% during the Holocene. Current climate warming and wetting in the region led to a lake area increase by 0.89% for the 1999-2013 period and an increase by 4.15% for the 1999-2018 period.

- Veremeeva, A., *et al.* (2021). Geomorphological and Climatic Drivers of Thermokarst Lake Area Increase Trend (1999–2018) in the Kolyma Lowland Yedoma Region, North-Eastern Siberia. *Remote Sensing*, 13(2), 30 p. DOI: 10.3390/rs13020178.

CRYOLITHOLOGY & GLACIOLOGY DEPARTMENT, GEOGRAPHICAL FACULTY, LOMONOSOV MOSCOW STATE UNIVERSITY

Cryolithological research

The results of the study of cryolithological and geochemical features of Yedoma (Ice Complex) have been summarized by V.V. Rogov as part of a team of authors (Rogov et al., 2021; Shmelev et al., 2021):

- Rogov, V.V., Kurchatova, A.N., and Taratunina, N.A. (2021). Types and micromorphology of authigenic carbonates in the kolyma yedoma ice complex, Northeast Siberia. *Frontiers in Earth Science*, 9, 9 p. DOI: 10.3389/feart.2021.718904.
- Shmelev, D., *et al.* (2021). Reconstructing permafrost sedimentological characteristics and post-depositional processes of the yedoma stratotype duvanny yar, Siberia. *Frontiers in Earth Science,* 9, 14 p. DOI: 10.3389/feart.2021.727315.

I.D. Streletskaya summarized field data on key sections of the Kara Sea shores, made conclusions about the features of the formation of highly icy sediments and participate in a creation of a database and map of the Yedoma distribution:

- Strauss, J., *et al.* (2021). Circum-Arctic Map of the Yedoma Permafrost Domain. *Frontiers in Earth Science*, 9, 15 p. DOI: 10.3389/feart.2021.758360.
- Streletskaya, I.D., *et al.* (2021). The icerich permafrost sequences as a paleoenvironmental archive for the Kara sea region (western arctic). *Frontiers in Earth Science*, 9, 16 p. DOI: 10.3389/feart.2021.723382.

Under the leadership of V.I. Grebents, comprehensive studies of the state of the infrastructure of the Russian Arctic were carried out with an assessment of the degree of objects deformation and the influence of dangerous cryogenic and nival-glacial processes on the stability of buildings and structures:

- Grebenets, V.I., *et al.* (2021). The problem of storage of solid waste in permafrost. *Environmental Research Letters,* 16, 11 p. DOI: 10.1088/1748-9326/ac2375.

- Grebenets, V.I., *et al.* (2021). Impact of hazardous cryogenic processes on infrastructure in the Arctic (in press). *Moscow University Bulletin*. Series 5: Geography (In Russian).

A.I. Kizyakov and colleagues received new data on thermocirques (thaw slumps) growth rates on the Yugorsky Peninsula in 2010-2020:

- Leibman, M., *et al.* (2021). Coastal retreat due to thermodenudation on the Yugorsky Peninsula, Russia during the last decade, update since 2001–2010. *Remote Sensing*, 13(20), 21 p. DOI: 10.3390/rs13204042.

L.I. Zotova reviewed the available scientific achievements in the field of landscape-indicator studies in the permafrost zone, including the issues of clarifying the permafrost zones boundaries by the landscape-structural method:

- Zotova, L.I. (2021). Landscape indication of permafrost conditions for geoecological assessment & mapping at various scales. *Geography, Environment, Sustainability*, 14(4), 33-40. DOI: 10.24057/2071-9388-2021-039.

A.A. Maslakov and others carried out mapping and classification of cryogenic landscapes according to their susceptibility to climatic changes and potential anthropogenic impact:

- Maslakov A.A., *et al.* (2021). Vulnerability of the permafrost landscapes in the eastern chukotka coastal plains to human impact and climate change. *Land*, 10(5) 14 p. DOI: 10.3390/land10050445.

S.A. Sokratov and others developed a new training course for students of the cryolithology and glaciology department on laboratory study of the mechanical properties of snow, ice and frozen soil.

V.I. Grebenets and A.A. Maslakov carried out annual active layer monitoring fieldwork to as part of the CALM program at sites in the Talnakh (the north of Krasnoyarsk Territory) and in Eastern Chukotka.

Glaciological research

Under the leadership of V.V. Popovnin, fieldwork was carried out in the basin of the representative mountain glaciers in the Central Caucasus (Djankuat) and Tien Shan (Karabatkak, Sary-Tor, Bordu). All data were included in the annual national report for the World Glacier Monitoring Service (WGMS).

N.A. Volodicheva and A.D. Oleinikov continued snow-avalanche studies to detect changes in snowfall and avalanche activity at the Elbrus educational and scientific base of MSU.

S.A. Sokratov collected data on the height of snow cover in various regions of Russia in order to assess the correspondence of the distributions of the maximum height for the year to a certain type of statistical distribution:

- Sokratov S.A., Seliverstov Yu.G., and Glazovskaya T.G. (2021). On the issue of performing avalanche calculations during engineering and hydrometeorological surveys. XVI All-Russian Scientific and Practical Conference: "Prospects for the development of engineering surveys in construction in the Russian Federation", 1-3 December 2021, online (in Russian).

N.V. Kovalenko and others continued annual glaciological monitoring of the Kolka Glacier. In contradiction with downwasting of the Caucasus glaciers, Kolka continues to increase mass.

M.A. Vikulina published a paper on the history of research, including glaciological ones, was completed at the Khibiny educational and scientific base of the Geographical Faculty of MSU. Expeditionary work was carried out to study the dynamics of small forms of glaciation in the Khibiny Mountains:

- Vikulina M.A., *et al.* (2021). Moscow University's field station in the Khibiny Mountains, Russian Arctic: A 70-year history to the present day. *Polar Record*, 57(e10), 1-12. DOI: 10.1017/S0032247421000012.
- Vikulina M.A., Zimin M.V., and Romanenko F.A. (2021). Assessment of the state of minor glaciation in the Khibiny // InterKarto. *InterGIS*, 27(1), 409-417 p. (in Russian).

For more information contact Dmitry S. Drozdov (ds_drozdov@mail.ru).

SPAIN

BY MARC OLIVA (UNIVERSITAT DE BARCELONA), MIGUEL ÁNGEL DE PABLO (UNIVERSIDAD DE ALCALÁ), NURIA DE ANDRÉS & DAVID PALACIOS (UNIVERSIDAD COMPLUTENSE DE MADRID)

ACTIVITIES OF THE IPA-SPAIN GROUP

The second year of the COVID-19 pandemic has strongly influenced the research activities carried out by the different groups working on permafrost and periglacial processes in Spain. In contrast to previous years, field seasons were mostly focused in Iberian mountains (Pyrenees, Cantabrian Mountains, Sierra Nevada, Iberian Range, Central Iberian Range), although some researchers carried out research also in Antarctica. Despite these difficulties, there has been a fruitful cooperation between the different groups. Researchers from 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 have collaborated in different projects, along with other international centres.

In parallel, IPA-Spain members have started preparing the next European Conference on Permafrost that will be held in the heart of the eastern Pyrenees in June 18-22, 2023.

RESEARCH BY SPANISH GROUPS

Members of the Department of Geography at the University of Barcelona integrated within the Antarctic, Arctic and Alpine environments (ANTALP) Research Group have conducted research activities in the Central Pyrenees and Iberian System. The Arctic season that was expected to take place in July on Ellesmere Island, Canada was also cancelled because of COVID-19. ANTALP research included a field season in the Pallars Valley aiming at reconstructing the glacial and postglacial landscape evolution. The team collected tens of samples for cosmogenic dating purposes from glacial records (moraines, erratic boulders and polished surfaces) as well as from rock glaciers in order to better understand the origin, evolution, and stabilization of these permafrost-related features (Fig. 52). This work was complemented with an accurate geomorphological survey and map using UAVs.

The team also maintained the dataloggers installed in the rock glacier existing in the Besiberri valley, where the rock wall thermal regime was also examined. We also continued the long-term monitoring

Fig. 52. Rock glaciers in the Pyrenees.

of soil and air temperatures in high mountain environments in the Eastern Pyrenees, namely in Cerdanya area, including new sites for assessing the influence of microtopography and soil temperatures in the formation of earth hummocks (Fig. 53).

The High Mountain Physical Geography (GFAM) Research Group of the University Complutense of Madrid continues to date and search for the origin of rock glaciers formed during the Last Deglaciation. New research is being carried out in the relict rock glaciers of several mountain ranges of the Iberian Peninsula and in still active rock glaciers in Sierra Nevada (Spain) and the Tröllaskagi Peninsula (northern Iceland). This team plans to conduct several campaigns in 2022 on these active rock glaciers to investigate their origin and timing by applying methods such as 36Cl cosmic-ray exposure, Schmidt hammer

Fig. 53. Earth hummocks in La Feixa plateau.

and lichenometric dating, with high-resolution Digital Surface Models (DSMs), which will be obtained from historical aerial photographs and ground-view field photographs processed through Structure from Motion (SfM) photogrammetry. A research group of GFAM led by Dr. Jose Úbeda is working in collaboration with the Guías de Espeleología y Montaña, the Peruvian geological survey (INGEMMET), and other institutions on tropical permafrost research. Since 2010, two air and ground monitoring stations, at 5200 m asl are recording temperatures in the Coropuna and Chachani volcanoes (southern Peru; Fig. 54). This group is planning to incorporate new higher (6000 m asl) and deeper (10 m) stations during 2022 austral winter in both volcanoes.

The permafrost research team of the Alcalá University continued the maintenance of the TSP and CALM stations on the Livingston and Deception Islands, Antarctica, thanks to the resource support provided by the Spanish Polar Committee for maintaining the Antarctic temporal series. Members of the team were able to participate in the short Spanish Antarctic Season 2021 due to restricted COVID-19 limitations. During the fieldtrip, researchers downloaded data from the loggers and measured the active layer thickness in most of their monitoring sites (Fig. 55). This year they hired a graduate student examining the ground temperatures data from all the monitoring stations recorded between 2005 and 2021. In addition, the group continues to study Mars' environmental conditions as part of NASA's Curiosity mission, which contributes to the development of Mars2020 (NASA) and ExoMars (ESA) - the next missions to Mars.

Fig. 54. Air and ground temperature station at 5200 m asl in the Coropuna Volcano.

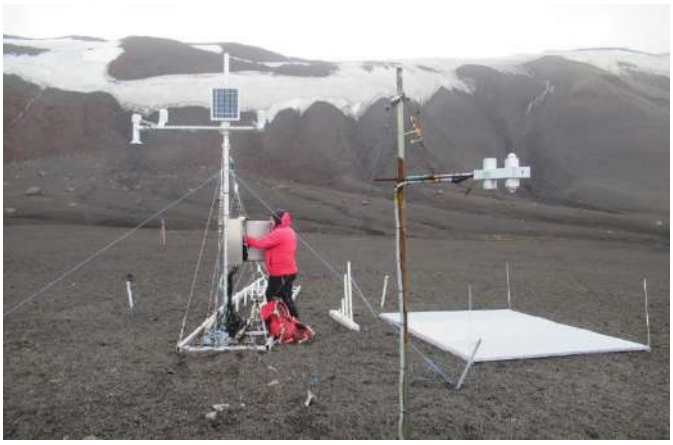


Fig. 55. Miguel Angel de Pablo fixing the instrumentation of the Snow Pack Analyser installed at the Crater Lake CALM site in Deception Island Antarctica (Feb. 2021).

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

SWITZERLAND

BY CÉCILE PELLET (UNIVERSITÉ DE FRIBOURG), DANIEL FARINOTTI (ETH ZURICH), ISABELLE GÄRTNER-ROER (UNIVERSITY OF ZURICH) CHRISTOPHE LAMBIEL (UNIVERSITY OF LAUSANNE) & MARCIA PHILLIPS (WSL SLF)

SWISS PERMAFROST MONITORING NETWORK

The Swiss Permafrost Monitoring Network (PERMOS) systematically documents 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), the Swiss Federal Office for the Environment (FOEN) and the Swiss Academy for Sciences (SCNAT) in collaboration with six research institutions in charge of data collection and maintenance of the field installations: ETH Zurich (ETHZ, D. Farinotti, L. Compagno, J. Beutel), the Universities of Fribourg (UNIFR, R. Delaloye, C. Hauck, C. Hilbich, M. Hoelzle, C. Mollaret, C. Pellet, D. Amschwand, J. Wee, J. Wicky, S. Morard), Lausanne (UNIL, C. Lambiel, S. Vivero), Zurich (UZH, I. Gärtner-Roer, A. Vieli, A. Cicoira), the WSL Institute for Snow and Avalanche Research (SLF, M. Phillips, J. Noetzli, R. Kenner, S. Weber) and the University of Applied Sciences and Arts of Southern Switzerland (SUPSI, C. Scapozza, C. Del Siro). The network is managed by the PERMOS Office (J. Noetzli and C. Pellet) who is in charge of the coordinating the monitoring activities, managing the data and disseminating the results to the research community and general public.

The monitoring strategy of PERMOS is based on field measurements of three complementing variables:

1. Ground temperatures at the surface and at depth;
2. Permafrost resistivity to assess changes in ground ice content; and
3. Rock glacier velocities.

In 2021, the network setup included 27 field sites: 22 near surface temperatures sites (236 loggers in total), 15 ground temperatures sites (29 boreholes total), 6 automatic weather stations, 5 permanently installed electrical resistivity tomography profiles, 15 rock glaciers amongst which 8 are equipped with permanent GNSS. Fieldwork took place in 2021; results show that the 2021 hydrological year was characterized by colder conditions at the surface and in the uppermost meters of the ground (colder GST and slower rock glacier velocities), whereas the permafrost temperatures at larger depth (~20 m) continued to increase. The results from the active layer thickness, temperature measurements at 10 m depth and electrical resistivities were heterogeneous depending on site specific processes/conditions. A more detailed overview of the results of the hydrological year 2021 is published in:

- PERMOS (2022). *Swiss Permafrost Bulletin 2021*. J., Noetzli, and C., Pellet (eds.), 3, 22 p. DOI: 10.13093/permos-bull-202.

Additionally, Noetzli *et al.* (2021) published best practice recommendations for borehole temperature measurements in mountain permafrost based on two decades of experience of the PERMOS group.

- Noetzli, J., *et al.* (2021). Best Practice for Measuring Permafrost Temperature in Boreholes Based on the Experience in the Swiss Alps. *Frontiers in Earth Science*, 9, 20 p. DOI: 10.3389/feart.2021.607875.

IPA ACTION GROUPS

Two IPA Action Groups led by University of Fribourg are currently ongoing. The IPA action group *Rock glacier inventories and kinematics (RGIK)* launched in 2018 is in its second phase. Since October 2021, it is supported by the GCOS Switzerland funded project RGIKS (R. Delaloye, C. Barboux, C. Pellet, T. Echelard, S. Vivero). The objectives of the Action Group are:

- To define community-based standard guidelines for inventorying rock glaciers, including indications on their activity rates;
- To promote rock glacier velocities as a new associated parameter to the ECV Permafrost and provide monitoring requirements and guidelines; and
- To establish an operational service (RGIKS) for the coordination, centralization and promotion of rock glacier observations.

In 2021, the Action Group published three baseline documents relative to rock glacier inventories, kinematics as an optional attribute of rock glacier inventory and rock glacier velocity. Currently the practical guidelines to implement the baseline concepts are being compiled. Additionally, in 2021, rock glacier velocity was officially adopted by GCOS and GTN-P as a new associated parameter to the ECV permafrost. The guidelines and recommendations of the

Action Group were used to define the product requirements. Learn more about the Action Group by subscribing to the mailing list on the webpage.

The Action Group *Towards an international database of geoelectrical survey on permafrost (IDGSP)* was launched in 2021 with the support of the GCOS Switzerland funded project REP-ERT (C. Hauck, C. Hilbich, C. Mollaret, C. Pellet). The objectives of the Action Group are:

- To create an international database centralizing geoelectrical surveys on permafrost;
- To develop community-based standards for the repetition and processing of geoelectrical surveys; and
- To support financially and strategically the repetition of legacy measurements.

A database has been setup (hosted at the University of Fribourg) that currently holds metadata from 240 profiles from 11 research groups. A call for geoelectrical metadata is open. In 2021, the Action Group supported two field campaigns and a call for financial support for 2022 is currently open. The Action Group is open to every researcher and can be joined by emailing ertdb@unifr.ch.

NEWS FROM RESEARCH PROJECTS & ACTIVITIES

In addition to monitoring mountain permafrost related parameters, the High Mountain Geomorphology group of the Institute of Earth Surface Dynamics, University of Lausanne (lead C. Lambiel), has worked on several projects. To increase our knowledge on the permafrost distribution in steep high mountain slopes, several ERT profiles were performed at the top of Mont Fort (3330 m asl) and at the Pointes de Mourti (3563 m asl) (Fig. 56). We also drilled two boreholes through the hanging glacier in the north flank of the latter summit to investigate the thermal regime of this type of glaciers (collaboration with L. Ravanel and F. Magnin, Université de Savoie, France). S. Vivero continued his PhD Thesis on rock glacier dynamics, using mainly UAV for the quantification of surface changes at very high resolution, with the objective of increasing our knowledge on rock glacier motion. We finalized the study on rock glacier kinematics in the Southern Alps of New Zealand using Sentinel-1 InSAR. We also continued our investigations on rock glacier hydrology, with the particular objective of identifying the origin of water emerging at the rock glacier fronts. Finally, Dr J. Mourey investigated how climate change impacts the mountaineering itineraries in the Valais Alps (Switzerland).

In parallel to the long-term monitoring of permafrost temperatures (M. Phillips) in cooperation with PERMOS and GTN-P (J. Noetzli), the WSL Institute for Snow and Avalanche Research SLF continues to investigate permafrost slope deformations, their kinematics and the processes controlling them using techniques such as terrestrial laser scanning and seismometers (R. Kenner, S. Weber, H. Horgan) (Fig. 57). The role of permafrost and water in large rock slope instabilities is investigated at selected sites in the context of the WSL CCAMM (Climate Change

Fig. 56. ERT survey in the north face of the Pointes de Mourti (3563 m asl). Photo: Christophe Lambiel.

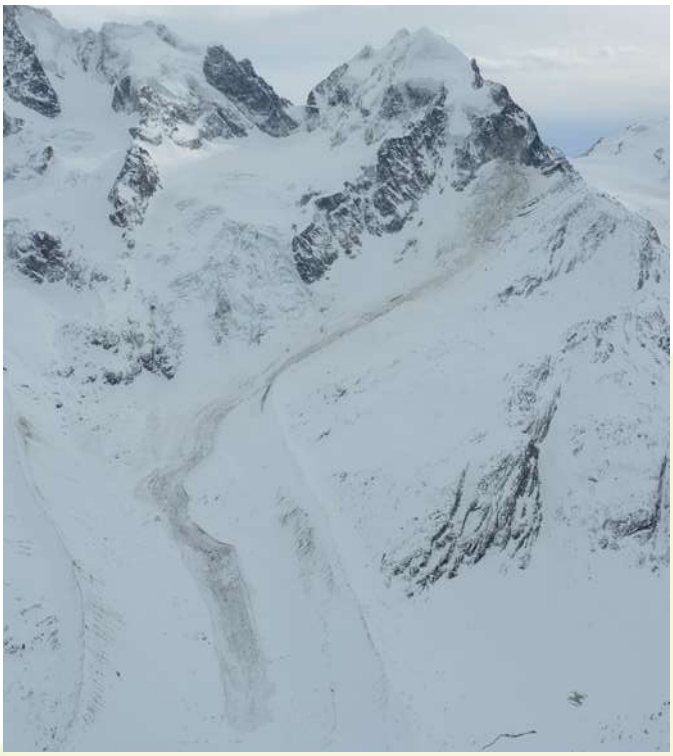


Fig. 57. Rock avalanche (90,000 m³) from a North facing permafrost rock wall at 3350 m asl on Piz Roseg in January 2021. The rock avalanche entrained snow and ice from the underlying glacier (Vadret dals Aguagliouls) and the ensuing mixture travelled 3.3 km. Photo: Marcia Phillips.

and Alpine Mass Movements) research program, using thermo-mechanical modelling (R. Kenner, S. Weber, M. Bazargan). The research group continues to investigate conditions leading to rock slope failure and to process chains when rock masses hit snow, ice or water. Rock fall events data are now available on PERMOS (J. Noetzli). Using cross-borehole ERT and piezometers, changing water contents are being monitored in ice-rich permafrost (M. Phillips, A. Bast, S. Weber). Mountain infrastructure stability and temperatures around structures are monitored in collaboration with various engineering companies. Together with biologists, we are investigating the emissions (microorganisms, gases, heavy metals etc.) from thawing permafrost ground and ice melt in the context of the WSL Extremes research program (C. Rixen, A. Udke, M. Zehnder).

At ETH Zurich, WSL Birmensdorf and SLF Davos (L. Pruessner, M. Huss, M. Phillips, and D. Farinotti), a doctorate dedicated to the evolution of ice-rich permafrost in Alpine terrain was successfully completed by L. Pruessner. The work investigated how long-term changes in subsurface temperatures can be modelled in a spatially distributed manner. The findings of site-specific investigations were integrated as a new module in the Glacier Evolution and Runoff Model (GERM). The model was then used in combinations with climate projections stemming from the so-called CH-2018 scenarios to estimate the evolution of both subsurface temperatures and water yields for three rock glaciers in the Swiss Alps. Conducted in the frame of WSL's Climate Change Impacts on Alpine Mass Movements (CCAMM) program, the project showed that even in very warm, dry summer months, the water contributions from these ice-rich permafrost features is expected to be minor when compared to catchment-wide runoff. The model can be anticipated to be of interest when conducting similar analyses in other regions of the planet.

Beside its commitment to the monitoring of rock glaciers within PERMOS (ground surface temperatures and kinematics at various sites, borehole Murtèl) and contributions to the IPA Action Group RGIK (lead at University of Fribourg), the University of Zurich started a new project on rock glaciers in Greenland (I. Gärtner-Roer, A. Vieli, A. Cicoira; in cooperation with J. Beutel, University of Innsbruck and T. Strozzi, Gamma). This project is funded by the Swiss Polar Institute (SPI) and focusses on rock glacier Dynamics on Disko Island (RockDynDisko) by providing first in-situ data on ground surface temperatures and surface displacements. With this study, we provide initial data from a region with special topo-climatic characteristics which is not yet covered in global rock glacier analyses.

Permafrost research in the Cryosphere & Geophysics research group at the University of Fribourg focuses on developing geophysical measurements and modelling techniques to quantify ground ice content and its temporal evolution. The so-called petrophysical joint inversion (PJI) scheme using electric and seismic data to quantify ground ice content, water content and porosity is being applied and developed by C. Mollaret, S. Morard in collaboration with F. Wagner/Aachen University. In 2021, C. Mollaret successfully completed her PhD thesis entitled *"Geophysical monitoring and joint inversion to improve the quantitative characterization of mountain permafrost"*. Spectral induced polarization (SIP) and Transient Electromagnetic (TEM) methods to quantify ground ice are explored within the swiss-german-austrian collaboration project SPICE by combining laboratory measurements (Uni Bonn, Germany) with field-based SIP and TEM surveys and monitoring (TU Vienna, Austria & Uni Fribourg, T. Maierhofer, A. Flores Orozco, C. Hilbich) in the Swiss and Italian Alps. The SNSF project MODAIRCAP (J. Wicky, C. Hauck) ended in 2021 and yielded the development of a 2D convective heat flow model capable of simulating the thermal effects of convective heat flow on coarse blocky permafrost terrain. In another project C. Koenig developed a 2D hydro-thermal model to simulate the future runoff characteristics of high-altitude sites in the Chilean Andes in the context of climate induced thawing of permafrost (in collaboration with BGC Engineering, Canada). A new project aiming at measuring and modelling tipping points in mountain permafrost systems using geophysical surveys and numerical modelling started in 2021 with a focus on the long time series in the Swiss Alps (S. Morard, C. Hauck). A project aiming at understanding the heat exchange through the coarse debris mantle to better predict the thermal evolution of the underlying permafrost in response to climate change started in 2020 and continues (D. Amschwand, M. Scherler, M. Hoelzle). Detailed energy balance and heat flux have been continuously measured since 2020 at the surface and within the debris mantle of the Murtèl rock glacier. In 2021, T. Mathys started her PhD thesis with a project aiming at (re-)establishing the monitoring of cryospheric-variables in central Asia (M. Hoelzle, C. Hilbich). More specifically, the permafrost distribution and its ice content are investigated at catchment scale using geophysical surveys and numerical modelling.

The Alpine Cryosphere and Geomorphology research group focuses on investigating the dynamics of permafrost related landforms in mountain environment and their geomorphic context. The research group surveys the dynamics of over 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 ESA (European Space Agency) Permafrost CCI (Climate Change Initiative) project, promoting the integration of mountain permafrost in worldwide overviews of permafrost state and evolution (C. Barboux, C. Pellet, R. Delaloye). J. Wee continued her PhD thesis on the topic of glacier forefields in mountain permafrost environments. She characterizes and analyses the changes within these systems using a combination of photogrammetry techniques, in-situ geophysics and geodetic surveys (Fig. 58).

Fig. 58. Terrestrial geodetic survey on a rock glacier in the Turtmann Valley, Switzerland (oct. 2021). Photo: Isabelle Gärtner-Roer.

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

UNITED STATES OF AMERICA

BY U.S. PERMAFROST ASSOCIATION (USPA)

OVERVIEW

The U.S. Permafrost Association (USPA) is a professional membership organization and currently consists of over 350 individual scientists, engineers, students, agencies, university departments, institutes, and corporate members. The Association was formed in 2001, and formally organized with its first Board of Directors in 2002; thus, 2022 will be the Association's 20th Anniversary. The mission of the Association is to provide a forum for the U.S. permafrost engineering and science community and to provide input reflecting the views of Association members to the International Permafrost Association. The USPA also promotes the Permafrost Young Researchers Network (PYRN), including representation on the Association's 13-member Board of Directors and support of various PYRN activities. Activities of the Board of Directors and Association committees are related to education, communications, membership support, and public outreach.

THE YEAR IN REVIEW

The Annual Meeting of the U.S. Permafrost Association (USPA) was held virtually on 9th December 2021, due to COVID-19 safety concerns. Participating in the meeting were approximately 25 members including Board members and Committee chairs. Results of the Board of Directors elections were announced. Anna Wagner was elected to President-elect and John Thornley assumed the Presidency. New Board members are Eva Stephani, Treasurer, and Michael Lilly, Member-at-Large. Molly McGraw replaced Susan Wilson as Secretary in 2021. Continuing on the Board are Cathy Wilson, as Past-President; Peppi Croft, newly elected as Member-at-Large, and Jessica Ernakovich and Michelle Walvoord as Members-at-Large. Kevin Schaefer and Edward Yarmak, continue as U.S. Representatives to the Council of the International Permafrost Association (IPA) and Fritz Nelson as representative of the IPA Executive Committee. These latter three attended the earlier virtual IPA Council meeting in June 2021. Helena Bergstedt, stepped down as PYRN Board Member, and Emma Lathrop was nominated by PYRN and then accepted by the BOD to be Helena's replacement on the Board. Torsten Mayrberger completed his term on the Board and his dedicated services, as well as those of Helena Bergstedt and Susan Wilson, are gratefully acknowledged.

The USPA and the American Society of Civil Engineers (ASCE) jointly convened the IPA 2021 Regional Conference on Permafrost (RCOP) and 19th International Conference on Cold Regions Engineering (ICCRE) on October 24-29, 2021. Due to the ongoing COVID-19 pandemic, the organizers chose an all-virtual meeting platform. Of the 416 registered participants from 20 countries, 237 were from the United States and 98 from Canada. A total of 280 plenary, oral, and poster presentations took place over the four days. PYRN held its annual meeting the day prior to the opening ceremonies. It included presentations and breakout meetings on proposal writing, science communication, and work-life balance; four awards were made for best oral and poster presentations. The ASCE's Cold Regions Engineering Division under the leadership of Jon Zufelt, published a special conference volume of 34 papers. USPA thanks the conference sponsors for their added support.

- Zufelt, J. (2021). *Permafrost 2021: Merging Permafrost Science and Cold Regions Engineering*. In: Proceedings of the 2021 RCOP and the 19th ICCRE, Online, 24-29 October 2021. American Society of Civil Engineers (ASCE), 381 p.

Alaska Senator Lisa Murkowski opened the conference with a video presentation followed by Larry Hinzman of the White House Office of Science and Technology Policy. Other plenary presentations included the Eb Rice Lecture *"Tears of a Rapper: The Science and History behind the Art of Frozen Debris Lobe Rap Videos"* by Margaret Darrow and *"Perspectives on Climate Change: On-the-Ground Impacts of Climate Change in Arctic Communities"* by Darcy Peter of the Woodwell Climate Research Center. Jerry Brown received the IPA Lifetime Achievement Award presented by IPA President Chris Burn with Fritz Nelson providing a tribute on Jerry's career accomplishments. The ceremonies included a tribute to Art Lachenbruch (1925-2021) and acknowledgement of other deceased members of our permafrost community.

The following are brief reports from the Association's standing committees. The more comprehensive Annual Report including organizational reports will be available on the website in the near future.

The USPA Diversity, Equity and Inclusion (DEI) Committee is currently composed of nine USPA members, with newly appointed co-chairs Jessica Ernakovich and Bob Bolton. In 2021, the DEI group met 10 times and discussed and worked on several potential DEI initiatives, including finalizing the USPA DEI statement. The DEI Committee initiated background education through the Unlearning Racism in the Geosciences (URGE) curriculum - including setting "ground rules" on how we interact with each other during our committee meetings. We ended the year by preparing a survey of the USPA membership (to be distributed in early 2022) to learn more about USPA membership needs and to prioritize our DEI-focused activities in 2022. If you would like to join or participate in the DEI Committee, contact Bob Bolton (wrbolton@alaska.edu).

The Membership Committee (MCOM), chaired by Jerry Brown, reported that in 2021, USPA gained three Corporate members, two Institutional members, two Lifetime members and one Sustaining member. USPA membership increased from a mid-summer level of approximately 200 paid members to the end-of-year total of 350 members (Fig. 59). This increase was mainly due to registration for the 2021 RCOP that offered, by becoming a member, a reduced conference registration fee. Of this total, 257 members are from the U.S. representing over 50 universities, 10 federal and state agencies, and 20 private organizations from 36 States. International membership is represented by 17 countries, with Canadian membership numbering 55 and Germany 13. Approximately 100 USPA members belong to PYRN. MCOM will meet early in 2022 to review much needed updates to the Committee charter, update Committee membership, and plans for its role in the USPA's 20th anniversary activities.

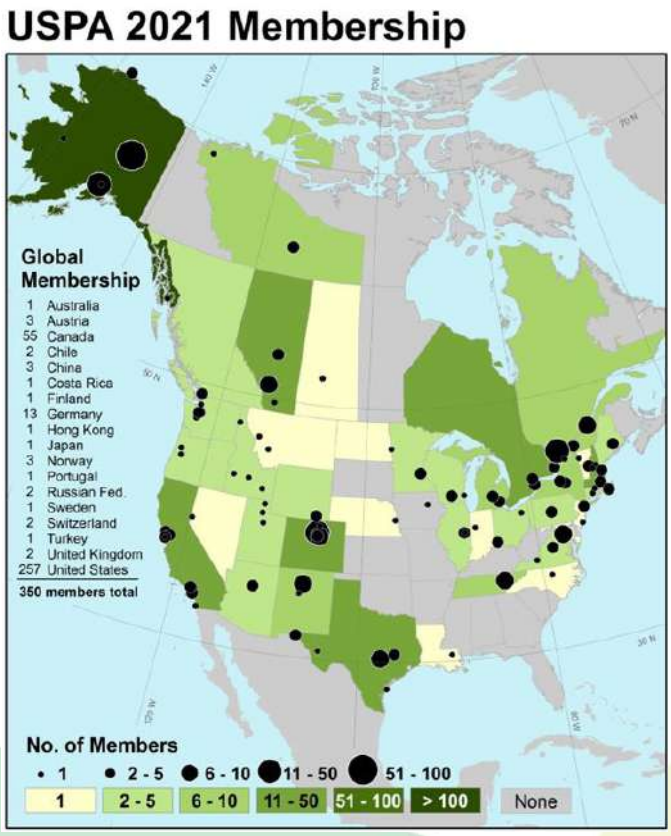


Fig. 59. Geographic diversity of USPA 2021 membership. Map prepared by Kelsey Nyland, George Washington University.

The new MemberClicks membership management service was initiated in August and used for RCOP registration and for on-going membership updates and maintenance, including these end-of-year statistics. The Membership Committee, on behalf of the Association, extends its appreciation to Peppi Croft, former Treasurer, for her services related to the initial MemberClicks developments and the new USPA web site, and to former Secretary Susan Wilson whose prior support provided the Committee and the USPA membership with many much-needed services.

The Communications Committee (CCOM), chaired by Michael Lilly, coordinates with the American Geosciences Institute (AGI) to provide the monthly catalog of world-wide, permafrost literature. In 2021 the twelve-monthly issues of Permafrost Monthly Alert (PMA) added 561 accessions. With the transfer of PMA to the new website, PMA content inquiries (views by individual readers) are no longer available. The number of annual PMA content viewers were approximately 13,000 in 2020. Other Committee activities included postings of relevant information on Facebook, Twitter, and Instagram and assisted by Julian Dann, Oliver Frauenfeld, and Michael Lilly. For the fourth consecutive year, committee member Kristina Levine, student at Texas A&M University and supported by GW Scientific, took the leadership in preparing the compilation of permafrost-related presentations for the 2021 AGU Fall Meeting. The 344 abstract compilation was made available to the USPA membership prior to Fall Meeting. Among those presenting were 67 USPA members including 24 PYRN members. After many years of service to the Committee Oliver Frauenfeld is retiring from the Committee. Many thanks for his past contributions.

The PYRN Educational Fund (UPEF) Committee was taking a break from its prior active years. The Chair, Kelsey Nyland stepped down due to other commitments, and her past services to USPA and the UPEF are gratefully acknowledged, including her assistance in preparing the attached 2021 membership map.

The USPA is happy to announce that our new PYRN representative, Emma Lathrop, has accepted the additional role of UPEF Chair.

The Public Relations Committee, chaired by Peppi Croft, was established in mid-2021. The committee's primary goal was the promotion of the 2021 RCOP, the development of RCOP sponsors, and the launch and operation of the new USPA website and web-based services. It is also tasked with the promotion of the USPA mission, goals, and activities. The committee works in coordination with other committees to provide USPA promotion and awareness for consistent image and messaging to membership, sponsors, partners, and other organizations and associations. Current committee members include Peppi Croft, Cathy Wilson, Kevin Schaefer, and Julian Dann.

The Association thanks its past and new Corporate and Institutional members, sponsors and donors for their continued involvement and generous support.

The extended 2021 USPA Annual report will include individual member reports and be made available on the USPA website on its release.

In addition to individual members, 2021 USPA membership included the following Institutional and Corporate Members.

Institutional Members:

- American Geosciences Institute
- Geophysical Institute Permafrost Laboratory, UAF
- International Arctic Research Center, UAF
- Institute of Northern Engineering-Water and Environmental Research Center (WERC), UAF
- University of Colorado, National Snow and Ice Data Center (NSIDC)
- University of Maine, School of Earth & Climate Sciences
- University of Virginia, Dept. of Env. Sciences
- U.S. Arctic Research Commission
- Woodwell Climate Research Center

Corporate Members:

- Alaska Ecoscience
- ABR Inc.
- Arctic Foundations (Life member)
- Syngen
- Golder Associates
- GW Scientific, Inc.
- Onset Computer Corporation
- Northern Geotechnical Engineering
- PND Engineers Inc.
- R&M Consultants Inc.
- Ukpeagvik Inupiat Corporation Services

Non-member organizations and networks that report annually include:

- Alaska Dept. of Natural Resources, Div. of Geological & Geophysical Surveys
- American Society of Civil Engineers (ASCE)
- Oak Ridge National Laboratory
- U.S. Army Cold Regions Research and Engineering Laboratory
- U.S. Geological Survey
- George Washington University
- Michigan State University
- Penn State University
- Stockton University
- University of Alaska Anchorage, Dept. of Civil Engineering
- University of Alaska Fairbanks, Alaska Geobotany Center
- University of New Hampshire - UNH Arctic
- Permafrost Carbon Network
- Permafrost Young Researchers Network (PYRN)
- Permafrost Collaboration Team

Sponsors of RCOP included: AFI, Geo-Watershed Scientific, PND Engineers, Golder Associates, BGC, Campbell Scientific, Woodwell Climate Research Center, CRW Engineering Group, Beadedstream, Cryogeeks, NSIDC, Stantec.

IN MEMORIAM

We recognize those engineering and science permafrost leaders that helped form our community foundation. Knowing our past will help guide our future.

- Arthur Lachenbruch (1925-2021)
- Tingjun Zhang (1956-2022)

For more information contact Ed Yarmak (eyarmak@arcticfoundations.com) and Kevin Schaefer (kevin.schaefer@colorado.edu).