

3rd ASIAN CONFERENCE ON PERMAFROST

ACOP

2026

28 June - 2 July / MONGOLIA /



PROGRAM & PROCEEDINGS



3rd Asian Conference
On Permafrost



The International Permafrost
Association



Institute of Geography and
Geoecology of Mongolian
Academy of Sciences



Mongolian Permafrost
Association



Northwest Institute of
Eco-Environment and Resources
of Chinese Academy of Sciences



3rd ASIAN CONFERENCE ON PERMAFROST

ACOP

Program & Proceedings of the ACOP 2026
Coordinators: Institute of Geography and Geoecology of Mongolian
Academy of Sciences
Mongolian Permafrost Association

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Welcome to ACOP 2026



Dear honoured guests, dear colleagues and friends from all around the world,

We are delighted to welcoming you to the 3rd Asian Conference on Permafrost (ACOP), which brings us to Mongolia! The fact that you all contribute to this meeting and travel to Ulaanbaatar, underlines the global significance of our exchange. It also reflects the developments of permafrost research in Mongolia and its important role for the IPA and will be a major opportunity to highlight on the developments of permafrost research and engineering in Asia.

Organizing this conference was a major undertaking, but we all know that it was worth it. We are incredibly grateful to our Mongolian and Chinese colleagues for making this conference possible and bringing us to Ulaanbaatar. A special thank you goes to the organizing team, partners, and sponsors who have made this outstanding event possible.

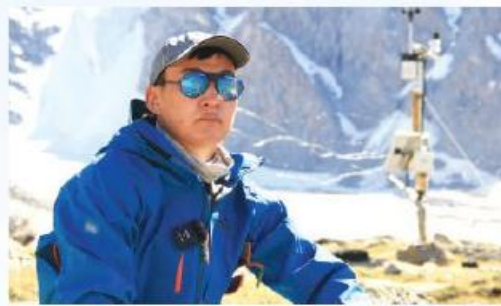
We gather here as a community dedicated to permafrost: scientists, engineers, local and international stakeholders, and early-career researchers, united by the curiosity and mandate to investigate and understand our changing permafrost environments.

Over the coming days, we will dedicate ourselves entirely to permafrost, its changes and related impacts. We will share cutting-edge research, debate engineering solutions for infrastructure in warming ground, hear about education and outreach projects, and learn directly from the Indigenous and local communities, who are those more immediately affected by permafrost changes in their daily lives.

Our goal is to get new insights, share ideas, and develop innovative solutions for the challenges of our times. We are aiming at bridging the gap between science and engineering, and also to bring science into practice and influence policy.

We encourage you to actively engage in the sessions, poster halls, and field trips. Let this conference be a space for new ideas, networking, and collaborative action. Thank you for bringing your expertise and passion to this important event.

Isabelle Gärtner-Roer and Gonalo Vieira,
Co-Presidents of the IPA



Dear distinguished guests, esteemed colleagues, and members of the international permafrost community,

On behalf of the Organizing Committee, Institute of Geography and Geoecology of Mongolian Academy of Sciences, and Mongolian Permafrost Association, it is my great honor to welcome you to the 3rd Asian Conference on Permafrost (ACOP) 2026 in Ulaanbaatar, Mongolia.

Since its inception in Lanzhou in 2006 and its continuation in Sapporo in 2017, ACOP has become a vital platform for advancing permafrost science and fostering international collaboration. Today, we continue this tradition in Mongolia under the theme: “Challenges Posed by Asian Permafrost Thaw to the Global Community.”

Permafrost degradation affects ecosystems, water resources, infrastructure, carbon cycling, and livelihoods, with consequences extending far beyond permafrost regions. Addressing these challenges requires strong international cooperation and evidence-based solutions.

Asia hosts remarkably diverse permafrost environments—from Siberia and the Tibetan Plateau to the mountains of Mongolia and Central Asia—offering unique opportunities for comparative and interdisciplinary research.

During ACOP 2026, more than 300 participants from 24 countries will exchange knowledge through 17 thematic sessions covering field observations, experiments, remote sensing, and modeling. As the future of permafrost science depends on the next generation of researchers and our collective efforts, I am especially pleased that ACOP 2026 places strong emphasis on supporting early-career scientists, facilitating exchanges with leading experts in the field, and fostering international collaboration.

We extend my sincere gratitude to the International Permafrost Association, conveners, reviewers, speakers, sponsors, partners, and volunteers for making this conference possible.

I wish you productive discussions, new collaborations, and an inspiring stay in Mongolia.

Welcome to ACOP 2026, and welcome to the Land of the Eternal Blue Sky, Mongolia.

Dashtseren Avirmed
Chair, ACOP 2026

Conference Venue

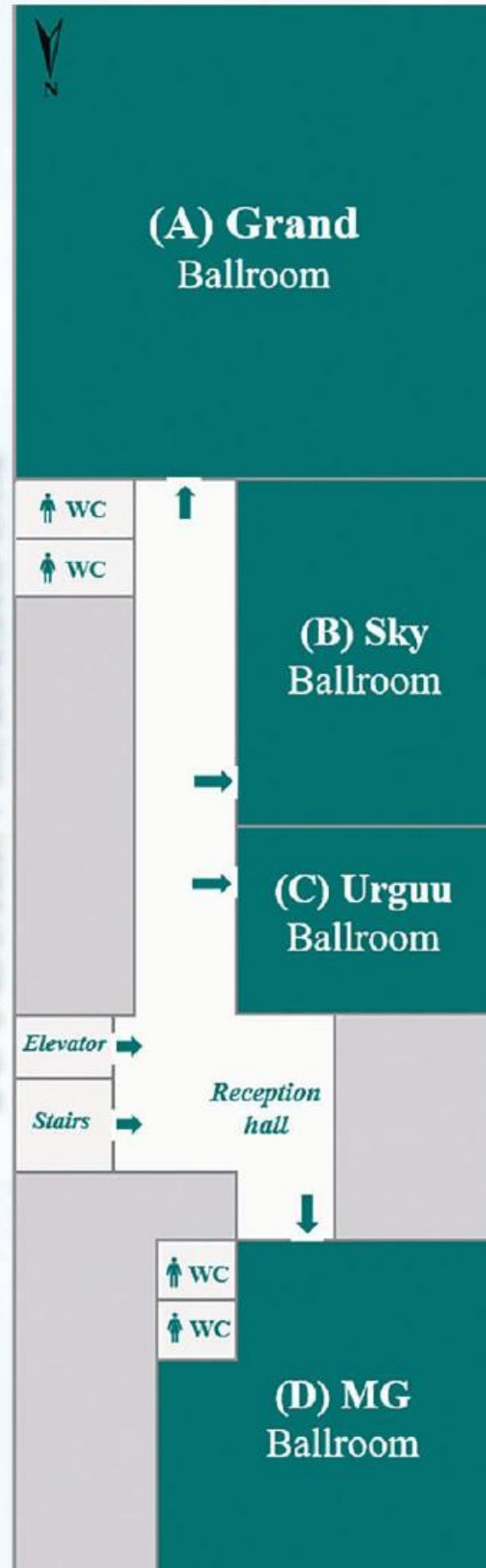
Galleria, Ulaanbaatar



The conference will be held in the **Juulchin Ballroom** on the 3rd Floor of Galleria Ulaanbaatar, located in the heart of Ulaanbaatar, Mongolia.

The **floor plan shows** the locations of the conference rooms and ballrooms to help participants navigate the venue. Additional information and assistance will be available at the venue throughout the conference. For more information visit www.galleriaub.mn.

JUULCHIN BALLROOM





General Information

BANK

The nearest bank is Khan Bank, located on the 2nd Floor of Galleria Ulaanbaatar Shopping Center, Sukhbaatar District, 8th Khoroo, Ulaanbaatar 14200, Mongolia. Additional banks and ATMs are also available throughout the city center.

POSTAL SERVICE

Visitors who wish to send postcards, letters, or small parcels can use the services of Mongol Post, Mongolia's national postal service. Postcards and stamps are available at souvenir shops and post offices. Mail can be sent directly from the Central Post Office or deposited in public postal boxes located throughout the city. [Sukhbaatar Square - 9, 1st Khoroo, Chingeltei District,

PHARMACY

There is several pharmacy in Ulaanbaatar. The closest ones from the ACOP are: Monos [Sukhbaatar Square Street Confederation of Mongolian Trade Union, Chingeltei District - 1 khoroo, Ulaanbaatar 15160] or Pharmacie du Bionica [SBD - 8 khoroo, Ulaanbaatar 14200].

CONFERENCE SUPPORT & ASSISTANCE TEAM

Participants are encouraged to contact the Support Team before and during the conference for any assistance related to their stay in Ulaanbaatar.

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WEBSITE LINK

You can have an overview of the main informations about the ACOP on the website [<https://event.fourwaves.com/acop2026/pages>]



WIFI

Name: Juulchin Ballroom

Password: 75091144

Name: Mg_guest

Password: 75055551

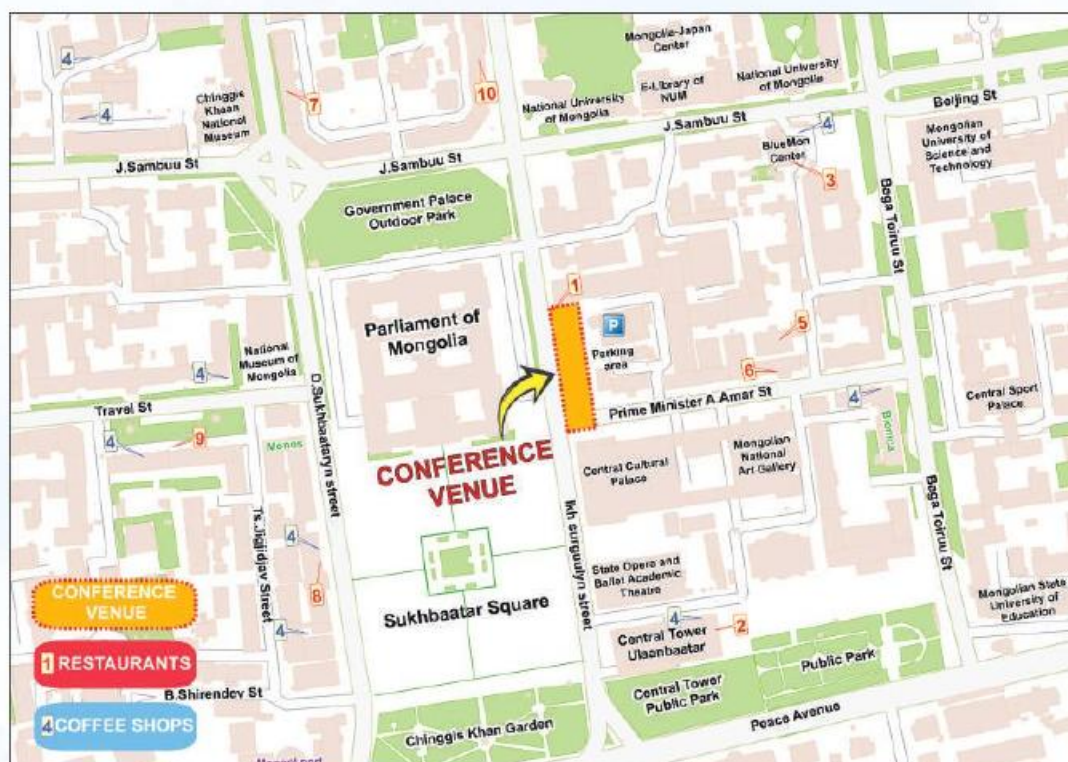
BUS

Ulaanbaatar's public bus system provides convenient access throughout the city. Visitors can use the UBCARD mobile application, available in English, to view real-time bus locations, search routes, find nearby bus stops, and plan journeys.

For more information about public transportation in Ulaanbaatar, please visit: <https://ubcard.mn>

SHOPPING & RESTAURANTS

The map below highlights the conference venue and nearby shopping and dining destinations in central Ulaanbaatar. Galleria Ulaanbaatar, Central Tower, and BlueMon Center offer a variety of restaurants, cafés, retail stores, banking facilities, and other services within walking distance of the venue.



1. Galleria ulaanbaatar shopping center

Galleria Ulaanbaatar offers a wide range of shopping, dining, and lifestyle services, including Mongolia's largest cashmere store, souvenir shops, cafés, restaurants, international retail brands, and well-known food and beverage outlets such as KFC, Pizza Hut, and Subway.

2. Central tower ulaanbaatar

Central Tower Ulaanbaatar hosts a diverse selection of dining establishments, including Asian and international restaurants, specialty ramen restaurants, cafés, and bakeries, such as Asiana Restaurant, Biwon Restaurant, Akamaru Ramen, Makotoya Ramen, Quartz Restaurant, Alfie Restaurant, Paul Bakery, Coffee Fellows, Coffee Namu, and Lavazza.

3. Bluemon center

BlueMon Center hosts a diverse selection of dining establishments, including The Bull Hot Pot Restaurant, Sura Korean Restaurant, Tse Pub, Shulundu Fast Food, Buuzger Chain Restaurant, Dessert39, and Pepper Lunch.

4. Coffee Shops & Convenience Stores:

Tom N Toms Coffee, Caffé Bene, CU, GS25, and other nearby outlets offering refreshments, light meals, snacks, and daily necessities.

5. Agnista vegan restaurant

Prime Minister A. Amar Street, 8th Khoroo, Sukhbaatar District, Ulaanbaatar 14200, Mongolia

Tel: +976 7733 3636

6-7. Modern Nomads Restaurant

Prime Minister A. Amar Street, east side of Best Western Premier Tuushin Hotel, 8th Khoroo, Sukhbaatar District, Ulaanbaatar 14200, Mongolia

Tel: +976 7012 0808

8. Broadway Restaurant

UB City Government, D.Sukhbaatar Street, 1st Khoroo, Chingeltei District, Ulaanbaatar 15160, Mongolia

Tel: +976 70107878

9. Route 22 Restaurant & Wine Lounge

Tourist Street 1st khoroo 15160, CHD - 1 khoroo, Ulaanbaatar 15160, Mongolia

Tel: +976 7707 4705

10. Le Bistrot Francais

Ikh Surguuli St 2, SBD - 6 khoroo, Ulaanbaatar 14200, Mongolia

Tel: + 011320022



Workshops & Side Meetings



PYRN Early Career Researcher Workshop

Sunday, 28 June 2026, 09:00–17:00 /// Room (B) Sky Ballroom

Organized by the Permafrost Young Researchers Network (PYRN), the Early Career Researcher (ECR) Workshop provides a dedicated forum for students and early-career scientists to exchange ideas, build professional networks, and engage with researchers from across the international permafrost community. The workshop combines invited presentations, interactive networking activities, career development discussions, and practical training sessions designed to strengthen both scientific and professional skills. Participants will have opportunities to discuss fieldwork experiences, scientific communication, interdisciplinary collaboration, and emerging challenges in permafrost research. The workshop aims to foster long-term collaboration and support the next generation of permafrost scientists.



RGIK Side Meeting

Sunday, 28 June 2026, 10:00–12:00 /// Room (C) Urguu Ballroom

Meeting of the Rock Glacier Inventories and Kinematics (RGIK) Standing Committee of the International Permafrost Association (IPA).

This side meeting provides an opportunity for participants to learn about the objectives, mission, and organizational framework of RGIK as it transitions into its operational phase. The session will introduce key tools, standardized guidelines, best practices, and ongoing working-group activities related to rock glacier inventories and kinematics. Discussions will focus on aligning regional inventory efforts with global standardization and synthesis goals, while strengthening collaboration within the Asian rock glacier research community. Participants will also have the opportunity to exchange experiences and contribute to future regional and international initiatives through a round-table discussion.



GTN-P Workshop

Sunday, 28 June 2026, 14:00–18:00 /// Room (C) Urguu Ballroom

Organized by the Global Terrestrial Network for Permafrost (GTN-P), this workshop brings together researchers, monitoring specialists, and institutional representatives involved in permafrost observation and data management across Asia. The programme includes regional presentations on permafrost conditions and monitoring activities in Mongolia, Siberia, the Tibetan Plateau, and the Hindu Kush–Himalayan region, together with discussions on the GTN-P Data Platform, data availability, monitoring techniques, and regional collaboration. Interactive breakout sessions will provide opportunities to exchange experiences and explore strategies for strengthening permafrost observation networks and data-sharing structures throughout Asia.

Early Career Researcher Activities



PYRN–IPA Early Career Researcher Workshop

Sunday, 28 June 2026, 09:00–17:00 /// Room (B) Sky Ballroom

Organized by the Permafrost Young Researchers Network (PYRN), this full-day workshop provides a dedicated forum for students and early-career researchers to engage with members of the international permafrost community. The programme includes invited presentations, networking activities, breakout discussions, and training sessions focusing on scientific communication, career development, interdisciplinary collaboration, and emerging challenges in permafrost research. The workshop aims to strengthen professional networks and support the development of future leaders in permafrost science.

FrostBytes – “Soundbytes of Cool Research”

All ACOP 2026 participants are encouraged to prepare a short video presentation introducing their research. FrostBytes provides an opportunity to communicate scientific findings to a broader audience through concise and engaging presentations. Submitted videos will be made available online following the conference, and outstanding contributions will be recognized during the conference closing events.

PYRN – IPA ACOP Grants

The Permafrost Young Researchers Network (PYRN), with support from the International Permafrost Association (IPA), provides financial assistance opportunities for eligible Early Career Researchers presenting oral or poster contributions at ACOP 2026. The programme aims to increase participation, promote international collaboration, and encourage scientific excellence among emerging researchers in permafrost and cold-region sciences.

Networking and Professional Development

Throughout ACOP 2026, Early Career Researchers will have opportunities to interact with internationally recognized scientists, participate in scientific discussions, build professional networks, and explore future research collaborations. These activities are designed to promote knowledge exchange, mentorship, and long-term engagement within the global permafrost community.



Travel Grants and Financial Support

Travel Grants

To promote broad international participation, ACOP 2026 offered travel grants to support students, Early Career Researchers (ECRs), and delegates from developing countries. A total of USD 10,000 in travel grant funding has been secured by the ACOP 2026 Organizing Committee. A total of 22 applicants have been selected to receive travel grants through this programme. The travel grant programme aims to reduce financial barriers to conference attendance and encourage wider participation in permafrost research and collaboration across Asia and beyond.

Financial Support

The Organizing Committee of the 3rd Asian Conference on Permafrost (ACOP 2026) expresses its sincere gratitude to the Mongolian National Foundation for Science and Technology, the National Forest Agency of the Government of Mongolia, Geocryo LLC, and the Unitel Group for their generous financial support. Their valuable contributions have been instrumental in the successful organization of ACOP 2026 and in promoting international scientific collaboration and knowledge exchange within the global permafrost research community.



Through the “Let It Be Green” program, Unitel Group implements environmental conservation initiatives that help protect ecosystems, reduce environmental impact, support sustainability, and strengthen collaborative partnerships.

Watering Ponds

Constructing artificial watering ponds to improve water availability for wildlife in arid and semi-arid ecosystems and support surrounding vegetation.

2021–2024: 71 watering ponds established across 21 specially protected areas in Mongolia. Monitoring by local rangers has recorded use by threatened and endangered species, including snow leopards, khulan, black-tailed gazelles, and Siberian ibex.



Bird Nests

Supporting ecosystem balance by installing artificial nesting platforms for birds of prey, natural predators that help regulate rodent populations and reduce pressure on grassland ecosystems. Piloted in 2022 in Bagakhangai District, Ulaanbaatar, where monitoring has shown an inverse relationship between nest occupancy by birds of prey and local rodent abundance. In 2025, baseline studies were conducted in additional suitable habitats, and the project was expanded to rural areas in partnership with a local conservation NGO.



Green Grove

Supporting urban ecosystem restoration while fostering environmental stewardship among employees through annual tree-planting activities at the Chingeltei Complex. Between 2021 and 2024, employees planted 7000, contributing to the establishment and expansion of a dedicated green grove.

To support the long-term survival and growth of the planted trees, a deep-water well was constructed to provide a reliable irrigation source.





3rd ASIAN CONFERENCE ON PERMAFROST

28 June - 2 July / MONGOLIA /



3rd ACOP 2026

“Challenges Posed by Asian Permafrost Thaw to the Global Community”

ACOP 2026 Organizers



Institute of Geography and Geoecology of Mongolian Academy of Sciences



Mongolian Permafrost Association

ACOP 2026 Co-organizer



Northwest Institute of Eco-Environment and Resources of Chinese Academy of Sciences



24

Countries



17

Thematic Sessions Covering Permafrost Science



20

Selected Papers to be published in Permafrost and Periglacial Processes



4

Scientific Field Excursions
Local field trip, Khurkh-Khuiten valleys, Khovsgol and Khangai mountainous trip, Altai Mountains trip

By attending the 3rd ACOP in 2026, you will have the opportunity to share your scientific findings on permafrost and its interactions with natural systems and human societies. As the Asian continent encompasses a wide variety of permafrost types, the conference will provide a platform to present and compare research from across the globe, from field observations to remote sensing and model-based studies. The conference will explore the challenges faced in permafrost regions and define future perspectives to support international and governmental policies and programs.

PARTNERS



The International Permafrost Association



Office of The President of Mongolia



Ministry of Economy and Development



Wildlife science and conservation center of Mongolia



United Nations Educational, Scientific and Cultural Organization



National University of Mongolia



Sub-Assembly of Geography, Geography & Environment of Mongolian Academy of Sciences



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WELCOME TO MONGOLIA – THE LAND OF THE ETERNAL BLUE SKY



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Dr. Anarmaa Sharkhuu, Professor of Department of Biology, National University of Mongolia, Mongolia

Dr. Guoyu Li, Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, University of Chinese Academy of Sciences, China

Advisory Committee

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Prof. Gonçalo Vieira, IPA President, Professor at University of Lisbon, Institute of Geography and Spatial Planning, Portugal

Sc.D. Demberel Sodnomsambuu, President of Mongolian Academy of Sciences, Mongolia

Dr. Jambaljav Yamkhin, IPA representative of Mongolia, Chairman of Mongolian Permafrost Association, Director of Geocryo LLC, Mongolia

Dr. Fujun Niu, IPA Vice-President, Professor at School of Environmental and Geographical Sciences, Shanghai Normal University, China

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Prof. Antoni G. Lewkowicz, Environment and Geomatics University of Ottawa, Canada

Dr. Bernd Etzelmüller, University of Oslo, Norway

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National Organizing Committee

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MSc. Maralmaa Ariunbold, Researcher, Division of Permafrost Research, Institute of Geography and Geoecology, Mongolian Academy of Sciences, Mongolia

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BSc. Tsend-Ayush Tserentogtokh, Researcher, Division of Environmental and Natural Resource Management, Institute of Geography and Geoecology, Mongolian Academy of Sciences, Mongolia

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Sc.D. Dashjamts Dalai, Professor of Mongolian University of Science and Technology, Mongolia

Dr. Batkhoo Nyam-Osor, Professor of Forest Environmental Sciences at the National University of Mongolia

Dr. Munkhjargal MunkhDavaa, Scientist at Millennium Challenge Account - Mongolia



Session Chairs:

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- Alexander Fedorov
- Alberto Carrera
- Ayumi Kotani
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- Ylva Sjöberg
- Yoko Kugo
- Yoshihiro Iijima
- Youhua Ran
- Yunfa Miao
- Zhaohui (Joey) Yang
- Ulambayar Ganbold

Social Events



Group Picture

(A) Grand Ballroom

Monday, 29 June 2026, 09:10–09:30

The official ACOP 2026 Conference Group picture will be taken in the Grand Ballroom of Galleria Ulaanbaatar. This picture will serve as a lasting record of the participants attending the 3rd Asian Conference on Permafrost and the international permafrost community gathered in Mongolia. All participants are kindly invited to attend and are requested to arrive promptly at the designated time.



Ice-Breaking Reception

Niche Tuul Garden

Monday, 29 June 2026, 18:00–21:00

The Ice-Breaking Reception provides participants with an informal opportunity to meet colleagues, establish new professional connections, and engage with members of the international permafrost community prior to the continuation of the scientific programme.



Chinggis Khaan National Museum Visit

Northwest of Sukhbaatar Square, Ulaanbaatar, Mongolia.

Wednesday, 1 July 2026, 15:20–17:00

Participants will visit the Chinggis Khaan National Museum, offering an opportunity to explore Mongolia's rich history, cultural heritage, and national identity.



Equestrian Statue of Chinggis Khan /Tsonjin Boldog/

Erdene Soum, Töv Province, Mongolia

Thursday 2 July 08:30–16:00

Located approximately 54 km east of Ulaanbaatar, the Chinggis Khaan Equestrian Statue Complex is one of Mongolia's most visited landmarks. The 40-meter-tall stainless-steel monument honors Chinggis Khaan and offers visitors an opportunity to explore Mongolia's history, culture, and nomadic heritage through its museum and exhibition facilities.



Conference Banquet

(A) Grand Ballroom

Thursday, 2 July 2026, 18:00–21:00

The Conference Banquet offers participants an opportunity to celebrate the successful completion of ACOP 2026 while enjoying Mongolian cuisine, cultural performances, and informal networking with colleagues from around the world. The event provides a memorable setting for strengthening professional relationships and fostering future collaborations within the international permafrost community.



Plenary Session I

Monday 06/29 | 09:30 - 10:00 // Keynote Speaker



Dashtseren Avirmed
(A) Grand Ballroom
Institute of Geography and
Geoecology of Mongolian
Academy of Sciences, Mongolia

Marginal Permafrost in Mongolia under Climate Change: Implications for Environmental Resources and Processes

Dr. Dashtseren Avirmed is a Mongolian cryosphere scientist with more than 20 years of experience in cryosphere and climate change research. He earned his Ph.D. in Earth System Science from Hokkaido University, Japan. His research focuses on permafrost dynamics, seasonal frost, glaciers, rock glaciers, hydrology, and the impacts of climate change on cold-region environments and ecosystems in Mongolia. He has led numerous national and international research projects and has contributed significantly to understanding permafrost degradation and its environmental consequences. His work combines field observations, environmental monitoring, remote sensing, GIS, and modeling to investigate cryosphere processes and their interactions with climate and ecosystems. Together with colleagues from the international cryosphere community, he has published numerous scientific papers on permafrost and cryosphere science. He currently serves as Director of the Institute of Geography and Geoecology, Mongolian Academy of Sciences, and UNESCO Chair in Environmental Sciences in Eastern Central Asia.

Monday 06/29 | 10:00 - 10:30 // Keynote Speaker



Sebastian Westermann
(A) Grand Ballroom
Department of Geosciences,
University of Oslo

Simulating permafrost thaw and its impacts in a changing climate

Sebastian Westermann's research focuses on field measurements, remote sensing, and numerical modeling of permafrost dynamics. He completed his PhD at the Alfred-Wegener-Institute in Germany and later moved to Oslo, Norway, where he is a professor at the Department of Geosciences, University of Oslo. His research group is a main hub for developing the CryoGrid permafrost models, inspired and guided by field observations mostly in Svalbard and Norway. CryoGrid is now widely used for terrestrial cryosphere simulations, from global permafrost mapping to process-based simulations of climate change impacts. A particular focus is the interplay between numerical models and satellite observations, which his research group investigates through projects supported by the European Space Agency. In recent years, Sebastian has regularly visited Mongolia, exploring ecosystem-permafrost interactions together with Mongolian partners.

Monday 06/29 | 10:30 - 11:00 // Keynote Speaker



Florence Magnin
(A) Grand Ballroom
EDYTEM Laboratory, CNRS-
University Savoie Mont Blanc

Advancing Alpine Permafrost Knowledge for Slope Failure Assessment: Insights from the French Alps

Florence Magnin holds a PhD in Physical geography and is a full-time CNRS researcher at the EDYTEM Laboratory (University Savoie Mont Blanc, France). Her research interest focuses on alpine permafrost, periglacial geomorphology and rock slope hazards. To conduct her investigations, she combines in-situ measurements (such as ground temperature and geophysics), various modeling approaches, and GIS. While she mainly leads projects in the European Alps, she has also contributed to projects in Norway, Island, the Pyrenees and the Peruvian Cordillera Blanca. She is leading several research initiatives funded by the French Ministry of Ecological Transition to better assess risks from periglacial origin and is a core member of the PermaFrance observatory network, which monitors permafrost evolution in the French Alps.

Plenary Session II

Tuesday 06/30 | 09:00 - 09:30 // Keynote Speaker



Mamoru Ishikawa
(A) Grand Ballroom
 Faculty of Environmental
 Earth Science, Hokkaido
 University

Geocryology and ecohydrology of Mongolian permafrost

Mamoru Ishikawa is an associate professor with 24 years of experience on field-based research in Mongolia, collaboration with Institute of Geography and Geocology, Mongolian Academy of Science, National University of Mongolia, and Institute of Meteorology and Hydrology. He has also supervised several PhD students from Mongolia. His publications cover diverse topics, involving permafrost states and mapping, land-atmosphere interaction, landform developments associated with ground ice dynamics, natural spring states, and sociological aspects.

Tuesday 06/30 | 09:30 - 10:00 // Keynote Speaker



Fujun Niu
(A) Grand Ballroom
 Shanghai Normal
 University, Director of
 Yangtze River Delta Urban
 Wetland Ecosystem National
 Field Scientific Observation
 and Research Station

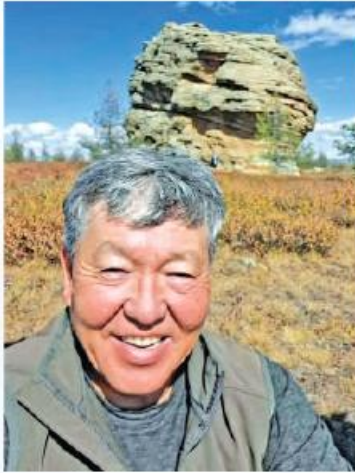
The Prevention and Mitigation of Engineering Distresses in Permafrost Areas of the Qinghai-Tibet Plateau

Prof. Fujun Niu received his Ph.D. in Geological Engineering from Chang'an University (1998). He currently works at Shanghai Normal University and serves as Vice-President of the International Permafrost Association (IPA) and Associate Editor of Permafrost and Periglacial Processes and Cold Region Engineering. His research interests focus on geohazards and engineering in cold regions, particularly permafrost degradation, thaw-induced slope failures, thermokarst lake evolution, and cooling technologies for transportation infrastructure. He has led over 20 major projects, including the Second Tibetan Plateau Scientific Expedition and key NSFC projects. He has published more than 300 papers and holds 10 invention patents. Prof. Niu has received numerous awards, including the National Science and Technology Progress First Prize (Innovative Team), the Outstanding Scientific Achievement Award of CAS, and the Young Geology Science and Technology Award of China. He was selected as a "National Hundred Thousand Talents Project" expert.



Plenary Session III

Wednesday 07/01 | 09:00 - 09:30 // Keynote Speaker



Jambaljav Yamkhin
(A) Grand Ballroom
President of Mongolian
Permafrost Association
& Executive Director of
Geocryo LLC

History, Development, and Current Challenges of permafrost studies in Mongoli

Dr. Jambaljav Yamkhin is a leading Mongolian permafrost scientist specializing in engineering geology, hydrogeology, permafrost mapping, and spatial-temporal modeling of permafrost systems. He received his B.Sc. and M.Sc. degrees from Moscow State University, Russia, and earned a Ph.D. in Geography from the National University of Mongolia. Since 2015, he has served as President of the Mongolian Permafrost Association and has been Mongolia's National Representative to the International Permafrost Association since 2009. His research focuses on permafrost distribution, monitoring, engineering applications, and climate-related permafrost dynamics. Dr. Yamkhin has led numerous national and international projects, including the development of the new Permafrost Distribution Map of Mongolia and the establishment of the nationwide Permafrost Monitoring Network comprising approximately 200 observation sites. He has authored and co-authored numerous scientific publications in leading international journals and has made significant contributions to permafrost research, infrastructure protection, and environmental management in Mongolia.

Wednesday 07/01 | 09:30 - 10:00 // Keynote Speaker



Natalie Arpin
(A) Grand Ballroom
Civil Engineering, Queen's
University, PhD Candidate

Understanding the Impacts of Frost Jacking on In-Situ Infrastructure: Insights from the Hudson Bay Railway in Manitoba, Canada

Natalie is a PhD candidate in Civil Engineering at the GeoEngineering Centre, jointly based at Queen's University and the Royal Military College of Canada. She also completed her undergraduate degree in Civil Engineering at Queen's University. Her research focuses on understanding the impacts of frost jacking on operational infrastructure, with a particular focus on the Hudson Bay Railway in Manitoba, Canada. This work is part of the broader PermaRail project, completed in partnership with Arctic Gateway Group and a multidisciplinary team of Canadian universities.

Natalie also serves as President of the Permafrost Young Researchers Network, an international organization that connects early-career researchers working across a wide range of permafrost-related disciplines. Through community building, networking, and transdisciplinary learning opportunities, the network supports collaboration and knowledge exchange among the next generation of permafrost researchers.



ACOP2026

3rd ASIAN CONFERENCE ON PERMAFROST

CONFERENCE PROGRAM

PLENARY
SESSIONS

ORAL
SESSIONS

POSTER
SESSIONS

WORKSHOPS &
MEETINGS

29 JUNE - 2 JULY 2026

Galleria ULAANBAATAR, MONGOLIA



General Program

TIME	PRE-CONFERENCE TRIP	SUNDAY · 28 JUNE (Pre-Conference)		MONDAY · 29 JUNE (Day 1)
08:00				08:00–08:40 Welcome Desk Opens 08:40–09:30 Opening Ceremony
08:30	KHENTII MOUNTAIN FIELD TRIP June 25–27 (3 days) Wetland & peatland ecosystems • Greenhouse gas flux studies • Biodiversity & migratory bird monitoring			
09:00		09:00–18:00 Registration		
09:30				
10:00		09:00–17:00 PYRN Workshop Room (B)	10:00–12:00 RGIK Side Meeting Room (C)	09:30–11:00 Plenary Session I
10:30				11:00–11:20 Coffee Break
11:00				11:20–12:50 Parallel Oral Session 1 (Rooms A-D)
11:30				
12:00				
12:30			14:00–18:00 GTN-P Workshop Room (C)	12:50–14:00 Lunch
13:00				
13:30				
14:00				
14:30		15:30–15:50 Coffee Break		
15:00		15:50–17:20 Parallel Poster Session 1		
15:30				
16:00				
16:30				
17:00				18:00–21:00 Ice-Breaking Reception
17:30				
18:00				
18:30				
19:00				
19:30				
20:00	Rooms			
20:30	(A) Grand Ballroom			
21:00	(B) Sky Ballroom			
	(C) Urguu Ballroom			
	(D) MG Ballroom			

TUESDAY · 30 JUNE (Day 2)	WEDNESDAY · 1 JULY (Day 3)	THURSDAY · 2 JULY (Day 4)	POST- CONFERENCE TRIP 1	POST- CONFERENCE TRIP 2	TIME	
					08:00	
		08:30–16:00 LOCAL FIELD TRIP Near Ulaanbaatar	KHOVSGOL & KHANGAI FIELD TRIP July 3–9 (7 days) • Permafrost sites • Mountain taiga • Thermokarst & Pingo • Cave study	ALTAI MOUNTAIN FIELD TRIP July 3–9 (7 days) • High mountain permafrost • Glaciers • Alpine ecosystems • Field observations	08:30	
09:00–10:00 Plenary Session II	09:00–10:00 Plenary Session III				09:00	
10:00–10:20 Coffee Break	10:00–10:20 Coffee Break				09:30	
10:20–11:50 Parallel Oral Session 3 (Rooms A-D)	10:20–11:50 Parallel Oral Session 5 (Rooms A-D)				10:00	
					10:30	
					11:00	
					11:30	
					12:00	
					12:30	
11:50–13:30 Lunch	11:50–13:30 Lunch				13:00	
					13:30	
13:30–15:00 Parallel Oral Session 4 (Rooms A-D)	13:30–15:00 Parallel Oral Session 6 (Rooms A-D)				14:00	
					14:30	
15:00–15:20 Coffee Break	15:00–15:20 Coffee Break				15:00	
					15:30	
15:20–16:50 Parallel Poster Session 2	15:20–17:00 Chinggis Khaan National Museum				16:00	
		16:30				
		17:00				
		17:30				
		18:00				
		18:30				
		17:00–17:25 Closing Ceremony			19:00	
		The IPA Lifetime Achievement Award			19:30	
			17:25–17:40 ICOP 2028 Delivery Speech			20:00
						20:30
						21:00
		17:40–22:00 Conference Banquet				
				Plenary & Oral Sessions	19:30	
				Coffee Breaks & Posters	20:00	
				Lunches	20:00	
				Workshops & Meetings	20:30	
				Ceremonies & Banquet	20:30	
				Local & Regional Field Trips	21:00	

**DAILY PROGRAM: MONDAY · 29 JUNE (day 1)**

TIME	Session	TITLE / ACTIVITY	Room
08:00–08:40		Welcome Desk Open	Juulchin Ballroom
08:40–09:30		Opening Ceremony	(A) Grand Ballroom
09:30–11:00		Plenary Session I	(A) Grand Ballroom
11:00–11:20		Coffee Break	
11:20–12:50	Parallel Oral Session 1	Advances and Challenges in Permafrost Monitoring, Mapping, and Modeling I	(A) Grand Ballroom
		Engineering Solutions for a Thawing Permafrost: Prevention, Adaptation, and Mitigation	(B) Sky Ballroom
		Mountain Cryosphere Landforms in a Warming Climate: Rock Glaciers and Beyond I	(C) Urguu Ballroom
		Hydrology of Permafrost-Affected Wetlands I	(D) MG Ballroom
12:50–14:00		Lunch	
14:00–15:30	Parallel Oral Session 2	Advances and Challenges in Permafrost Monitoring, Mapping, and Modeling II	(A) Grand Ballroom
		GTN-P: Local Observations to Global Assessments	(B) Sky Ballroom
		Mountain Cryosphere Landforms in a Warming Climate: Rock Glaciers and Beyond II	(C) Urguu Ballroom
		Hydrology of Permafrost-Affected Wetlands II	(D) MG Ballroom
15:30–15:50		Coffee Break	
15:50–17:20		Parallel Poster Session I	(A) Grand Ballroom
18:00–21:00		Ice-Breaking Reception	Niche Tuul Garden

DAILY PROGRAM: TUESDAY · 30 JUNE (day 2)

TIME	Session	TITLE / ACTIVITY	Room
09:00–10:00		Plenary Session II	(A) Grand Ballroom
10:00–10:20		Coffee Break	
10:20–11:50	Parallel Oral Session 3	Advances and Challenges in Permafrost Monitoring, Mapping, and Modeling III	(A) Grand Ballroom
		Thaw-Induced Hazards and Engineering Implications I	(B) Sky Ballroom
		Mountain Permafrost Mapping and Risk Assessment: Insights from Remote Sensing and Ground-Based Observations	(C) Urguu Ballroom
		Long-Term Cold-Environment Permafrost Changes I	(D) MG Ballroom
11:50–13:30		Lunch	
13:30–15:00	Parallel Oral Session 4	Permafrost and Ecosystem Interactions I	(A) Grand Ballroom
		Thaw-Induced Hazards and Engineering Implications II	(B) Sky Ballroom
		Periglacial Dynamics in High-Low Latitudes I	(C) Urguu Ballroom
		Long-Term Cold-Environment Permafrost Changes II	(D) MG Ballroom
15:00–15:20		Coffee Break	
15:20–16:50		Parallel Poster Session II	(A) Grand Ballroom



DAILY PROGRAM: WEDNESDAY 1 JULY (Day 3)

TIME	Session	TITLE / ACTIVITY	Room
09:00–10:00		Plenary Session III	(A) Grand Ballroom
10:00–10:20		Coffee Break	
10:20–11:50	Parallel Oral Session 5	Permafrost and Ecosystem Interactions II	(A) Grand Ballroom
		Infrastructure, Communities, and Permafrost Dynamics: Risk, Resilience & Adaptation	(B) Sky Ballroom
		Periglacial Dynamics in High-Low Latitudes II	(C) Urguu Ballroom
		Communicating Permafrost Science: Knowledge Transfer through Education, Outreach, and Participatory Research	(D) MG Ballroom
11:50–13:30		Lunch	
13:30–15:00	Parallel Oral Session 6	High-Resolution Remote Sensing and In-Situ Integration for Permafrost Modelling	(A) Grand Ballroom
		Modeling Permafrost Dynamics Across Scales	(B) Sky Ballroom
		Himalayan Permafrost in a Warming World: Distribution, Evolution, and Societal Implications	(C) Urguu Ballroom
		Global Activities on Permafrost in the Next Decade	(D) MG Ballroom
		Permafrost and Climate Change Feedback and Policy Implications	
15:00–15:20		Coffee Break	
15:20–17:00		Chinggis Khaan National Museum	

DAILY PROGRAM: THURSDAY 2 JULY (Day 4)

TIME	Session	TITLE / ACTIVITY	Room
08:30–16:00		LOCAL FIELD TRIP	Near Ulaanbaatar
17:00–17:15		CLOSING CEREMONY	(A) Grand Ballroom
17:15–17:25		The IPA Lifetime Achievement Award	
17:25–17:40		ICOP 2028 Delivery Speech	
17:40–22:00		CONFERENCE BANQUET	



DETAILED SCHEDULE OF THE ORAL PRESENTATIONS

SESSION NAME

№	Theme	Session	Code
1	Permafrost monitoring	Advances and Challenges in Permafrost Monitoring, Mapping, and Modeling	1A
2		Long-Term Cold-Environment Permafrost Changes	1B
3		GTN-P: Local Observations to Global Assessments	1C
4	Engineering (Hazards & Risks)	Engineering Solutions for a Thawing Permafrost: Prevention, Adaptation, and Mitigation	2A
5		Thaw-Induced Hazards and Engineering Implications	2B
6		Infrastructure, Communities, and Permafrost Dynamics: Risk, Resilience & Adaptation	2C
7	Mountain Permafrost	Himalayan Permafrost in a Warming World: Distribution, Evolution, and Societal Implications	3A
8		Mountain Cryosphere Landforms in a Warming Climate: Rock Glaciers and Beyond	3B
9		Mountain Permafrost Mapping and Risk Assessment: Insights from Remote Sensing and Ground-Based Observations	3C
10	Ecosystems, Hydrology & Periglacial Processes	Hydrology of Permafrost-Affected Wetlands	4A
11		Periglacial Dynamics in High-Low Latitudes	4B
12		Permafrost and Ecosystem Interactions	4C
13	Society, Culture & Knowledge	Communicating Permafrost Science: Knowledge Transfer through Education, Outreach, and Participatory Research	5A
14	Policy, Global Coordination	Global Activities on Permafrost in the Next Decade	6A
15		Permafrost and Climate Change Feedback and Policy Implications	6B
16	Modelling & Integration	High-Resolution Remote Sensing and In-Situ Integration for Permafrost Modelling	7A
17		Modeling Permafrost Dynamics Across Scales	7B



ORAL PRESENTATIONS /// MONDAY 29 JUNE

PARALLEL ORAL SESSION 1 / 11:20-12:50

1A: Advances and Challenges in Permafrost Monitoring, Mapping, and Modeling I

Chairs: Youhua Ran, Huijun Jin

Room: (A) Grand Ballroom

Time	Presenter	Topic
11:20-11:32	Etzelmüller Bernd	Repeated geophysical surveys help understanding permafrost degradation in Norway
11:32-11:44	John Woodward	30 years of change in the Vaišjeäggi Palsa Mire, Utsjoki, Finland
11:44-11:56	Sebastian Ruiz Pereira	Geometry-controlled, non-linear groundwater responses to permafrost degradation at 5,200 m ASL
11:56-12:08	Sergey Sokratov	Dependence of active layer depth on meteorological parameters
12:08-12:20	Thomas Douglas	Quantifying degrading permafrost with repeat airborne lidar, geophysics, and thaw probing
12:20-12:32	Go Iwahana	Warming of mountain permafrost in the Daisetsu Mountains, Hokkaido, Japan
12:32-12:44	Yoshihiro Iijima	Thermokarst lake evolution and potential channelization in the Darkhad Basin, Northern Mongolia
12:44-12:50	Panel Discussion and Q&A	

2A: Engineering Solutions for a Thawing Permafrost: Prevention, Adaptation, and Mitigation

Chairs: Fujun Niu, Saruulzaya Adiya

Room: (B) Sky Ballroom

Time	Presenter	Topic
11:20-11:32	Lukas Arenson	A Innovative Thermosyphon Technology for Stabilizing Permafrost-Affected Rock Slopes: Early Successes from the Piz Nair Summit Station
11:32-11:44	Tom De Ville	Structural Health Monitoring System for Critical Infrastructure at Risk from Permafrost Degradation in Greenland
11:44-11:56	Erika Grechishcheva	Laboratory macromodeling of thawing halo formation around an oil well using ultra-thin liquid thermal insulation
11:56-12:08	Hanli Wu	Thermal stability analysis of cellular concrete air convection embankments for cold regions
12:08-12:20	Jing Luo	Spatiotemporal Evolution and Mitigation Technologies for Retrogressive Thaw Slumps on the Qinghai-Tibet Plateau
12:20-12:32	Aleksandr Zhirkov	Restoration and protection of destroyed territories with ice-rich deposits in the conditions of central yakutia
12:32-12:50	Panel Discussion and Q&A	

3B: Mountain Cryosphere Landforms in a Warming Climate: Rock Glaciers and Beyond I

Chairs: Yan Hu, Cécile Pellet, Mishelle Wehbe**Room:** (C) Urguu Ballroom

Time	Presenter	Topic
11:20-11:32	Line Rouyet	Rock glacier inventory in Tsengel Khairkhan Massif, Western Mongolia
11:32-11:44	Mishelle Wehbe	Rock Glacier Velocity (RGV) Investigations in the Alpine Regions of Western Canada
11:44-11:56	Thibaut Duvanel	7500 rock glaciers reveal 2000 m of periglacial belt migration in the Swiss Alps since the end of the Last Glacial Maximum
11:56-12:08	Karianne Lilleøren	Statistical prediction modelling of rock glacier distribution in Norway
12:08-12:20	Marc Oliva	Permafrost in the Pyrenees: Current knowledge and future perspectives
12:20-12:32	Giulio Saibene	Multi-annual and seasonal patterns of Murtèl rock glacier borehole deformation: controls and implications for kinematic monitoring.
12:32-12:50	Panel Discussion and Q&A	

4A: Hydrology of Permafrost-Affected Wetlands I

Chairs: Juliane Wolter, Helena Bergstedt**Room:** (D) MG Ballroom

Time	First name	Submission title
11:20-11:32	Nandintsetseg Nyam-Osor, Tatiana Minayeva	Ecological Indication of Permafrost Features for Purposes of Peatland Ecosystem Restoration in Mongolia
11:32-11:44	Mélissa Laurent	Hydrological changes enhance Carbon-Nitrogen interactions during abrupt thaw: a mesocosm study in a fennoscandian palsa
11:44-11:56	Anfisa Pismeniuk	Methane production in thermokarst ponds across a thaw gradient in permafrost peatlands of Northern Norway
11:56-12:08	Elizaveta Chezhina	Geochemical composition changes of lacustrine bottom sediments in the permafrost zone of the Yamalo-Nenets Autonomous Okrug (Russian Arctic) over the past 500 years under the climate change impact
12:08-12:20	Samuel Lee	Investigating Surface and Ground Water Flow During the Winter at Kuparuk River, Arctic Alaska, Combining Near-surface Geophysics and Cryo-hydrological Modeling
12:20-12:32	Juliane Wolter	Reconstruction of the life cycles of two drained lake basins on the Baldwin Peninsula, W Alaska
12:32-12:44	Zeyong Gao	Hydrogeochemical evidence for suprapermfrost groundwater recharge to thermokarst lakes on the Qinghai-Tibet Plateau
12:44-12:50	Panel Discussion and Q&A	



PARALLEL ORAL SESSION 2 / 14:00-15:30

1A: Advances and Challenges in Permafrost Monitoring, Mapping, and Modeling II

Chairs: Tonghua Wu, Jambaljav Yamkhin

Room: (A) Grand Ballroom

Time	Presenter	Topic
14:00-14:12	Charlotte Pearson	Detecting Active Layer Detachments Using High-Resolution Terrain Data And Machine Learning In The Brooks Range, Alaska
14:12-14:24	Helena Bergstedt	Lake - Drained Lake Basin (L-DLB) Systems of the Lena and Kolyma Lowlands of Eastern Siberia
14:24-14:36	Alexander Shiklomanov	Impacts of climate variability and permafrost thaw on present day and future hydrological regimes in the Selenge basin
14:36-14:48	Junqiang Bai	Potential for mapping seasonal and interannual permafrost surface deformation with sentinel-1 in the northern hemisphere
14:48-15:00	Dmitrii Sergeev	Problems of Regional Analysis of the Permafrost State and Dynamics (European North and Eastern Siberia's Cases)
15:00-15:12	Dmitry Andriushin	Geocryological mapping with landscape-integrated variability for active layer thickness and 10 m ground temperature in Yenisey North
15:12-15:24	Youhua Ran	Rethinking permafrost distribution, change, and impact: A data-driven perspective
15:24-15:30	Panel Discussion and Q&A	

1C: GTN-P: Local Observations to Global Assessments

Chairs: Dimitry Streletskiy, Anna M. Irrgang

Room: (B) Sky Ballroom

Time	Presenter	Topic
14:00-14:12	Anarmaa Sharkhuu	Long-term monitoring of thermal state of permafrost in Mongolia
14:12-14:24	Dariimaa Gereljargal	Impact of precipitation on soil temperature in Mongolian permafrost regions
14:24-14:36	Temuujin Khurelbaatar	Ground Thermal Regime Variability in the Altai and Khangai Mountains Based on Frost Number and Surface Offset
14:36-14:48	Tonghua Wu	Establishment of Siberia-Mongolia-Tibet Permafrost Observation Transect: Progress & Perspective
14:48-15:00	Olga Makarieva	New research and monitoring network in the mountainous permafrost region of the northeastern eurasia
15:00-15:12	Cécile Pellet	State of permafrost in the Swiss Alps after 25 years of coordinated observation
15:12-15:24	Dmitry Streletskiy	Global Changes in the Active Layer Thickness and Thaw Subsidence Rates in the Permafrost Regions
15:24-15:30	Panel Discussion and Q&A	

3B: Mountain Cryosphere Landforms in a Warming Climate: Rock Glaciers and Beyond II

Chairs: Mishelle Wehbe, Yan Hu, Cécile Pellet**Room:** (C) Urguu Ballroom

Time	Presenter	Topic
14:00-14:12	Anastasiia Zemlianskova	Climate change impact on the seasonal giant Anmagynda aufeis in mountainous permafrost of the Northeastern Eurasia
14:12-14:24	Oksana Zhunusova	Formation of Infiltration Ice in Talus Slopes and Its Influence on Runoff of a Permafrost Watershed (Northeastern Russia)
14:24-14:36	Andreas Kellerer-Pirklbauer	Tracking rock glacier velocity by geodetic surveys: a methodological contribution to the essential climate variable "Permafrost"
14:36-14:48	Dmitrii Bantsev	Isotopic composition of glacier ice and upland rivers in North-Western Mongolia and the Russian Altai
14:48-15:00	Francesco Brardinoni	Thaw-driven disintegration of an active rock glacier: A geomorphic cascade modulated by retrogressive slumping, debris-flow sediment evacuation, and fluvial reworking
15:00-15:12	Yan Hu	Seasonal kinematic behavior of alpine rock glaciers
15:12-15:24	Matthias Lichtenegger	Monitoring of unfrozen water and porewater pressure dynamics in two rock glaciers in the eastern Swiss Alps (Grisons)
15:24-15:30	Panel Discussion and Q&A	

4A: Hydrology of Permafrost-Affected Wetlands II

Chairs: Juliane Wolter, Helena Bergstedt**Room:** (D) MG Ballroom

Time	Presenter	Topic
14:00-14:12	Moritz Langer, Sofia Antonova	On ThinIce: Emerging Risks from Drilling Mud Sumps in the Mackenzie Delta Driven by Permafrost Thaw and Hydrological Change
14:12-14:24	Michelle Blade	Utilizing community-relevant perennial groundwater springs to assess a cryohydrogeological regime in transition in Nunavut, Canada
14:24-14:36	Elchin Jafarov	Exploring Talik Development Beneath Beaver Ponds in Arctic Alaska
14:36-14:48	Natalia Ilinova	Coupling of Vegetation Dynamics and Permafrost Landforms in Post-Agricultural Steppes of Tuva
14:48-15:00	Alexander Kholodov	Effect of topography on ground temperature and functioning of ecosystems within open tundra biome. Case study at the Seward Peninsula, Alaska
15:00-15:12	Ping Wang	Changes in the Arctic Hydrological System Under a Warming Climate
15:12-15:30	Panel Discussion and Q&A	



ORAL PRESENTATIONS /// TUESDAY 30 JUNE

PARALLEL ORAL SESSION 3 / 10:20-11:50

1A: Advances and Challenges in Permafrost Monitoring, Mapping, and Modeling III

Chairs: Alexander Fedorov, Bingquan Wang

Room: (A) Grand Ballroom

Time	Presenter	Topic
10:20-10:32	Barbara Widhalm	InSAR derived land surface deformation across Arctic lowland permafrost regions
10:32-10:44	Valentina Ekimova	Geophysical Imaging of Near-Surface Permafrost in Utqiagvik, Alaska using ERT and GPR
10:44-10:56	Ivan Misaylov	Establishment of a Permafrost Monitoring System in Arctic Yakutia
10:56-11:08	Etzelmüller Bernd	Warming and degrading permafrost in norway and svalbard
11:08-11:20	Vasily Tolmanov	Trends in multi-decadal subsurface thermal moisture and regime of the soils of active layer, northern alaska.
11:20-11:32	Ren Li	Synergistic Regulatory Mechanism of Surface Albedo and Longwave Radiation Loss on Soil Thermal Dynamics in the Permafrost Active Layer of the Mongolian Plateau
11:32-11:44	Roman Razumovskiy	Geocryological and landscape conditions of igarka district: current state
11:44-11:50	Panel Discussion and Q&A	

2B: Thaw-Induced Hazards and Engineering Implications I

Chairs: Zhaohui (Joey) Yang, Jing Luo

Room: (B) Sky Ballroom

Time	Presenter	Topic
10:20-10:32	Nataliia Nesterova	Predictive maps of active layer thickness in the upper Kolyma Highlands
10:32-10:44	Guoyu Li	Thaw Settlement Mitigation for Buried Warm-Oil Pipelines in Permafrost Regions: Performance Effectiveness from Indoor Testing and Simulations
10:44-10:56	Tatsuya Watanabe	Time-series InSAR detection of seasonal freeze-thaw ground deformation around Ulaanbaatar, Mongolia
10:56-11:08	Tom Larrue	Calibration of an energy balance model at an alpine permafrost site with thermokarst features and an anthropogenically modified sub-horizontal surface
11:08-11:20	Peiqing Lou	A transferable deep learning framework using Sentinel-1 and Sentinel-2 data for large-scale thaw slump mapping across the Northern Hemisphere permafrost domain
11:20-11:32	John Thornley	Alaska case studies related to repairing infrastructure due to thawing permafrost
11:32-11:50	Panel Discussion and Q&A	

3C: Mountain Permafrost Mapping and Risk Assessment: Insights from Remote Sensing and Ground-Based Observations

Chairs: Nadine Salzmann, Temuujin Khurelbaatar

Room: (C) Urguu Ballroom

Time	Presenter	Topic
10:20-10:32	Yi Deer	Physically Informed Machine Learning for Permafrost Stability Mapping in Central Mongolia: Leveraging InSAR and Downscaled Thermal Regimes
10:32-10:44	Yonghong Yi	Long-term InSAR and streamflow recession analysis reveal human activities accelerated permafrost degradation in Qilian Mountain
10:44-10:56	Saruulzaya Adiya	Risk Assessment of Potential Ground Ice Contents in the Permafrost Region of Mongolia
10:56-11:08	Pema Eden	Assessment of global permafrost models and ensemble machine learning for high-resolution permafrost mapping in Bhutan
11:08-11:20	Andrei Ostashov	Spatiotemporal Variability of Giant Auefs in the Northeastern Eurasia
11:20-11:32	Edoardo Riva	PERMACLIM 2.0: An updated model for mapping permafrost conditions in mountain regions
11:32-11:44	Hanna Lee	Storyline-based projections of permafrost thaw subsidence and risks to Arctic infrastructure
11:44-11:50	Panel Discussion and Q&A	

1B: Long-Term Cold-Environment Permafrost Changes I

Chairs: Kazuyuki Saito, Mamoru Ishikawa

Room: (D) MG Ballroom

Time	Presenter	Topic
10:20-10:32	Félix García-Pereira	Recent permafrost retreat is very likely unprecedented in the Common Era
10:32-10:44	Hyeonjeong Jeong	Environmental shifts from the LGM to the Holocene recorded in sulfur isotope geochemistry of ice wedges
10:44-10:56	Maria Box	A 600,000 year speleothem-based history of Mongolian permafrost
10:56-11:08	Nikolai Fedorov	Cold-Season Precipitation Isotope-Temperature Relationships at Yakutsk, Central Yakutia: Implications for Paleoclimate Research
11:08-11:20	Maria Martirosyan	Methane in the Holocene Ice wedges of the Western Siberia and Eastern Chukotka
11:20-11:32	Josephine Galipon	Immediate on-site RNA extraction reveals the impact of transport and storage temperature on RNA integrity and microbial gene expression in permafrost
11:32-11:44	Frank Kienast	Deep down the squirrel hole: Diet and habitat of a Pleistocene ground squirrel in Western Beringia
11:44-11:50	Panel Discussion and Q&A	

**PARALLEL ORAL SESSION 4 / 13:30-15:00****4C: Permafrost and Ecosystem Interactions I****Chairs:** Robin Benjamin Zweigel, Hotaek Park**Room:** (A) Grand Ballroom

Time	Presenter	Topic
13:30-13:42	Ivan Alekseev	Biogeochemical features of permafrost-affected soils: results from multi-year monitoring in polar regions
13:42-13:54	Michael Loranty	Fire mediated forest density influences on active layer processes in Siberian larch forests
13:55-14:06	Gansukh Yadamsuren	Anthropogenic impacts on soil distribution and properties underlain by isolated permafrost in north-eastern Mongolia
14:06-14:18	Holger Gärtner	Differentiating active and inactive rockglaciers based on wood anatomical and isotopic analyses of shrubs
14:18-14:30	Joachim Otto Habeck	Prospects for land-management strategies and transdisciplinary research in a permafrost region of northern Mongolia
14:30-14:42	Julian Murton	The sulfur isotopic signature of permafrost degradation in retrogressive thaw slumps and implications for palaeofaunal isotope analysis
14:42-14:54	Simone Maria Stuenzi	Forest Canopy Regulation of Permafrost Thermal Dynamics: Implications for Frozen Carbon Vulnerability
14:54-15:00	Panel Discussion and Q&A	

2B: Thaw-Induced Hazards and Engineering Implications II**Chairs:** Guoyu Li, John Thornley**Room:** (B) Sky Ballroom

Time	Presenter	Topic
13:30-13:42	Zhaohui (Joey) Yang	Permafrost Thaw Strain Prediction: Empirical Methods vs. Machine Learning Models
13:42-13:54	Simon Dumais	Advancing Mining Geotechnics for Changing Permafrost: Theoretical Frameworks, Predictive Modeling, and Heterogeneity
13:55-14:06	Tsogt-Erdene Gansukh	Current status of road damage in permafrost region (example of the Khangai mountains region)
14:06-14:18	Teddi Herring	Preliminary geophysical observations of permafrost dynamics along the Hudson Bay Railway
14:18-14:30	Irina Streletskaia	Tabular ground ice distribution in the Yamal Peninsula as a base to predict activation of hazardous cryogenic processes
14:30-14:42	Fei Wang	Impact of Differential Thaw Settlement on Vertical Soil Pressure at the Crown of Trench-buried Pipeline: Insights from DEM and Theoretical Analysis
14:42-15:00	Panel Discussion and Q&A	

4B: Periglacial Dynamics in High-Low Latitudes I

Chairs: Francesco Grifoni, Mauro Guglielmin**Room:** (C) Urguu Ballroom

Time	Presenter	Topic
13:30-13:42	Anarmaa Sharkhuu	Monitoring of active layers of permafrost in Mongolia: Limits of active layer thickness as an indicator of permafrost stability
13:42-13:54	Mauro Guglielmin	A decade (2013-2022) of permafrost and active layer thickness monitoring in Antarctic Peninsula Area
13:54-14:06	Stefano Ponti	Human disturbance on Antarctic permafrost: the impact of an airstrip construction
14:06-14:18	Francesco Grifoni	Long-term monitoring of active layer, ice wedges, and frost cracking conditions in northern Victoria Land, Antarctica (2004-2023)
14:18-14:30	Amin Wen	Characterizing Polygonal Patterned Ground on the Central Qinghai-Tibet Plateau: Spatial distribution and Climatic Implications
14:30-14:42	Marina Leibman	Yamal Peninsula, Permafrost-related Terrain Phenomena: Tabular Ground Ice, Thermocirques and Gas Emission Craters
14:42-14:54	Artem Khomutov	Regular field and remote-sensing observations of cryogenic landsliding and mapping of its hazard in Central Yamal, Russia
14:54-15:00	Panel Discussion and Q&A	

1B: Long-Term Cold-Environment Permafrost Changes II

Chairs: Kazuyuki Saito, Takahiro Abe, Yoshihiro Iijima**Room:** (D) MG Ballroom

Time	Presenter	Topic
13:30-13:42	Alexander Fedorov	Arctic-Subarctic Yakutia's Permafrost-Climate dynamics from 1965 to 2023
13:42-13:54	Julustan Sivtsev	Moisture origin of ice wedges in Central Yakutia
13:54-14:06	Iana Tikhonravova	Formation mechanism of composite wedges from the Batagay Megaslump's Outcrop (North-East Siberia, Russia)
14:06-14:18	Jael Rebekka Mencke	Holocene Development of a Thermo-erosional Valley on Kurungnakh Island, Lena River Delta
14:18-14:30	Vladislav Isaev, Xiaolei Li	Multiproxy study of Tibetan & Putorana peat records elucidates high-latitude Holocene paleoclimate, ecology and landscape change.
14:30-14:42	Samira Hosseini	Forest Species Discrimination to Refine Active Layer Thickness Estimation
14:42-14:54	Lev Kuziakin	Lithological and geochemical indication of sedimentation conditions of sediments with massive ice in the north of Western Siberia
14:54-15:00	Panel Discussion and Q&A	



ORAL PRESENTATIONS /// WEDNESDAY 1 JULY

PARALLEL ORAL SESSION 5 / 10:20-11:50

4C: Permafrost and Ecosystem Interactions II

Chairs: Ayumi Kotani, Simone Maria Stuenzi

Room: (A) Grand Ballroom

Time	Presenter	Topic
10:20-10:32	Robin Benjamin Zweigel	Climatic and topographic limits of permafrost-forest systems in central Mongolia - Insights from numerical modelling with cryogrid
10:32-10:44	Krystyna Koziol	Chemical impacts on surface waters of a degrading permafrost bank of the Kolyma River (Ne Siberia)
10:44-10:56	Dong Wang	Projection of the Status and Future Shifts of Topsoil Organic Carbon Stocks in Northern Hemisphere Permafrost Regions: Patterns and Drivers
10:56-11:08	Xingchen Lin	Revealing the impacts of environmental and anthropogenic factors on permafrost deformation in the central Qinghai-Tibet Plateau using insar and interpretable machine learning
11:08-11:20	Kai Frey	Differences in Isotope Composition and Anatomical Structure of Swiss Willow Shrubs Growing on Active and Inactive Rockglaciers
11:20-11:32	Xiaodong Wu	Land cover types and depth regulate carbon and nitrogen cycle functional genes in permafrost regions
11:32-11:44	Vladislav Isaev	Comprehensive Studies of Organogenic Deposits on the Qinghai-Tibet Plateau (China) and Putorana Plateau (Russia)
11:44-11:50	Panel Discussion and Q&A	

2C: Infrastructure, Communities, and Permafrost Dynamics: Risk, Resilience & Adaptation

Chairs: Lin Chen, Mingyi Zhang, Ulambayar Ganbold

Room: (B) Sky Ballroom

Time	Presenter	Topic
10:20-10:32	Mingyi Zhang	Engineering measures for embankments in high-altitude permafrost regions: theory analysis, experimental investigation, and numerical modeling
10:32-10:44	Lin Chen	Long-term performance of mitigation techniques for protecting cold-region transportation infrastructure under complex environmental conditions
10:44-10:56	Steffen Ringsø Nielsen	Geophysical mapping of permafrost distribution in West Greenland from the Ice cap to the Ocean to support landslide modelling
10:56-11:08	Tom De Ville	Critical Infrastructure Framework tailored to the Arctic
11:08-11:20	Zhaohui (Joey) Yang	Seismic Site Response of Degrading Permafrost in Alaska
11:20-11:32	Svet Milanovskiy	Possibilities of borehole geophysics for spatial monitoring of processes of anthropogenic impact on permafrost
11:32-11:44	Kazuyuki Saito	Underground food storage facilities using frozen ground environment in Mongolia -history and situations
11:44-11:50	Panel Discussion and Q&A	

4B: Periglacial Dynamics in High-Low Latitudes II

Chairs: Francesco Grifoni, Mauro Guglielmin**Room:** (C) Urguu Ballroom

Time	Presenter	Topic
10:20-10:32	Ulbayar Ganbold	Aufeis issues in Ulaanbaatar, Mongolia
10:32-10:44	Daria Andreeva	Spatial variability and decadal change in flow duration of intermittent permafrost rivers in Central Yakutia (Eastern Siberia)
10:44-10:56	Yuki Sawada	Factors controlling extra-zonal permafrost distribution in block slopes at low elevations: A case study in Hokkaido, Japan
10:56-11:08	Filippo Caccia	Modelling of Ground Surface Thermal Properties Based on Snowpack Characteristics in Northern Alaska
11:08-11:20	Juan Ignacio López Moreno	Interaction between snow, wind and vegetation in a pyrenean subalpine environment: implications on spatial variability of soil temperature and moisture
11:20-11:32	Annett Bartsch	Sea ice area variations and Northern Eurasian ground temperatures
11:32-11:50	Panel Discussion and Q&A	

5A: Communicating Permafrost Science: Knowledge Transfer through Education, Outreach, and Participatory Research

Chairs: Frédéric Bouchard, Josefine Lenz**Room:** (D) MG Ballroom

Time	Presenter	Topic
10:20-10:32	Maria Peter	New ways to practice scientific outreach - engaging the wider public with permafrost and cold environment research through data-based soundscapes and immersive sensory events
10:32-10:44	Frédéric Bouchard	Building a network for international permafrost internships: the PermaIntern and SEDNA UArctic initiatives
10:44-10:56	Pavel Kotov	Permafrost education in the Norilsk industrial district: a model for experiential learning and knowledge transfer
10:56-11:08	Tillmann Lübker	Communicating pan Arctic permafrost landscape change to non specialist audiences using the Arctic Landscape Explorer (ALEX)
11:08-11:20	Josefine Lenz	Co-Creating Permafrost Knowledge: Youth Engagement and Climate Literacy with the UndercoverEisAgenten
11:20-11:32	Leena Viitanen	Arctic Permafrost Atlas
11:32-11:50	Panel Discussion and Q&A	

**PARALLEL ORAL SESSION 6 / 13:30-15:00**

7A: High-Resolution Remote Sensing and In-Situ Integration for Permafrost Modelling

Chairs: Stefano Ponti, Alberto Carrera**Room:** (A) Grand Ballroom

Time	Presenter	Topic
13:30-13:42	Mirko Pavoni	Assessing the Potential of separable Dual-Coil Frequency-Domain Electromagnetic (FDEM) Systems for Detecting Frozen Layers in Alpine Permafrost
13:42-13:54	Alberto Carrera	Integrated Geophysical Investigation of Mountain Permafrost in a Pseudo-Relict Rock Glacier: Insights from Electrical, Active Seismic, and Gravity Methods
13:54-14:06	Anastasia Zemlianskova	Permafrost-hydrogeological structure of the giant anmangynda aufeis according to the data of geophysical research (northeastern eurasia)
14:06-14:18	Clarissa Willmes	Improving Ground Ice Representation and Thaw Trajectories by Data Assimilation of inter-annual Ground Subsidence
14:18-14:30	RAAJ Ramsankaran	Freeze-Thaw-Driven Surface Deformation and Active Layer Thickness Estimation in Himalayan Permafrost: Insights from Tso Kar Valley
14:30-14:42	Stefano Ponti	Methane fluxes spatialization from chamber measurement to PlanetScope and UAV in the Alaskan arctic tundra environment
14:42-14:54	Qianhui Liu	Charactering the spatial and temporal variability of permafrost active layer thickness in the Pan-Arctic region and its non-linear relationship with seasonal deformation
14:54-15:00	Panel Discussion and Q&A	

7B: Modeling Permafrost Dynamics Across Scales

Chairs: Clarissa Willmes, Simone Maria Stuenzi**Room:** (B) Sky Ballroom

Time	Presenter	Topic
13:30-13:42	Yi Zhao	A Hybrid Modeling Approach for Improved Simulation of Thermal-Hydrological Dynamics in Active Layer on the Qinghai-Tibet Plateau
13:42-13:54	Elchin Jafarov	Modeling Circumpolar Permafrost Carbon Fluxes
13:54-14:06	Pavel Kotov	Permafrost forecasting at regional scale: south of Taymyr Peninsula
14:06-14:18	Frederieke Miesner	Representation of canopy effects in global-scale monitoring of permafrost
14:18-14:30	Sonia Dupuis	Long-term thermal remote sensing archives as a resource for permafrost change detection
14:30-14:42	Félix García-Pereira	Assessing the implications of Arctic permafrost thermodynamics and hydrology on industrial climate with the MPI-ESM
14:42-15:00	Panel Discussion and Q&A	

3A: Himalayan Permafrost in a Warming World: Distribution, Evolution, and Societal Implications

Chairs: RAAJ Ramsankaran, Yunfa Miao**Room:** (C) Urguu Ballroom

Time	Presenter	Topic
13:30-13:42	Soumik Das	Permafrost in the Himalaya: A review of science and policy of the sub-surface ice in a warming climate
13:42-13:54	Yunfa Miao	The relationship between the uplift of the Qinghai-Tibet Plateau (QTP) and the formation of mid-latitude permafrost
13:54-14:06	Elora Chakraborty	Long-Term Permafrost Evolution in the Miyar Valley, Western Himalaya: Evidence from CRN, Radiocarbon, and OSL Chronologies
14:06-14:18	Lukas Arenson	A High-Resolution Probabilistic Permafrost Distribution Model for South-Central and Inner Asia
14:18-14:30	Mohd Farooq Azam	Do Remote Sensing Estimates Overestimate Permafrost in the Hindu Kush Himalaya? Insights from Chandratat Lake
14:30-14:42	Prachi Rajput	Process-based permafrost mapping in the cold-arid Trans-Himalayan Spiti region using the CryoGrid community model and high-resolution topography
14:42-14:54	Manasi Debnath	Glacier-Permafrost Controls on Glacial Lake Dynamics and GLOF Risk in the Lachung Basin, Eastern Himalaya, INDIA
14:54-15:00	Panel Discussion and Q&A	

6A: Global Activities on Permafrost in the Next Decade & 6B: Permafrost and Climate Change Feedback and Policy Implications

Chairs: Isabelle Gärtner-Roer, Battogtokh Dorjgotov**Room:** (D) MG Ballroom

Time	Presenter	Topic
13:30-13:42	Irina Chesnokova	Consequences of changing permafrost conditions for the russian arctic zone
13:42-13:54	Paul Dziatkowicz, Inela Agolli	Science Diplomacy and Permafrost Thaw in Times of Geopolitical Fragmentation
13:54-14:06	Line Rouyet	Permacost: New International Research Network for Coordinated and Standardised Monitoring of Permafrost Response to Climate Change
14:06-14:18	Anna M. Irrgang	Tracking a Thawing World: The new GTN-P (Global Terrestrial Network for Permafrost) Data Platform
14:18-14:30	Jinho Ahn	Geochemical Constraints on Greenhouse Gas Formation in Arctic Ice Wedges
14:30-14:42	Robert Sysoliatin	A comprehensive meteorological dataset for the continuous permafrost zone of northeastern eurasia
14:42-14:54	Yao Xiao	Beyond carbon: multi-scale thermal and hydrological feedback of permafrost on the Tibetan Plateau
14:54-15:06	Aleksandra Priadilina	Dynamics of Open Sands in the West Siberian Arctic-Risks and Climate Adaptation Potential



DETAILED SCHEDULE OF THE POSTER PRESENTATIONS

POSTER PRESENTATIONS /// MONDAY 29 JUNE

Poster Session 1 15:50-17:20		Session on this day
		1A-Advances and Challenges in Permafrost Monitoring, Mapping, and Modeling 1C-GTN-P: Local Observations to Global Assessments 2B- Thaw-Induced Hazards and Engineering Implications 3B-Mountain Cryosphere Landforms in a Warming Climate: Rock Glaciers and Beyond 3C-Mountain Permafrost Mapping and Risk Assessment: Insights from Remote Sensing and Ground-Based Observations 4A-Hydrology of Permafrost-Affected Wetlands 7B-Modeling Permafrost Dynamics Across Scales
ID	Presenter	Topic
ID 56	Elizaveta Fedyanina	Formation conditions of slushflows
ID 60	Florence Magnin	Action Plan For Risks Of Glacial And Periglacial Origin In The French Alps: Ongoing Developments To Better Assess Permafrost-Related Hazards
ID 65	Xin Ma	Spatiotemporal variations of permafrost extent in Mongolia during 1950-2022
ID 66	Jinbiao Zhao	Monitoring Arctic Cryosphere Change Using Interferometric Synthetic Aperture Radar: Progress, Applications, and Challenges
ID 68	Franck Garestier	Imaging permafrost active layer thickness under forest
ID 79	Tom Larrue	Development of a diagnostic method of Alpine permafrost for operational purposes: a numerical modelling approach
ID 81	Ben Robson	How do rock and debris surface temperatures differ on intermediately-steep Alpine permafrost slopes?
ID 83	Maybrit Goldau	Seasonal active-layer thickness dynamics at the Orravatnsrústir palsa mire complex, Icelandic Highlands
ID 90	Alexei Kouraev	Dynamics of hydro-ecosystems in periglacial landscapes from multi-satellite observations and field data
ID 111	Thibaut Duvanel	Rock Glacier Dynamics in the Swiss Alps (RoDynAlpS): a collaborative research project covering different spatio-temporal scales
ID 123	Léo Martin	Advancing land cryo-hydrological modeling in the Paiku catchment (southern QTP) to improve understanding of future hydrological changes
ID 128	Leonid Gagarin	Patterns of icing development within the Aldan-Timpton Watershed (Southern Yakutia, Russia)
ID 136	Valery Grebenets	Permafrost and Snow Cover within Urban Areas of the Russian North
ID 143	Peng Gong	Rapid Lake Expansion Driven by Asymmetric Increases in Precipitation and Permafrost Thaw Across the Northern Tibetan Plateau
ID 146	Bingquan Wang	Ground ice mapping in the Northern Hemisphere permafrost region
ID 148	Yibo Liu	High-resolution reconstruction of permafrost ground temperature from 1981 to 2022 using a physics-informed deep learning model
ID 149	Nikolai Torgovkin	Frozen ground temperature on key sites of Prilenskoe Plateau, Siberia
ID 152	Hong Yang	Improving Permafrost Soil Representation in a Dynamic Global Vegetation Model Enhances Predictions of Boreal Forest Carbon Dynamics



ID 156	Junmig Hao	Kinematics of permafrost thaw-related landslide in East Qinghai-Tibet plateau
ID 161	Kemal Ege Sural	Evaluating climate forcing uncertainty for permafrost modeling in the Selenge River basin
ID 168	Xiaoning Guo	Hydrology and sediment texture drive spatial divergence in microbial assembly and functions in a drained lakebed on the northwestern Qinghai-Tibet Plateau
ID 172	Ekaterina Torgunakova	Lithological and geochemical characterization of the active layer in permafrost deposits of the Lower Ob Region
ID 175	Elizaveta Nikolaeva	Icing dynamics of the Chulman Plateau: a 25-year remote sensing perspective
ID 202	Alexey Maslakov	Long-term soil and permafrost thaw subsidence: evidence from «Eastern Chukotka Coastal Plains» research station, Russia
ID 203	Lingcao Huang	Mapping the occurrences of retrogressive thaw slumps in all the land north of 60°N using H3 grids and multi-source remote sensing data
ID 224	Simon Gernez	Testing the sensitivity of ground ice persistence under various unfavorable climate conditions and ground ice content with numerical modeling
ID 227	Soňa Tomašková	Systematic errors in long-term borehole temperature records in permafrost
ID 254	Simon Gernez	Modelling coupled thermal dynamics and hydrology in fractured permafrost rock walls
ID 262	Shuai Liu	Simulating the active layer thickness in Northeast China from the perspective of energy balance
ID 273	Batzorig Batbold	Temporal Changes of Thermokarst Lakes in the Khukh and Khuiten Nature Reserve, Mongolia
ID 276	Nemekhbayar Gankhuyag	Spatial Distribution of Soil Organic Carbon and Peatland in Mongol Altai and Gobi-Altai Mountainous Regions
ID 321	Bilguun Tsogoo	Determination of the Annual Ablation of the Doloonnuur Glacier on Mt. Munkhkhairkhan Using the Degree-Day Model
ID 328	Birgit Heim	ESA CCI+ Permafrost-Validation using international and national permafrost monitoring networks
ID 335	Mats Ippach	Changes of soil organic matter along thaw transects of permafrost peat plateaus in Finnmark, Norway
ID 338	Julie Røste	Towards quantifying ice contents in mountain permafrost environments
ID 342	Kathrin Habegger	Intra-Seasonal Variation in Water Temperature, Electrical Conductivity, and Isotopic Composition across Two Periglacial Catchments in the Swiss Alps
ID 350	Mishelle Wehbe	CanRoGI: Towards a Comprehensive National Rock Glacier Inventory for Canada
ID 362	Francesco Brardinoni	Geomorphological mapping and InSAR-based kinematic characterization of rock glaciers in the Baralacha La area, Western Himalaya, India
ID 366	Ary Leonel Miño	Pitfalls and constraints in Multi-Technique Geophysical interpretation of ice
ID 381	Purevdulam Yondonrentsen	Simulating runoff in the Delgermurun River Basin: Challenges of SWAT modeling in Mongolian permafrost regions
ID 392	Mengze Li	Constructing Rock Glacier Velocity Time Series on the Tibetan Plateau using InSAR

POSTER PRESENTATIONS /// TUESDAY 30 JUNE

Poster Session 2 15:20-16:50		Session on this day
		1B-Long-Term Cold-Environment Permafrost Changes 2A-Engineering Solutions for a Thawing Permafrost: Prevention, Adaptation, and Mitigation 2C- Infrastructure, Communities, and Permafrost Dynamics: Risk, Resilience & Adaptation 4B-Periglacial Dynamics in High-Low Latitudes 4C-Permafrost and Ecosystem Interactions 6B-Permafrost and Climate Change Feedback and Policy Implications 7A-High-Resolution Remote Sensing and In-Situ Integration for Permafrost Modelling
ID	Presenter	Topic
ID 21	Guo Li	Quantification of snow insulation effect on the thermal energy budget in Sub-Arctic Embankment
ID 24	Kaichi Qiu	Thermo-mechanical stability of building ventilation pile foundations in Sub-Arctic permafrost regions
ID 26	Valentina Bondar	Studying the probability distributions of polygonal ice wedges morphological structures based remote sensing data
ID 37	Taro Nakai	Measurements of spatial variability in permafrost thaw depth in a larch forest in Northeastern Mongolia
ID 49	Shengyun Chen	Divergent responses of bacterial communities to permafrost degradation and their associations with carbon across vertical profile
ID 59	Artem Khomutov	The results of the active layer changes observations in polygonal peatlands along lakeshores in the north of the Pur-Taz interfluvium in 2025
ID 69	Hanno Meyer	Late Quaternary environmental dynamics on the Baldwin Peninsula (West Alaska) based on permafrost and ground ice analyses
ID 72	Sebastian Wetterich	The Batagay megaslump: cryolithology, chronology, and current dynamics of the world's largest retrogressive thaw slump
ID 86	Go Iwahana	Operation and Physical Environment of Food Storage Facilities Utilizing Natural Cold Energy
ID 101	Hitoshi Saito	Thermokarst development and related vegetation successions detected from InSAR and optical satellite images
ID 108	Nadine Salzmann	Filling White, Blue and Blind Spots in High Mountain Asia - The Bhutanese-Swiss CRYO-SPIRIT Project
ID 129	Enkhzaya Batbayar	Estimation Methods for Frost Penetration Depth in Paved Roads of Mongolia Using Thermal Conduction Analysis
ID 163	Qi Ou	Permafrost signals in Sentinel-1 velocities over the Tibetan Plateau, Qilian Shan and Tian Shan
ID 170	Takahiro Abe	Spatial variations of thaw depth, surface displacement and vegetation in the Poker Flat Research Range, interior Alaska
ID 176	Lutz Schirrmeister	Late Pleistocene (MIS 3/MIS 2) and Holocene (MIS 1) climate data reconstruction in the Northeast Siberian Arctic using paleoecological and modeling data
ID 179	Joanna Potapowicz	Contrasting Geochemical Tracers of Permafrost Thaw in Marginal Cold Regions: Metals, Isotopes, and PAHs from the Caucasus and Maritime Antarctica
ID 182	Valentina Palamarchuk	Thermal and moisture regime of the upper vadose zone in the Peski Sandy Massif (Transbaikalia)



ID 183	Valentina Palamarchuk	Groundwater discharge from a sandy massif in continuous permafrost: hydrochemical and isotopic evidence from the Peski Site (Transbaikalia)
ID 184	Ksenia Sotnikova	Numerical Assessment of Solar Radiation Effects on the Thermal Regime of Railway Embankments in the Cryolithozone of Russia
ID 196	Zhuoxuan Xia	Allometric scaling of retrogressive thaw slumps on the Qinghai-Tibet Plateau
ID 197	Zhuoxuan Xia	Vegetation Recovery Following Retrogressive Thaw Slumps Across Northern Tundra Regions
ID 201	Nikolai Fedorov	Geochemical Signatures of Enclosed Gas as Indicators of Ground Ice Genesis
ID 208	Anne Morgenstern	From thaw processes to surface water chemistry: ice-rich permafrost degradation in Northwestern Alaska
ID 209	Tatiana Sidorova	Influence of Vegetation and Snow Cover Structure on Heat Flow and Active Layer Regimes in Arctic Permafrost
ID 212	Ignat Platonov	Geochemical and lithological characteristics of active layer and Ice Complex of permafrost in the Eastern Siberia, Russian Arctic
ID 216	Nikita Samokhvalov	Long-term dynamics of seasonal thawing and phytomass in typical tundra of Western Yamal as a base to predict activation of hazardous cryogenic processes
ID 229	Aleksandr Dunaev	The origin of the massive ice of Western Yamal based on their geochemical and isotopic composition
ID 238	Jakub Petricek	Multi-frequency InSAR observations of permafrost thaw subsidence
ID 245	Danuta Szumińska	Organic chemistry in river-lake system's in the context of permafrost occurrence (Mongolia, Valley of the Lakes)
ID 247	Lev Kuziakin	Methane concentration of massive ice beds and host sediments of Eastern Chukotka as an indicator of their origin
ID 258	Michael Loranty	FireALT: a data set of active layer thickness estimates for paired burned and unburned sites across the Northern High latitudes
ID 272	Hotaek Park	Model assessment for snow impacts on permafrost and greenhouse gas fluxes
ID 289	Ayumi Kotani	Active layer regime shifts in a Larch Forest following extreme wetting in East Siberia
ID 291	Shijin Wang	Permafrost degradation services for Arctic greening
ID 292	Yaohui Cheng	Discrete-Element-Based Investigation of Damage Mechanisms of Subgrade Soils Under Freeze-Thaw Cycles
ID 323	Maralmaa Ariunbold	Mapping of soil organic carbon content in permafrost regions: Case study area Bayanzurkh soum in Khuvsgul
ID 354	Vasiliy Kuvaev	Water crystallization as an energy source for heating non-residential buildings
ID 368	Mariia Kuklina	Permafrost as a frozen commons: lessons from the Arctic
ID 376	Undrakhbayar Enkhjargal	Spatiotemporal dynamics of river aufeis along the Eg and Ider rivers, Mongolia (2017-2025)
ID 379	Danzanchadav Ganbat	Spatiotemporal Climate Variability And Permafrost Sensitivity In Mongolia (1981-2024)
ID 387	Anarmaa Sharkhuu	Land-use disturbances amplify thermal stress and accelerate permafrost regime shifts in Mongolia



CONFERENCE PROCEEDING



KEYNOTE ABSTRACTS

Keynote Speakers	Topic
PhD. Dashtseren Avirmed	Marginal Permafrost in Mongolia under Climate Change: Implications for Environmental Resources and Processes
Prof. Sebastian Westermann	Simulating permafrost thaw and its impacts in a changing climate
PhD. Florence Magnin	Advancing Alpine Permafrost Knowledge for Slope Failure Assessment: Insights from the French Alps
Prof. Mamoru Ishikawa	Geocryology and ecohydrology of Mongolian permafrost
Prof. Fujun Niu	The Prevention and Mitigation of Engineering Distresses in Permafrost Areas of the Qinghai-Tibet Plateau
PhD. Jambaljav Yamkhin	History, Development, and Current Challenges of permafrost studies in Mongolia
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MARGINAL PERMAFROST IN MONGOLIA UNDER CLIMATE CHANGE: IMPLICATIONS FOR ENVIRONMENTAL RESOURCES AND PROCESSES



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Mongolia is located along the southern boundary of the Eurasian permafrost region, where marginal permafrost ecosystems are particularly sensitive to climate change. Situated in one of the regions experiencing warming rates exceeding the global average, Mongolia has undergone rapid environmental changes during recent decades. As a landlocked country with a dry continental climate and strong dependence on natural resources, changes in the cryosphere have important implications for environmental sustainability and socioeconomic development.

This study synthesizes long-term observations and recent research to evaluate climate-induced changes in Mongolia's permafrost and their consequences for environmental resources and processes. Permafrost degradation in Mongolia has been observed across many regions, manifested by active-layer thickening, ground drying, and local permafrost disappearance. These changes are accompanied by shifts in vegetation, increasing desertification, land degradation, and alterations in hydrological processes, ultimately reducing ecosystem resilience. Future climate projections suggest that continued warming will further reduce permafrost extent and intensify environmental changes in mountain and steppe ecosystems.

Permafrost, forests, and water resources are closely interconnected components of Mongolia's mountain ecosystems. Permafrost regulates soil moisture and groundwater storage, sustaining forest ecosystems and river runoff, while forests influence snow accumulation, surface energy balance, and ground thermal regimes. Degradation of permafrost and changes in forest cover may therefore alter hydrological processes, reduce water availability, and weaken ecosystem resilience under a warming climate.

Changes in the surface energy balance play a key role in regulating permafrost dynamics. Climate warming modifies the partitioning of energy among sensible heat flux, latent heat flux, and ground heat flux, thereby influencing soil thermal regimes and freeze-thaw processes. Increasing sensible heat flux enhances atmospheric warming near the surface, while changes in latent heat flux associated with evapotranspiration alter moisture availability and ecosystem productivity. Variations in ground heat flux directly affect heat transfer into the subsurface, accelerating permafrost thaw and changing active-layer dynamics. These coupled processes have cascading impacts on hydrology, carbon cycling, ecosystem resilience, glacier retreat, desertification, land degradation, and water resources, contributing to increasing water scarcity in arid and semi-arid regions of Mongolia.

SIMULATING PERMAFROST THAW AND ITS IMPACTS IN A CHANGING CLIMATE



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Permafrost is warming and thawing world-wide, as evident from borehole temperature measurements, surveys of thaw depth, and geophysical investigations. This development has significant impacts from local to global scales, including hydrological shifts that reshape ecosystems and traditional livelihoods, ground destabilization that damages infrastructure, and the release of greenhouse gases from decomposing organic material. Numerical models have become key tools for assessing and projecting current and future permafrost evolution. We present recent developments in the CryoGrid community model, a modular toolbox for permafrost simulations that allows choosing between model formulations of varying complexity.

Within CryoGrid, simple yet computationally efficient heat-conduction models are used to quantify permafrost warming and thawing worldwide in the CCI Permafrost project of the European Space Agency. In this framework, satellite-derived land surface temperatures serve as the upper boundary condition, enabling the production of annual maps of ground temperature and active-layer thickness at a spatial resolution of 1 km. These data provide a spatially explicit picture of ground-temperature change, revealing a pronounced warming trend particularly in parts of Eurasia that are poorly covered by terrestrial observation networks.

A key challenge for spatially distributed modeling is representing small-scale heterogeneity, which controls the ground thermal regime and permafrost occurrence at distances of only a few meters. In the CCI Permafrost simulations, this heterogeneity is represented statistically within each 1 km pixel: prescribed variability in model parameters—such as snow cover and ground thermal properties—provides an estimate of subgrid variability. In higher-resolution simulations, heterogeneity can be represented deterministically. High-resolution digital elevation models can be used to represent the variability in the surface radiation budget, and data assimilation techniques allow high-resolution satellite observations to be ingested into CryoGrid. For example, satellite-derived snow melt-out dates at 20 m resolution can be assimilated to constrain the spatial variability of the insulating winter snow cover, thereby improving the simulated ground temperatures and the seasonal evolution of the active layer.

While heat-conduction-based models capture ground warming, active-layer deepening, and talik formation, they cannot simulate many key impacts of permafrost thaw. To address these processes, CryoGrid includes dedicated process-based models focusing on thaw trajectories of ice-rich permafrost landforms, such as active-layer detachment slides, the accumulation of segregated ice, and three-dimensional configurations for simulating infrastructure responses to thaw. These frameworks also incorporate processes that strongly influence permafrost vulnerability, including ground salinity, the effects of shrub and forest canopies, and mechanical stability. Together with carbon-cycle models needed for a fully coupled representation of physical, ecological, and biogeochemical feedbacks, these approaches remain at the frontier of permafrost research.

ADVANCING ALPINE PERMAFROST KNOWLEDGE FOR SLOPE FAILURE ASSESSMENT: INSIGHTS FROM THE FRENCH ALPS



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Over the past two decades, rock slope failures have considerably increased in alpine environments, encompassing various destabilization processes such as rock falls, rock slides or rock avalanches, which can sometimes trigger high-magnitude cascading hazards. These hazards endanger high-mountain recreational and professional activities (e.g., mountaineering, guiding), infrastructure (ski lifts, huts, etc.) as well as populations and assets down in the valley. In this context, there is an increasing demand from stakeholders for a better assessment of rock slope destabilization likelihood, distribution and mechanisms to improve risk mitigation. This is particularly crucial in the face of global warming, as mountain areas increasingly serve as a temperate climate refuge while facing strong economic pressure. To support stakeholders in their mitigation strategies, it is crucial to deliver (i) high-resolution permafrost maps, (ii) an enhanced understanding of permafrost degradation processes and (iii) insights into its role in slope destabilization.

In this presentation, we will provide an overview of the research we have conducted over the past five years to address these goals. A significant portion of our work focuses on improving the resolution, precision, and accuracy of permafrost mapping in the high-mountain areas of the French Alps. This development aims to overcome the limitations of statistical models – which tend to classify mountain slopes either as ice-rich debris slopes (mostly rock glaciers) or as vertical rock walls – by treating mountain slopes as a physical continuum through the development, calibration and spatialization of energy balance modeling approaches. In parallel, we tackle the effect of water flows in permafrost dynamics to improve understanding of the non-linear degradation processes. This is achieved through Electrical Resistivity Tomography monitoring on a high-mountain rock wall site, the integration of coupled thermal and hydrogeological processes in numerical models, real-time monitoring of water flow timing and characteristics in rock walls, and hydrological balance modeling. This multi-method approach was applied to recently destabilized sites, allowing us to decipher the role of permafrost processes in slope failure preparation and triggering. In addition, statistical analysis of rockfall distribution and runout distances led to the development of a rockfall propagation mapping tool (RockavELA) used to assess assets exposed to such hazards.

While these developments enhance our understanding of permafrost distribution, dynamics and rock slope destabilization, they do not directly predict exactly when and where hazards will occur. Nonetheless, our cooperation with geotechnical companies and governmental agencies dealing with risk mitigation fosters a dynamic synergy between the development of fundamental knowledge, tools and workflows for operational purposes.

GEOCRYOLOGY AND ECOHYDROLOGY OF MONGOLIAN PERMAFROST



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Mongolia is located at the southernmost Eurasian permafrost, involving continuous, discontinuous, and isolated permafrost zones that extend across the northern and central parts of the country, while the central and southern regions are dominated by seasonal frozen ground. This spatial pattern reflects the temporal succession of permafrost degradation, i.e., stable permafrost transit to unstable and disappear subsequently. Our extensive research spanning over a quarter of a century has focused on hydrothermal states of southernmost permafrost, degradation of surface waters (i.e., lakes, springs), permafrost-vegetation interactions, and landform changes associated with ground ice dynamics. This talk summarizes research achievements and introduces the ongoing research projects.

1) Permafrost research boreholes have been established at multiple sites, covering entirely permafrost areas of Mongolia. This observation captured the present temperature profiles of permafrost, and enabled us to estimate permafrost warming rates in recent decades with comparison of permafrost data taken during the 1960s-1970s. The warming rate were also estimated by numerical modelling, in which mean annual permafrost temperatures from the 1980s to 2010s were reconstructed by combination of borehole temperature data and transient modelling schemes.

2) Comparable hydrometeorological monitoring sites were installed in permafrost-underlying forested slope and its adjacent permafrost-free grassland slope of Tov province. One of the important findings is the coexistence of forests and permafrost, forests require the permafrost-affected moist soils, while permafrost required for cold environment maintained by reduced solar radiation under the dense forest covers. The eddy covariance measurement above-canopy demonstrated interannual variations of CO₂/vapor fluxes.

3) Analysis of optical satellite images since the 1960s found the trends of expanding thermokarst lakes over continuous permafrost while shrinking over discontinuous to sporadic. Onsite- and satellite-based mapping together with machine-learning analysis of natural spring states indicated that 22.5% of spring were decaying over Khangai Mountains. Warming permafrost, increasing the amount of movable unfrozen water, would contribute to maintaining spring discharge even under decreasing precipitation.

4) Undulated landforms near inland water, lakes and rivers, are associated with excess ground ice. Dynamics of thermokarst, indicating ground ice degradation, were investigated in continuous and discontinuous permafrost. Thermokarst lakes in continuous permafrost are expanding while those in discontinuous permafrost are shrinking. InSAR analysis found the areas experiencing continuous uplifts where the favorable geomorphic setting of pingo developments in Khovsgol and Khangai Mountains. Chronological analysis indicated that pingo in continuous permafrost, having nearly 10 m of relative height, has been formed during 4000 years after paleo-lake drainage.

THE PREVENTION AND MITIGATION OF ENGINEERING DISTRESSES IN PERMAFROST AREAS OF THE QINGHAI-TIBET PLATEAU



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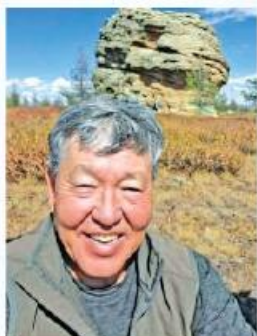
In 2024, the global average temperature exceeded pre-industrial levels by 1.57 °C for the first time, marking the hottest year on record. The ongoing climate warming, characterized by rising air temperatures and more frequent extreme climate events, is accelerating permafrost degradation worldwide. This degradation poses unprecedented challenges to engineering infrastructure in cold regions, including roads and railways. The primary consequences—reduced ground bearing capacity, increased thaw settlement, and more extensive freeze-thaw cycles—lead to material deterioration and structural functional loss. Consequently, preventing and mitigating freeze-thaw-related engineering distresses in permafrost areas has become increasingly difficult. Addressing these challenges is critical for improving construction quality and extending the service life of infrastructure.

In high-altitude permafrost regions, such as the Qinghai-Tibet Plateau, climate warming and humidification are particularly pronounced, leading to rapid permafrost degradation and increasing the risk of settlement-dominated engineering distresses. Traditional stability assessments for permafrost engineering, such as railway subgrades, have primarily focused on the effects of rising temperatures. However, given the observed trends, it is essential to move beyond this simplified approach. Future evaluations must integrate the combined impacts of warming and humidification, establishing a comprehensive assessment framework that emphasizes both thermal stability and mechanical stability.

To effectively mitigate engineering distresses, the modern permafrost engineering concept of “active cooling and permafrost protection” must be upheld. It is important to recognize the temporal mismatch between the geological history of permafrost aggradation and degradation and the designed service life of engineering structures. Nevertheless, the hazard effects of permafrost degradation cannot be overlooked. Strengthened composite measures, such as enhanced heat dissipation techniques for subgrades, are required to achieve overall ground cooling.

A paradigm shift from purely thermal stability management to integrated water-thermal-mechanical stability control is urgently needed. This can be accomplished through three synergistic strategies: comprehensive waterproofing to control surface water infiltration, overall cooling to lower ground temperature, and ground reinforcement to improve bearing capacity. Furthermore, the future of permafrost engineering lies in the convergence of numerical simulation and artificial intelligence. These advanced tools should be leveraged to accelerate the development and optimization of novel structural designs and resilient materials, enabling proactive rather than reactive responses to permafrost degradation. In conclusion, by adopting a holistic, multi-factor, and technology-driven approach, the prevention and mitigation of engineering distresses in permafrost areas can be significantly enhanced, ensuring long-term stability of infrastructures under a warming and wetting climate.

HISTORY, DEVELOPMENT, AND CURRENT CHALLENGES OF PERMAFROST STUDIES IN MONGOLIA



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Dr. Yamkhin Jambaljav, with more than 30 years of experience in permafrost investigations in Mongolia, presents an overview of the evolution of permafrost studies from the early exploratory surveys to modern multidisciplinary research involving geocryology, geophysics, remote sensing, climate analysis, and engineering applications. The presentation also acknowledges the valuable work of previous researchers whose studies established the foundation of contemporary permafrost science in Mongolia.

Permafrost currently underlies approximately 29.3% of Mongolia's territory, occurring across a wide range of climatic and geomorphological settings. It is distributed from continuous and discontinuous permafrost zones in northern Mongolia and high mountain regions to sporadic and isolated permafrost in low elevation areas, including intermountain depressions, river valleys, and wetlands. This diverse distribution makes Mongolia an important natural laboratory for studying the response of permafrost to climate change in semi-arid environments.

Over recent decades, the thawing and disappearance of permafrost have become significant environmental and socioeconomic challenges. Permafrost degradation contributes to the drying and disappearance of springs, wetlands, and small rivers that serve as critical water resources for local communities, livestock, and ecosystems. These changes alter groundwater dynamics, reduce water availability, and threaten biodiversity in permafrost dependent landscapes.

In semi-arid regions, the degradation and disappearance of permafrost initiate a cascade of environmental impacts. These include declining groundwater recharge, shrinking surface water bodies, deterioration of pastureland, increased soil erosion, and the expansion of desertification processes. As the frozen ground thaws, changes in soil moisture and vegetation cover further accelerate land degradation and ecosystem instability.

Permafrost thaw also poses serious risks to infrastructure and economic development. Ground settlement caused by the loss of ground ice can lead to uneven road surfaces, wave deformations, embankment instability, and pavement cracking. Buildings, and other engineering facilities constructed on permafrost are increasingly vulnerable to foundation instability, wall cracking, and structural deformation. These challenges are particularly important as Mongolia expands transportation corridors, mining infrastructure, and urban development in permafrost regions.

The presentation discusses the current state of permafrost monitoring and research in Mongolia, and it also highlights the need for enhanced long term monitoring networks, integrated environmental observations, improved engineering design standards, and adaptation strategies to address the growing impacts of climate warming on permafrost landscapes and infrastructure.

Understanding the history, present condition, and future evolution of Mongolia's permafrost is essential for sustainable water resource management, ecosystem conservation, infrastructure resilience, and climate change adaptation. Continued collaboration among scientists, engineers, policymakers, and local communities will be critical for addressing the challenges associated with permafrost degradation in the coming decades.

UNDERSTANDING THE IMPACTS OF FROST JACKING ON IN-SITU INFRASTRUCTURE: INSIGHTS FROM THE HUDSON BAY RAILWAY IN MANITOBA, CANADA



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As the singular land connection to Churchill, Manitoba, the Hudson Bay Railway (HBR) functions as a crucial transportation link within Canada. The railway is utilized by over 30,000 people in Northern Manitoba and Nunavut's Kivalliq region and is the sole access route to the Port of Churchill, the only deep sea (sub)arctic port in Canada. The location of the railway, traversing the Hudson Bay Lowlands through the transition from unfrozen ground in the south to continuous permafrost in the north, drives a series of challenges to its ongoing maintenance. Its previous closure in 2017 due to severe flooding and washout conditions had a significant economic impact on the Town of Churchill and remote communities that depend on the supply line, increasing the price of goods and leading to food and fuel shortages. One challenge is the maintenance of the track surrounding and crossing over the numerous bridges present along the length of the railway.

To investigate the impacts of bridge crossings on the Hudson Bay Railway, a multi-part study was undertaken focused on the northern 300 kilometres of the railway. Using five years of track geometry data, the long-term performance of the bridges in this region was evaluated using a track quality index. Through this evaluation, 67% of structures with high maintenance needs were identified to be impacted by frost heave and frost jacking. 70% of structures in the northern 200 kilometres of the railway have also been impacted by frost action, indicating the importance of further investigation of the behaviour of impacted structures and foundations for long-term.

Given the impacts of frost action on the Hudson Bay Railway's bridge infrastructure, one impacted site was selected for further investigation. The Horn Creek Crossing, located at the northern extent of the extensive discontinuous permafrost zone, had undergone an average of 455 mm of upward displacement between 2010 and 2022. A structural health monitoring system was implemented at the site to characterize the impacts of frost jacking and quantify its ongoing impact on the bridge. Validation of the system was undertaken when the bridge underwent a repair to re-level the structure. This medium-term solution reduced the length of the impacted piers to allow for the development of long-term replacement strategies. A rate of uplift at the site was measured to be 25 mm/year between 2022 and 2024. Isolated impacts from frost jacking at the northern pier of the bridge were found to be related to the differing thermal profile across the site, with an approximate 1 metre difference in the depth of frost penetration between the northern and southern sides of the creek. This study quantifies, for the first time in existing literature, the rate of uplift from frost jacking on operational infrastructure and the occurrence of seasonal recovery after uplift.



1A: ADVANCES AND CHALLENGES IN PERMAFROST MONITORING, MAPPING, AND MODELING

Conveners: Youhua Ran¹, Jambaljav Yamkhin², Min Feng³, Tonghua Wu¹ & Huijun Jin⁴

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Rapid climate change is exposing critical gaps in permafrost observation and mapping, hindering adaptation and mitigation efforts. This session brings together work spanning in situ measurements, long-term monitoring networks, remote sensing, and geospatial analysis. We invite contributions showcasing new datasets, AI-enabled mapping methods, and integrated observation systems that improve detection of permafrost changes and early-warning indicators, with emphasis on harmonizing multi-source observations and addressing uncertainties to support modeling, policy, and adaptation strategies.





REPEATED GEOPHYSICAL SURVEYS HELP UNDERSTANDING PERMAFROST DEGRADATION IN NORWAY

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Permafrost, a key component of the cryosphere, is undergoing rapid change under a warming climate, with pronounced spatial variability across Europe. In Norway, the thermal evolution of mountain permafrost has been studied for over two decades using borehole temperature measurements, remote sensing, and numerical modelling. Geophysical methods, particularly electrical resistivity and seismic surveys, offer complementary constraints on subsurface conditions and have been adopted in Norwegian permafrost research over the past 25 years. A coherent monitoring framework was initiated with the drilling of a 129 m borehole at Juvvasshøe (Jotunheimen) during the European PACE (Permafrost and Climate in Europe) project in 1999, forming a foundation for subsequent multi-temporal geophysical surveys across Europe. In 2025, we installed a novel, low-cost, low-power and robust Autonomous Electrical Resistivity Tomography (A-ERT) monitoring system in Jotunheimen, Norway, adjacent to the existing borehole and a long-running multi-temporal ERT array (Farzadian, M. et al, 2023, GRL, 10.1029/2023GL105770). The system leverages an open-source processing workflow for permafrost monitoring that integrates diagnostic, and filtering tools and uses the open-source inversion software ResIPy. This presentation synthesizes major findings from Norwegian multi-temporal monitoring since 2000 (Fig. 1) and introduces the first results from the A-ERT at Jotunheimen, based on a one-year data record. Together, these datasets demonstrate the value of continuous, autonomous geophysical monitoring for resolving seasonal to interannual subsurface changes, improving interpretation of borehole temperatures, and enhancing our ability to assess permafrost sensitivity and hazard potential under ongoing climatic warming.

Keywords: Norway, geophysical, ERT, permafrost change

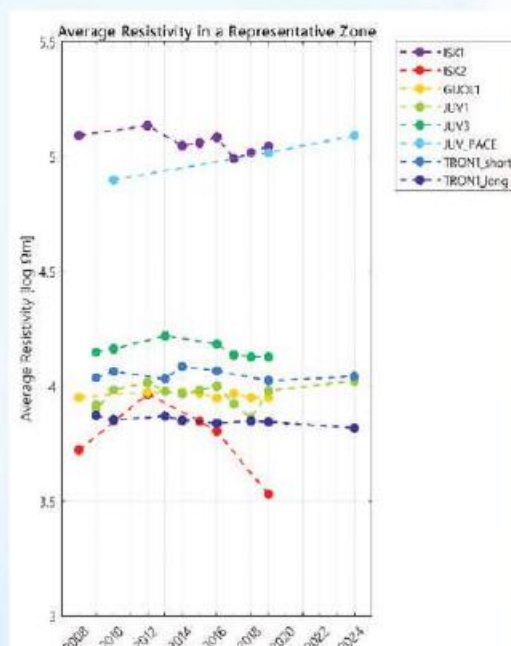


Fig 1. Development of specific resistivity at borehole locations at the sites where multi-temporal ERT surveys were measured in Norway. The values are calculated as a spatial mean over a defined area ("representative zone"). Isk = Iskoras/Northern Norway. Juv = Juvvass area, Jotunheimen, southern Norway. Tron = Tronfjell, s. Norway.



30 YEARS OF CHANGE IN THE VAIŠJEÄGGI PALSA MIRE, UTSJOKI, FINLAND

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Palsa, peat covered permafrost mounds with cores containing frozen peat, silty till with small ice crystals and segregated ice layers, are the dominant landsystem of the Vaišjeäggi Mire, Finland. Knowledge of recent change in these palsa is important to understand the response of the landsystem to ongoing regional climate change. Here we construct surface elevation models from 1986 using aerial photographs, and from 2010 and 2015 using ground based terrestrial laser scanning. Aerial photographs were scanned at 1700dpi with a photogrammetric scanner, producing a ground sample distance (pixel size) of 10 cm. Photogrammetric processing was carried out in BAE Systems SocetSet v5.5.0. Ten ground control points were located on fence posts and bedrock around the mire allowing the generation of a 1m grid digital terrain model (DTM) mosaic. 2010 and 2015 RIEGL terrestrial laser scanning surveys were cleaned, aligned and geo-registered in RiSCAN PRO. Eight scan locations were used with the scans co-register using targets distributed throughout the scanning scene and geo-referenced using Trimble differential GPS surveys. The point clouds were then used to build 1 m² DTM in order to ensure comparability with the photogrammetric DTM. The three DTM were differenced by subtracting the composite 2010 and 2015 raster datasets from the 1986 photogrammetric raster. Our results indicate substantial and accelerated degradation of the palsa mounds. Mounds are both (i) losing elevation with the centres of the palsa lowering, and (ii) reducing in spatial area with the steep edges of the palsa increasing in gradient and retreating towards the mound centre. Larger mounds are also subdividing into multiple smaller mounds with trenches to open water emerging between the new, smaller mounds. We suggest that as temperature of both the air and water of the mire rises, the palsa landsystems will degrade further with present mound systems being entirely degraded by 2050. This has implications for peatland hydrology, carbon storage and the ecosystem of the palsa mounds. Work was conducted with the late Professor Matti Seppala.

Keywords: Palsa, permafrost, degradation, climate change



GEOMETRY-CONTROLLED, NON-LINEAR GROUNDWATER RESPONSES TO PERMAFROST DEGRADATION AT 5,200 M ASL

Sebastian Ruiz Pereira, PhD

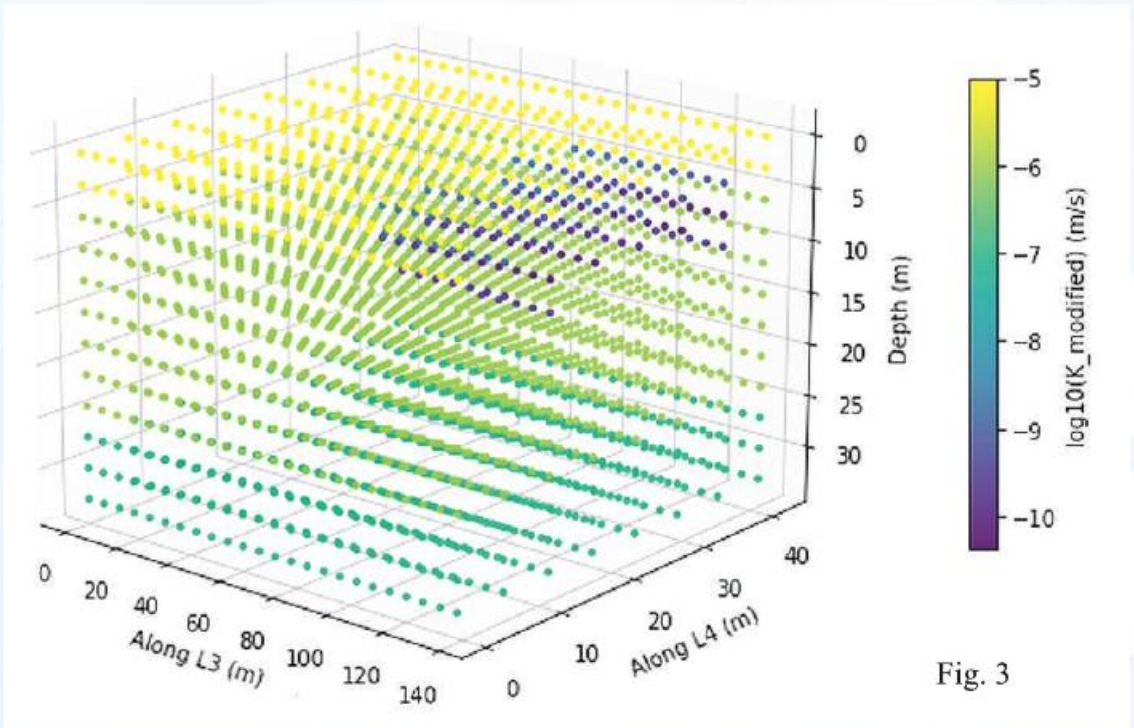
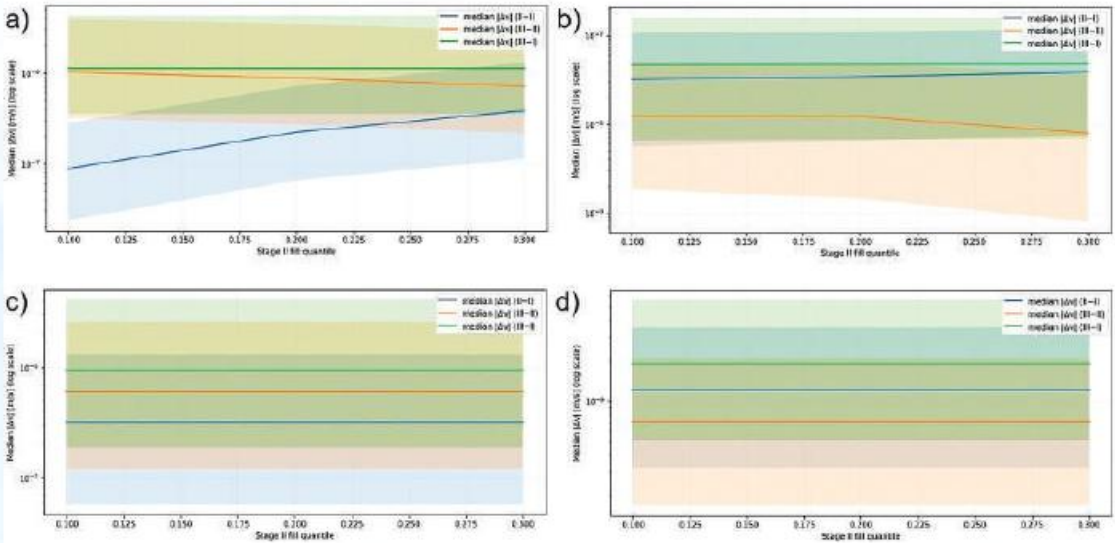
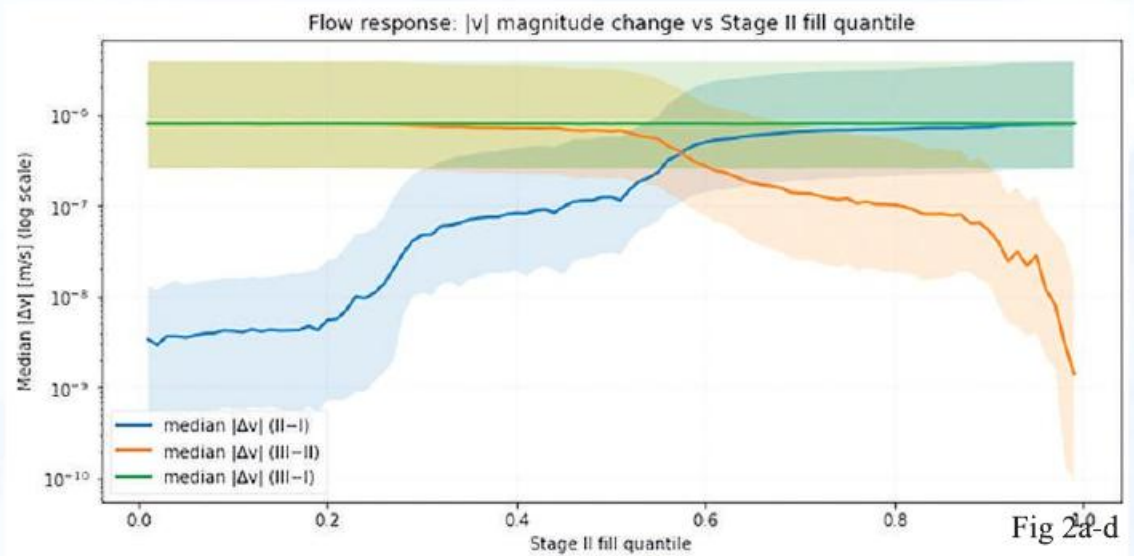
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Permafrost degradation fundamentally alters subsurface hydraulic connectivity in high-mountain environments, yet its hydrogeological consequences remain poorly constrained due to limited integration between field geophysics and process-based modeling. We investigate permafrost structure and its hydraulic role at Ojos del Salado volcano (Central Andes) using a combined geophysical and numerical modeling approach across contrasting sites. Electrical Resistivity Tomography (ERT), Seismic Refraction Tomography (SRT), and Time-Domain Electromagnetic (TDEM) surveys were conducted at a high-elevation site (Atacama camp), revealed high-resistivity ($>10^4 \Omega \cdot m$) and high-velocity ($>1500 \text{ m/s}$) layer consistent with frozen ground at $\sim 2\text{-}3 \text{ m}$ depth, underlain by a resistivity decrease at $\sim 15\text{-}20 \text{ m}$. These observations confirm strong lateral and vertical heterogeneity in frozen-ground distribution across the massif which implies a geometrical constraint for degradation and its impact on recharge. Hence, we translated these findings into a pseudo-3D hydraulic conductivity domain (Fig. 1) and integrated into MODFLOW 6 simulations. Progressive permafrost degradation was simulated through three structural scenarios, representing stepwise shrinkage of low-permeability volumes from baseline to aquitard absence. We examined flow velocity responses in these stages also using different pseudo-3D cubes and additionally, using the same amount aquitard data points from geophysics data, we changed the aquitard shape as a perched layer, a sphere and a negative aquitard control as full experiment (Fig. 2 a-d). Results show a non-linear hydrogeological response to permafrost degradation only in the geometries of field-geophysics and perched layer aquitard shapes. Flow-field reorganization exhibits threshold-like behavior, with a transition from fragmented to laterally integrated flow occurring at intermediate degradation levels ($\sim 20\%$). Spatial coherence of flow responses increases systematically with depth, while upwelling patterns display abrupt collapse and recovery as aquitard connectivity is modified. Further non-linear behavior around 50% degradation of the aquitard is also consistent for the structure of geophysics pseudo 3D cube (Fig. 3). These findings demonstrate that permafrost acts as a discontinuous aquitard whose degradation triggers emergent connectivity, in non-linear fashion rather than gradual hydraulic change and at different steps of aquitard modification. This study highlights the importance of integrating multi-method geophysics with reproducible numerical modeling to resolve permafrost hydrological interactions and provides a transferable framework for assessing subsurface connectivity thresholds in cold-region mountain systems.

Keywords: Mountain permafrost, hydrology, geophysics, MODFLOW





DEPENDENCE OF ACTIVE LAYER DEPTH ON METEOROLOGICAL PARAMETERS

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In the early published physical representations of the active layer depth, it was related temperature profile in the ground, its heat conductivity, moisture content and duration of thaw. Evidently, temperature distribution in the ground, as well as thermophysical characteristics of the ground, can rarely be measured and not easy to predict so, in terms of depth of freeze, the proposed equation includes “time of surface temperature to be below 0°” and “freezing resistance”. Based on Stefan solution proportionality of thickness of frozen layer to the square root of time was considered as a reasonable application to the thaw depth problem solution. Later, the correction factors from required surface temperatures to the measured air temperature for various ground surfaces were developed and resulted in algorithm to calculate the thaw depth. The effect of snow cover, vegetation and difference in thermal properties of frozen and thaw ground could be included into estimation of thaw or freezing depth as summands to temperatures and its amplitudes in corresponding units. Despite existence of rather detailed physical constructions to estimate freezing and thaw depth, they were repeatedly mentioned as having limited applicability due to lack of required data. In applied science the constructions are historically mainly replaced by semi-empirical “design curves”, relating frost depth to freezing index, assumed to be interchangeable with the pair thaw depth/thawing index. In mapping and classifications by linear relation between an “edaphic” and “climatic” terms. The recent works incorporating remote sensing data and collected on-site datasets are based on such interpretation of the Stefan solution. Some refinements to the solution are proposed involving correction from the alternative Neumann equation, but the basic numerical outcome that for 0 degree days the thaw depth is 0 is not affected. The presentation is an attempt to analyze such “axiom” on an example of selected CALM record.

Keywords: Active layer, thermal regime



QUANTIFYING DEGRADING PERMAFROST WITH REPEAT AIRBORNE LIDAR, GEOPHYSICS, AND THAW PROBING

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We have been measuring permafrost thaw and associated ground surface subsidence via field-based and remote-sensing techniques for 20 years near Fairbanks, Alaska. 400 meter long transects at four sites represent an unburned area and three fire scars (1988, 2001, and 2010). Three different types of permafrost quantification were used to measure lateral and top-down thaw of near-surface permafrost. First, measurements of ground surface elevation and depth to the top of near surface permafrost were repeated every few years. From this, we measured widespread near-surface permafrost degradation between 2004 and 2020 with top-down thaw of near-surface permafrost doubling from 18% to 36 %. Permafrost aggradation was almost completely absent by 2020. Second, rates of top-down versus lateral thaw were calculated using airborne lidar collected in 2014 and 2020. Tabular permafrost bodies thawed laterally and unfrozen zones (taliks) developed between the bottom of the seasonally frozen layer and the top of near-surface permafrost. Third, electrical resistivity tomography (ERT) measurements made in 2012 and 2020 allowed subsurface permafrost mapping up to 20 m deep. Though all methods allowed us to measure rates of permafrost degradation over time no single method provides all the information needed to adequately assess permafrost change. Frost probing is well suited for quantifying top-down and lateral thaw. Repeat lidar allows identification of vertical and lateral ground surface subsidence attributed to permafrost thaw but does not directly quantify thaw rates. Single pass ERT identifies the presence/absence of permafrost at tens of meters depth while repeat ERT can identify changes in subsurface morphology over time. Future applications of these methods should focus on relating surface and subsurface variables measured on the ground to information that can be remotely sensed across broad regions.

Keywords: Remote sensing, lidar, geophysics



WARMING OF MOUNTAIN PERMAFROST IN THE DAISETSU MOUNTAINS, HOKKAIDO, JAPAN

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Rapid climate change is exposing critical gaps in permafrost observation, particularly in marginal mountain environments where monitoring data is sparse. This study reports on the long-term results of permafrost and micrometeorological monitoring at the summit area of the Daisetsu Mountains, Hokkaido, Japan. Mountain permafrost is distributed in a complex manner in the higher zone (above approximately 1700 m a.s.l.) of this mountain range (43.6°N, 142.9°E). To understand the thermal regime and its response to global warming, a monitoring station was installed at four wind-exposed sites at Goshiki Station (2038 m a.s.l.) in 2005, initiating continuous micrometeorological measurements and ground thermal/hydrological monitoring that have now spanned two decades (2005-2025). Contemporaneously, ground temperature was also measured at three sites with varying topographic and geomorphological settings. Additionally, L-band SAR interferometry was employed to understand spatio-temporal variations in the surface displacements associated with freeze-thaw cycles. The monitoring results reveal a significant shift in the ground thermal regime. Current borehole observations at the Goshiki site confirm that permafrost extends from approximately 1.5 m to at least 10 m. The mean annual temperature at a depth of 5 m increased semi-monotonically from -3.1 to -1.8 °C until 2015. After a few years of a cooling period to -2.2 °C by 2018, we observed a rapid warming to -1.5 °C in 2024. The overall warming rate was 0.08 °C/year in the last two decades. From 2018 to 2025, ground temperatures rose at a rate of 0.13 °C/year, mainly driven by the recent rapid increase in air temperature widely observed in Japan. We report comparative warming trends in the other three boreholes in the Daisetsu Mountains. This accelerated warming is consistent with our recent findings in the neighboring Hidaka Mountains, where borehole observations in 2024 suggested the recent disappearance of permafrost due to similar rapid ground warming. InSAR analysis revealed continuous downslope mass wasting, likely of permanently frozen debris, at several locations along the range, and the seasonal ground surface displacement detected at the wind-exposed sites was well aligned with ground measurements. These findings indicate that the mountain permafrost environment in Japan is undergoing a rapid transition. Simple linear extrapolation indicates that the permafrost temperature at 5 m depth could reach 0 °C within the next two decades. This observation strongly supports recent numerical model predictions that the climatic conditions suitable for maintaining mountain permafrost in Japan may be lost in the near future. The rapid degradation of this “marginal” permafrost could significantly impact slope stability and mountain ecosystems. Our integrated monitoring provides essential in situ data to validate projection models and develop adaptation strategies for changing mountain environments.

Keywords: Mountain, warming, long-term, displacement, Daisetsu



THERMOKARST LAKE EVOLUTION AND POTENTIAL CHANNELIZATION IN THE DARKHAD BASIN, NORTHERN MONGOLIA

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In the permafrost regions of Northern Mongolia, particularly within the Darkhad Basin, thermokarst activity is intensifying in response to climate change. Recent observations suggest that these topographical alterations may fundamentally reorganize hydrological regimes by fostering channel networks within the depressions of polygonal microtopography. As ice-rich permafrost thaws, localized subsidence facilitates the formation of wetlands and small thermokarst lakes. Through horizontal expansion and lateral erosion, these water bodies eventually merge and drain, a cycle known as the “lake and drained lake basin (L-DLB) system.” In this semi-arid environment, such transitions induce profound shifts in water security and ecosystem stability. This study examines the Darkhad Basin as a critical site for emerging channelization. While satellite imagery identifies high densities of small water bodies (diameter <100 m), the subtle mechanisms of lateral erosion and incipient connectivity often elude coarse-resolution sensors. To bridge this gap, we conducted an intensive field campaign in August 2025 using Unmanned Aerial Vehicles (UAVs) to capture high-resolution imagery across key thermokarst clusters. By synthesizing ultra-high-resolution UAV-derived Digital Surface Models (DSMs) with the expansive spatial coverage of satellite products like AW3D, we developed a synergistic framework that enhances the interpretability of thermokarst dynamics. This approach allows high-precision local data to refine and validate regional trends, providing a multi-scale view of complex drainage evolution. Our geomorphological analysis confirms that numerous depressions are distributed across the basin, with nascent channels several meters wide already connecting adjacent lakes. These features indicate that drainage pathways are transitioning into formal channelized networks. Because conventional satellite imagery cannot definitively predict flow trajectories or merging sequences, the integration of UAV-based Structure-from-Motion (SfM) photogrammetry is essential. These models resolve micro-topographic gradients and erosional traces-undetectable at larger scales-to accurately estimate future channel directions. Since the turn of the century, intensified climate warming in Northern Mongolia has accelerated the expansion of thermokarst wetlands. The Darkhad Basin has entered a phase of rapid lacustrine development. As thawing continues, increased connectivity will likely trigger abrupt drainage events and subsequent landscape desiccation. Such hydrological shifts are inextricably linked to irreversible changes in ecological processes and pastoral productivity. Consequently, the high-resolution spatiotemporal evaluation initiated in 2025 is vital for forecasting the evolution of these fragile Mongolian permafrost landscapes.

Keywords: L-DLB systems, thermokarst, SfM, DSM



DETECTING ACTIVE LAYER DETACHMENTS USING HIGH-RESOLUTION TERRAIN DATA AND MACHINE LEARNING IN THE BROOKS RANGE, ALASKA

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Rapid Arctic warming is accelerating permafrost thaw and increasing the frequency of abrupt thaw processes that destabilise landscapes, mobilise carbon, and alter hydrological pathways. Active layer detachments (ALDs), shallow, translational failures of the seasonally thawed active layer, are poorly represented in regional and pan-Arctic permafrost inventories owing to their small areal extent, subtle topographic expression, rapid revegetation and limited spectral separability from other disturbances in freely available repeat satellite imagery. This study addresses these challenges by developing a scalable, terrain-based framework for detecting and characterising ALDs using remote sensing and machine learning techniques. The objectives of this research are to (1) quantify the geomorphological and environmental characteristics of ALDs, (2) develop an automated classification approach within Google Earth Engine (GEE) for detecting ALDs from high-resolution digital elevation data (ArcticDEM), and (3) assess the potential of terrain-derived parameters to improve permafrost disturbance mapping. Training and validation were conducted in the Brooks Range, Alaska, using an existing inventory of >2200 mapped ALDs. Methods combine ArcticDEM Version 3 mosaic data (2 m resolution) with cloud-based geospatial analysis in GEE. Terrain variables, including slope and mean curvature, were derived, with micro-topography enhanced using the Multi-Scale Relief Model (MSRM), parameterised to quantified ALD dimensions. Grey-level co-occurrence matrix (GLCM) textures derived from normalised terrain surfaces were used to capture edge structures and internal variability. Object-based image analysis was used to segment the terrain into geomorphologically meaningful units, which were used to train a Random Forest classifier using a high-density ALD area in the central Brooks Range (67.85-68.10° N, 156.07-155.85° W) and evaluated against the ALD inventory using standard accuracy metrics. Results show that ALDs exhibit statistically distinct morphometric signatures relative to surrounding hillslopes, occurring preferentially on moderate slopes, with strongly negative curvature and MSRM values indicating disrupted micro-relief. Classified ALDs follow characteristic dimensional ranges and scaling behavior consistent with power-law relationships reported for shallow permafrost failures. Comparison with the ALD inventory shows that the classifier reproduces mapped ALDs while capturing a more complete representation of ALD extent beyond that of optically visible bare scar areas, enabling improved estimates of total disturbed area. This work demonstrates that AI-enabled analysis of high-resolution terrain data can substantially improve detection of small-scale permafrost disturbances that are largely absent from existing mapping inventories. By leveraging widely available DEM products and a terrain-based classification workflow, the approach supports regional-scale mapping and improved characterisation of ALD extent. However, reduced performance beyond the Brooks Range, in regions with contrasting glaciation and vegetation histories, highlights the need for further refinement to improve transferability and reduce uncertainty across diverse permafrost landscapes.

Keywords: Active-layer detachments, Random Forest, ArcticDEM



LAKE - DRAINED LAKE BASIN (L-DLB) SYSTEMS OF THE LENA AND KOLYMA LOWLANDS OF EASTERN SIBERIA

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Lakes and drained lake basins cover 20% to 75% of permafrost lowland regions on a pan-Arctic scale. Lakes and DLBs create a heterogeneous and dynamic mosaic of terrain units which provide unique habitats for flora and fauna and substantially impact biogeochemical cycling of these regions. Lowland permafrost regions of Eastern Siberia are characterized by abundant L-DLB systems, including overlapping DLBs of different ages and at different drainage stages. The formation of DLBs leads to successional dynamics that include permafrost aggradation, soil formation, carbon sequestration, and creation of a diverse habitat mosaic in Arctic permafrost regions. Here we use DLB area extent data derived through a recently published scalable DLB mapping approach. The mapping approach is tailored to pan-Arctic lowland permafrost areas and employ a Random Forest model, utilizing a range of input parameters including surface characteristics, terrain information, and multispectral remote sensing data. The input parameters were chosen to be able to characterize critical landscape types associated with DLB regions, going beyond the typically studied lake-rich coastal lowland landscapes to include also boreal forest and discontinuous permafrost zones. The method was tested for a wide range of study areas across Alaska, Canada, and Siberia, representing different permafrost, climatological and geological settings. In addition to the DLB area extent, we characterize the variability present between DLBs of the Eastern Siberia permafrost lowlands utilizing a variety of data sets ranging from indices derived from multispectral satellite imagery, Synthetic Aperture Radar backscatter, landcover classifications, lake extent data sets to DEMs. Preliminary results indicate distinct differences between assumed basin ages, the north-south gradient and tundra and boreal regions. Results like this will contribute to large scale efforts quantifying basin age distributions, post-drainage successional trajectories, and spatial linkages between lake drainage, permafrost aggradation, and carbon accumulation across contrasting permafrost regions.

Keywords: Lakes, DLB, drainage, remote sensing



IMPACTS OF CLIMATE VARIABILITY AND PERMAFROST THAW ON PRESENT DAY AND FUTURE HYDROLOGICAL REGIMES IN THE SELENGE BASIN

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The Selenge River Basin is the largest drainage basin in Mongolia containing more than 65% of the total Mongolian population. The basin is located in a semi-arid region underlain by discontinuous to sporadic permafrost which is highly sensitive to climate change. Therefore, it is essential to examine the responses of the hydrological system to climate variability, permafrost thaw and human impacts. To assess contemporary and future changes in the water cycle processes across the basin and estimate the role of permafrost we applied the UNH Water Balance Model (WBM), which was recently coupled with the Geophysical Institute Permafrost Laboratory (GIPL) model to take into account dynamics of permafrost and seasonally frozen ground. The WBM has extensive modules designed to capture the broad-scale influences of humans on the water cycle. The model has a recently developed comprehensive water components and constituents accounting system allowing us to track water sources by their origin as water moves through the hydrologic system including snow, glacier, permafrost thaw components in streams and groundwater storages. The historical hydrological simulations for the Selenge drainage basin have been made for a set of climate drivers, including reanalysis the products of MERRA2 and ERA5 with spatial resolutions of approximately 50 and 10 km respectively. We have also produced downscaled 5 km resolution climate data using the regional Weather Research Forecasting model (WRF). Many climate input variables (e.g. precipitation, air temperature, humidity) as well as WBM/GIPL outputs (e.g. river discharge, ground temperature, active layer thickness) were validated with in-situ observations where some significant discrepancies were found in upstream parts of the basin with complex mountainous terrain. We used the WBM tracking system to evaluate contributions of different climatic variables and permafrost thaw to river flow in different parts of the basin over 1980-2023 and found that permafrost thaw added approximately 10% to streamflow at the end of summer and early fall. Precipitation variability was found to be a major factor of river discharge change in the basin impacting regional water availability for humans and livestock. We will also present results of future WBM hydrological simulations for several climate scenarios and GCM outputs downscaled with WRF. Most of the data used for our analysis is accessible through the Rapid Integrated Mapping and Analysis System for the SESTRA project (SESTRA-RIMS), an online tool for data sharing, exchange, and rapid analysis: <https://sestra.unh.edu>.

Keywords: Hydrology, permafrost, climate change



POTENTIAL FOR MAPPING SEASONAL AND INTERANNUAL PERMAFROST SURFACE DEFORMATION WITH SENTINEL-1 IN THE NORTHERN HEMISPHERE

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Permafrost degradation is widespread across the Northern Hemisphere under ongoing warming and increasing climate extremes. It has cascading impacts on hydrology, ecosystems, carbon cycling, and the integrity of built infrastructure. These risks are pronounced in Asia, where transportation and energy corridors cross mountain and transitional permafrost. Surface deformation driven by freeze-thaw cycling, excess-ice thaw, thermokarst development, and hydrologic redistribution is common in permafrost landscapes. It provides a quantitative indicator of active-layer and near-surface permafrost dynamics, not merely surface change. Radar interferometry (InSAR) is widely used to map surface deformation from seasonal to interannual scales, and the open Sentinel-1 archive (now >10 years) enables consistent, large-area monitoring. Yet C-band observations often suffer strong temporal decorrelation, which is mainly relating to freeze-thaw transitions, soil-moisture changes, vegetation and canopy motion, and snow accumulation and melt. Thus, the spatial extent and temporal scale over which Sentinel-1 can reliably support permafrost deformation mapping remain poorly constrained at hemispheric scale. Here we develop a permafrost-tailored bi-exponential temporal decorrelation model that represents both short-term seasonal decorrelation and longer-term interannual coherence loss. We apply the model to Sentinel-1 coherence using one-year seasonal coherence mosaics (winter, spring, summer, autumn) compiled at repeat intervals of 12, 24, 36, and 48 days across Northern Hemisphere permafrost regions. We map optimal maximum temporal baselines for both intra-annual and interannual interferograms using defined coherence thresholds. The resulting dataset provides practical guidance for interferogram selection and time-series network design. It also identifies regions where only seasonal deformation retrieval is robust and regions where interannual deformation retrieval is feasible. To assess controls on coherence loss, we combine ancillary datasets on temperature, snow regime, vegetation structure, moisture availability, and topography with explainable machine learning to quantify the relative importance of each factor by season and region. The results identify dominant decorrelation drivers and their geographic variability. As the first study to place Sentinel-1 coherence products into a consistent global framework, this work provides a baseline assessment of where Sentinel-1 can support surface-deformation monitoring and offers observational constraints to improve model representation of near-surface conditions relevant to permafrost stability.

Keywords: Permafrost, surface deformation, InSAR, coherence



PROBLEMS OF REGIONAL ANALYSIS OF THE PERMAFROST STATE AND DYNAMICS (EUROPEAN NORTH AND EASTERN SIBERIA'S CASES)

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There are no generally accepted approaches for the entire scientific community of permafrost scientists to the choice of regional indicators of the state and dynamics of permafrost. Simply averaging regional data is not enough. It is necessary to take into account regional variability in permafrost characteristics and different ways of analyzing them. We would like to discuss the importance of data scaling and the issues of comparability and representativeness of data from different regions. We need to choose: - An areal element used to estimate the state and dynamics of permafrost. There is experience in using a landscape taxon, a drainage basin, etc.- Typical depths for which an estimate of the state and dynamics of permafrost is provided. These may include the base of the active layer, the depth of seasonal temperature fluctuations, etc.- Indicators of the state of permafrost. For example, the temperature regime characteristics for a given year, the contact between permafrost and active layer, etc.- Indicators of permafrost dynamics, such as temperature trends, movement of talik boundaries, and the activity of periglacial processes. - A time interval for measuring the state and dynamics of permafrost, such as season, year, multi-year periods of different lengths. An important problem is also the determination of a method for a time and spatial data aggregation, in relation to different types of analysis and map scales. Approaches to solving the problems posed are discussed based on the analysis of a number of various monitoring data from regions of Russia. In the European North of Russia a lowering in the permafrost top in the mineral ground of the northern part of the region has been noted. Numerous cases of new permafrost have been observed in the discontinuous permafrost zone up to its southern boundary. This new permafrost is formed in areas of grass-sedge bogs and in inter-block depressions of convex peatlands. In the Baikal region the permafrost is located in the wetland depressions. Changes in soil temperature are slight. In permafrost, temperatures rise. In the active layer the temperature has been decreasing since 2012. In Northern Transbaikalia mountain the permafrost has been relatively warming over the past 20 years with a gradient of $+0.04 - +0.13^{\circ}/\text{year}$, and ground temperature in the intermountain depressions have, on the contrary, stabilized or even been relatively decreased (gradient $-0.01 - +0.03^{\circ}/\text{year}$). Long-term thermometric observations are carried out from 1986 to 2025. In Southern Transbaikalia, permafrost is almost continuous in the steppes and temperatures close to 0° . Permafrost temperatures have remained virtually unchanged for 5 years. Continuous permafrost is common in the Upper Kolyma Highlands (Magadan region). Observations are carried out in 29 boreholes, at 2 CALM sites, 4 gauging stations and 2 automatic weather stations. The observed dynamics of the giant Anmangyndinskaya Icing are related to changes in geocryological conditions. The possibility of a broad discussion of the formulated problems will make it possible to solve the task of updating small-scale permafrost maps.

Keywords: Permafrost state, regional analysis, monitoring



GEOCRYOLOGICAL MAPPING WITH LANDSCAPE-INTEGRATED VARIABILITY FOR ACTIVE LAYER THICKNESS AND 10 M GROUND TEMPERATURE IN YENISEY NORTH

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Reliable assessment and mapping of active layer thickness (ALT) and ground temperature at 10 m depth are critical for understanding permafrost dynamics and supporting infrastructure planning in Western Siberian permafrost regions characterized by sparse and unevenly distributed observational data. The study area in Yenisey North spans the transition between the West Siberian Plate and the Siberian Platform and is characterized by high-temperature permafrost (-0.5 to -0.1 °C), making the region particularly vulnerable to climate-induced thawing and degradation. This setting enables comparative analysis of geocryological conditions controlled by contrasting geological structures, lithology, ice content, and soil thermal regimes. While recent advances in remote sensing and machine learning enable high-resolution characterization of surface conditions, their application to subsurface thermal processes remains limited by weak physical interpretability, poor regional transferability, and insufficient representation of key controlling factors such as lithology, ice content, and soil moisture. This study presents a process-oriented, geology- and geomorphology-based framework for regional geocryological mapping at a 1:200,000 scale, explicitly targeting physically interpretable estimates of ALT and ground temperature at 10 m depth under conditions of sparse and unevenly distributed observations. The approach integrates geological information, including a digitized map of Quaternary deposits and data from approximately 100 boreholes documenting lithology, moisture, ice content, and ground temperature, with geomorphological information derived from terrain morphometry, providing a mechanistic basis for interpreting subsurface thermal variability across the transition zone. Landscape units capture variability in snow accumulation, surface roughness, and vegetation cover, enabling consistent assignment of snow depth and properties to representative terrain-landscape combinations without introducing independent modelling assumptions. Climatic forcing is represented by air temperature and precipitation from the ERA5 reanalysis, downscaled to regional conditions. Ground thermal conditions are simulated using a one-dimensional heat transfer scheme suitable for regional-scale mapping and monitoring. Key thermophysical parameters-including thermal conductivity, volumetric heat capacity, soil moisture, and ice content-are assigned numerically within physically plausible ranges. A scenario-based approach is used to address uncertainty by considering base, favorable, and unfavorable parameter combinations, allowing estimation of representative ALT and ground temperature at 10 m depth together with conservative upper and lower bounds reflecting environmental variability. The resulting product is a geocryological map integrating geological units, geomorphology, and landscape-based variability, providing physically interpretable estimates of ALT and ground temperature at 10 m depth with scenario-based uncertainty characterization. Initial validation in selected areas using borehole data indicates good agreement, with further refinements planned to improve the accuracy of quantitative assessments. The map highlights geocryological contrasts between the West Siberian Plate and the Siberian Platform, including differences in ALT and permafrost stability driven by lithological conditions and high-temperature permafrost regimes, offering insights into regional permafrost vulnerability. The proposed framework demonstrates how geology- and geomorphology-informed mapping, combined with landscape-based aggregation, can complement remote sensing and data-driven approaches in regions with sparse observations, contributing to advances in geocryological monitoring and mapping. The map supports preliminary engineering assessments and facilitates evaluation of subsurface thermal conditions before detailed site-specific investigations.

Keywords: Permafrost mapping, ALT, Western Syberia



RETHINKING PERMAFROST DISTRIBUTION, CHANGE, AND IMPACT: A DATA-DRIVEN PERSPECTIVE

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Rapid climate warming and intensified human activities have increased the complexity of permafrost-related impacts, posing higher demands on the accurate quantification of permafrost distribution, dynamics, and associated effects. In this study, we integrated multiple datasets to produce a new-generation international permafrost distribution map for the Northern Hemisphere, which serves as a new benchmark for understanding and assessing permafrost distribution. Using well-trained ensemble machine learning models, we further evaluated the potential impacts of future vegetation changes on Northern Hemisphere permafrost. The results indicate that, at the global scale, the effects of vegetation greening on permafrost are negligible. However, at regional and local scales, these effects are pronounced and depend on the magnitude of LAI changes and vegetation types. In addition, we developed a novel approach to assess the economic impacts of permafrost degradation on engineering infrastructure and, for the first time, quantified the potential future economic losses associated with permafrost degradation on the Qinghai-Tibet Plateau. These findings update current understanding of permafrost distribution, evolution, and its engineering implications.

Keywords: Ground temperature, machine learning, vegetations



INSAR DERIVED LAND SURFACE DEFORMATION ACROSS ARCTIC LOWLAND PERMAFROST REGIONS

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Interferometric Synthetic Aperture Radar (InSAR)-derived land-surface deformation provides indicators of potential permafrost degradation and its underlying drivers. We assessed both multi-annual and seasonal (unfrozen-period) deformation using Sentinel-1 data for seasonal signals and a combination of Sentinel-1 (C-band) and PALSAR-2 (L-band) observations for long-term trends. Seasonal deformation patterns differed significantly from multi-annual behaviour. To identify the dominant controls on deformation, we applied a Random Forest regressor using land-cover, soil properties, terrain, and disturbance variables. Both seasonal and long-term deformation were associated with vegetation patterns and disturbances (fires). Mean annual ground temperature showed relatively high importance for explaining long-term deformation in both C- and L-band data. The predictive performance was higher for seasonal than for multi-annual rates, particularly when multiple parameter groups were included, while parameter-importance rankings were more uniform across regions for long-term deformation. Our study regions included the Asian sites of the Yamal Peninsula in western Siberia and the Chersky region in eastern Siberia. While parameters influencing long-term deformation were similar for both of these regions, the seasonal deformation results showed a stronger dependence on vegetation for the Yamal transect, whereas topography played a slightly more dominant role in the Chersky region. In contrast to previous studies in the Qinghai-Tibet region, the effect of slope was comparably only minor in our results, which can be attributed to the focus on lowland areas. Given the weak to moderate model performance and the scarcity of in situ observations, reliable InSAR-derived deformation measurements remain essential for monitoring and understanding permafrost degradation across Arctic lowlands.

Keywords: InSAR, Arctic lowlands, Machine Learning



GEOPHYSICAL IMAGING OF NEAR-SURFACE PERMAFROST IN UTQIAĠVIK, ALASKA USING ERT AND GPR

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Permafrost provides the physical foundation of Arctic landscapes and infrastructure, but its long-term stability is tightly linked to surface thermal conditions that are now being disrupted by climate change and land use. Recent regional assessments indicate that nearly 70% of Arctic infrastructure could be affected by permafrost thaw by 2050, with Utqiagvik, Alaska highlighted as a hotspot of projected moderate to high ground subsidence under future climate scenarios (Hjort et al., 2022). These projections underscore the need for detailed, site-specific characterization of shallow permafrost in and around Arctic communities to understand how different infrastructure types and local surface processes influence thaw. Noninvasive geophysical techniques offer an effective way to resolve subsurface heterogeneity, providing information that is critical both for assessing site conditions prior to construction and for monitoring infrastructure performance over time. In this study, we use a combined geophysical and surveying approach, integrating Electrical Resistivity Tomography (ERT), Ground Penetrating Radar (GPR), and thaw probing, to characterize near-surface permafrost variability across four contrasting land use types in Utqiagvik: a gravel road, a snow fence, a residential building, and undisturbed tundra. This design provides an internally consistent dataset that links active layer thickness and permafrost structure to infrastructure configuration and local environmental conditions, including snow accumulation, shading, vegetation disturbance, and meltwater redistribution, all of which influence the ground thermal balance. Across all four sites, variations in active layer thickness were related to land use and surface characteristics. Ice-wedge polygon terrain adjacent to infrastructure, particularly near roads and snow fences, exhibited the deepest thaw (>0.5 - 1.0 m), low to moderate resistivity in ERT inverse solutions (10 - $1,000 \Omega \cdot m$), and diffracted or attenuated GPR reflections. These signatures indicate degradation of ice wedges and increased water saturation in the upper permafrost. In contrast, frost-heave-dominated terrain with undisturbed vegetation, natural drainage and minimal surface disturbance maintained shallower thaw (0.2 - 0.5 m) and high resistivity ($>1,000 \Omega \cdot m$), consistent with relatively stable, ice-rich permafrost. Snow thickness variations and meltwater pooling induced by infrastructure emerged as key drivers of active layer variability, producing sharp lateral contrasts between zones of enhanced thaw and areas of active frost heave. These results suggest that elevated buildings can partially decouple anthropogenic heat from the underlying ground and, through self-shading and reduced snow accumulation beneath the structure, may even foster local permafrost aggradation. At the same time, these buildings can promote degradation along their margins where roof runoff and wind-driven snow accumulation enhance ground warming and saturation. Building on these results, we propose that repeat or real-time ERT-GPR surveys combined with thaw probing should form the backbone of a robust urban permafrost monitoring strategy. Complementary borehole temperature observations, snow depth measurements, regular frost probing, and remote sensing products can further improve the detection of thaw fronts, frost heave, and other near-surface permafrost changes through time. Integrating these datasets will support the identification of ice-rich, thaw-prone zones and inform risk-aware siting, maintenance, and adaptation of Arctic infrastructure in communities such as Utqiagvik.

Keywords: Permafrost, Arctic infrastructure, geophysics



ESTABLISHMENT OF A PERMAFROST MONITORING SYSTEM IN ARCTIC YAKUTIA

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The basic methodological approach in frozen ground research is that seasonal frost or permafrost should be examined in close relationship to all controlling environmental factors, including primarily the genetic type of geological material (Kudryavtsev et al., 1979). This makes the landscape classification and mapping method a useful tool in the study of permafrost conditions. The method involves identification of natural units with homogeneous geocryological conditions. The study area is divided into subunits characterized by distinct lithological, geomorphological and bihydroclimatic conditions. Within each subunit (a key site), cause-effect relationships of permafrost and active-layer parameters with environmental and geological factors are examined in detail. Intensive site-based research of the local patterns are then extrapolated to broader areas with similar environments. Resulting information is used as a basis for predicting permafrost changes in response to climate change and human activities. The research reported here included collection and analysis of ground temperature data for the period 2021-2025, as well as data from geotechnical monitoring boreholes located in the village of Saskylakh. Landscape investigations were performed to identify and map landscape units at terrain type level in the Saskylakh area. Six thermal observation boreholes, up to 20 m deep, were drilled and instrumented with data logging systems near the villages of Saskylakh and Olenyok. Core samples were obtained for laboratory determination of mechanical, physical and thermal properties.

Keywords: Geological factors



WARMING AND DEGRADING PERMAFROST IN NORWAY AND SVALBARD

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Permafrost is a key geomorphological and geotechnical factor in mountain environments: it shapes landforms, affects infrastructure, and influences slope stability. More recently, permafrost has also been recognized as a significant reservoir of greenhouse gases and as a regulator of the thermal and mechanical integrity of steep rock walls and debris-mantled slopes. Ground thermal regimes control process rates ranging from rockfall and solifluction to large landslides, with important consequences for landscape evolution. Building on the EU-funded PACE project (initiated in 1999), which established suites of deep (>100 m) boreholes across European high-relief regions (including Norway, Svalbard, and Sweden), subsequent campaigns since 2004 have expanded this network by adding boreholes and temperature transects along altitudinal and latitudinal gradients. This study synthesizes two decades of ground temperature records from Norway and Svalbard to document subsurface warming, active-layer thickening, and the emergence and expansion of taliks. We discuss implications for permafrost continuity and slope stability and outline plausible future trajectories under continued warming. Our results underscore the accelerating thaw of mountain permafrost systems and highlight the need to communicate these dramatic changes and their consequences to the public. This communication effort is being developed through a new local project coordinated by the Mountain Museum in Lom, Jotunheimen.

Keywords: Norway, permafrost thermal state, talik



TRENDS IN MULTI-DECADAL SUBSURFACE THERMAL MOISTURE AND REGIME OF THE SOILS OF ACTIVE LAYER, NORTHERN ALASKA.

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Active layer thickness (ALT) of permafrost is one of the standard climate monitoring variables. It is a top layer of permafrost that thaws every summer and re-freezes every winter. Annual active layer formation strongly depends on both the amount of incoming heat penetrating the frozen soil and the moisture regime of soils. Soil temperature and moisture records from Northern Alaska are used for the assessment of the impact of both parameters on the formation of the active layer thickness for almost three decades in different geographic locations. Nine soil stations were implemented at the North slope of Alaska in 1996 and updated in 2006. They are located in Prudhoe Bay area, Sagwon Hills, Barrow, and Atkasuk and represent typical landscape conditions for 2 physiographic provinces: Coastal plain and Foothills. These stations monitor such climate parameters as air temperature, soil temperature at various depths, mostly in the active layer (AL), as well as soil water content at 10, 25, and 40 cm depths. We use daily averaged data for our research. These sites are closely located to the CALM (Circumpolar Active Layer Monitoring) grids or smaller experimental 1 ha plots, so the long-term ALT (Active layer thickness) data is available. Some characteristics of the climate variables including air and soil temperatures from 1996 to 2024 display statistically significant trends over the 20-year period. Mean Annual Air Temperature trend varies reaches 0.2 °C a year increasing inland from the Coast. Decrease in cumulative characteristics of the winter temperatures (DDF) appear in both Coastal plain and Foothills sites from up to 70-degree days per year. Increasing trends mainly relate to the freezing season, including fall, spring, and winter air and soil temperatures. We identified zero curtain effects for the sites and assessed the impact of the fall freezing process on the next year active layer formation. Zero curtain length increases in multiple sites and reaches over 100 days on 20-25 cm depth, so the active layer stays unfrozen for longer period of time. There is a positive statistically significant trend in zero curtain length as well. Delay in thawing start between the air and soil temperatures becomes apparent, which might suggest a) longer snowmelt, b) vegetation thickness increase. Zero-isotherm derived active layer thickness follow integral cumulative summer soil temperatures of the active layer, but trends in the physically measured ALT differ from those. This shows importance of monitoring of both variables in various localized controls such as vegetation, soil and moisture conditions, ground ice content, cryostratigraphy and transient layer thickness, resulting in microvariability of the thermal conductivity of the active layer. We see a lot of change especially in active layer's fall, winter, and spring thermal regimes as well as ecosystem-modified change in the summertime.

Keywords: Active layer, thermal regime



SYNERGISTIC REGULATORY MECHANISM OF SURFACE ALBEDO AND LONGWAVE RADIATION LOSS ON SOIL THERMAL DYNAMICS IN THE PERMAFROST ACTIVE LAYER OF THE MONGOLIAN PLATEAU

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Reflected solar radiation (S_d) and net longwave radiation (L_n) are key outgoing components in the surface radiation balance. Their variations and synergistic interactions significantly influence physical processes such as surface net radiation, subsurface thermal conditions, and land-atmosphere energy exchange. Based on in situ observational data collected at the Nalaikh Grassland permafrost monitoring site on the Mongolian Plateau from 2016 and 2020, this study analyzes the combined effects of surface albedo (α , the proportion of reflected solar radiation to total incoming solar radiation) and net longwave radiation loss ratio (η , the proportion of net longwave radiation to total incoming solar radiation) on the thermal dynamics of the active layer. Results indicate that both α and η exhibit a “U”-shaped seasonal pattern, with higher values during the frozen period (averaging 0.583 and 0.510, respectively) and lower values during the non-frozen period (0.183 and 0.350, respectively). Over the observation period, the average longwave net loss ratio was 0.417, exceeding the average albedo value of 0.341. This indicates that η plays a more dominant role than reflected solar radiation in the radiation balance of this permafrost region. Further analysis reveals that variations in surface albedo and net longwave loss ratio, along with their synergistic effects, significantly regulate the thermal dynamics of the active layer. Soil temperature, soil heat flux, and surface heat source intensity all show significant negative correlations with α and η , with multiple correlation coefficients as high as 0.925, 0.924, and 0.945, respectively. Across the four stages of the active layer (completely frozen, freeze-thaw transition, completely thawed, and thaw-freeze transition states), the contribution of the longwave loss ratio to changes in the abovementioned thermal parameters is greater than that of surface albedo. Compared to albedo, on average, the longwave loss ratio contributes 1.44 times more to soil temperature reduction in, 3.56 times more to the decrease in soil heat flux, and 1.7 times more to the weakening of surface heat source intensity. Overall, the net longwave loss ratio exerts a stronger cooling and energy-dissipating effect on the soil than surface albedo does. Thus, in researches of land surface processes in permafrost regions, beyond focusing on surface albedo, greater emphasis should be placed on the influence of net longwave radiation and its synergistic interaction with albedo.

Keywords: Permafrost, radiation loss, thermal regime



GEOCRYOLOGICAL AND LANDSCAPE CONDITIONS OF IGARKA DISTRICT: CURRENT STATE

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Igarka region is located on the border of the northern taiga and forest tundra subzones and is characterized by the presence of high-temperature (-0.5 - -3°C) discontinuous permafrost. Plant associations (acting as landscape indicators) have a significant impact on the temperature and distribution of frozen soils. The authors exercised field surveys in 2025, concerning a permafrost landscape mapping on a large scale (1:25,000). We have carried out comprehensive descriptions of 41 landscape points that include vegetation and measurements of the active layer thickness. The main objects of research are natural-territorial complexes - landscapes and their morphological parts: areas (mestnosty) and units (urotshistsha), that can be combined into the groups of units. Areas are connected with a certain complex of relief mesoforms within the boundaries of the same landscape. Units are characterized by their position in a single mesoform of relief, a similar moisture regime, and a combination of several soil varieties and biocenoses. We tried to identify the following types of areas and units in the Igarka district: 1) the area of moraine plains composed of Late Pleistocene diamictone, partially covered by peat. It includes two groups of units: a) directly moraine plains (five types), and b) hilly, mesotrophic, and oligotrophic swamps (four types); 2) the area of glacial plains composed of Late Pleistocene fluvio-glacial deposits, which includes the following groups of units: a) low-lying glacial plains (two types), and b) hilly and mesotrophic swamps (two types); 3) the area of river valleys composed of Late Pleistocene fluvio-glacial deposits overlain by Holocene alluvium (two types of tracts), characterized by a significant distribution of through and non-through taliks. A spatial analysis of the plant communities shows that gently convex-hummocky-boggy swamps occupy a dominant position in the tundra subzone with the hummocks exceeding the depressions by 2-3 m. Dwarf birch (*Betula nana*) and ledum-lichen cover, growing on the tops and slopes of the hummocks, have a fairly high thermal conductivity and affect the penetration of cold and heat waves. Sedges (*Carex globularis*), mosses (*Sphagnum fuscum*, *Sphagnum rubellum*) are located in the depressions. The largest group of units in the taiga zone occupy low-lying water-glacial plains (about 40% of the area), that are composed of fluvio-glacial deposits. The plant composition is dominated by larch-cedar-spruce forests and blueberry-sphagnum-green moss forests. The main forest-forming species are Siberian larch (*Larix sibirica*), Siberian spruce (*Picea obovata*), and common birch (*Betula alba*), with Siberian cedar pine (*Pinus sibirica*) as an admixture. The group of mound and mesotrophic swamp units, in general, is characterized by higher permafrost temperatures (-0.1 - -0.5°C) in comparison with the group of moraine and water-glacial plains units, composed of clay soils, delaying the solar heat flow into the ground. We have established that the active layer thickness varies from 50 cm in oligotrophic peatlands to 2 meters in birch-spruce-larch shrub-green moss forests in the river valleys composed of sandy loam deposits. The obtained results will be used in further research of the Yenisei North, where Igarka acts as an important key area.

Keywords: Igarka, landscape mapping, active layer



**ADVANCES AND CHALLENGES IN PERMAFROST MONITORING,
MAPPING, AND MODELING
POSTER**



SIMULATING RUNOFF IN THE DELGERMURUN RIVER BASIN: CHALLENGES OF SWAT MODELING IN MONGOLIAN PERMAFROST REGIONS

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In the high-mountain regions of northern Mongolia, permafrost plays a crucial role in regulating hydrological processes by controlling infiltration, groundwater recharge, and runoff generation, thereby sustaining regional water provision services. However, climate change and increasing aridity are causing permafrost to thaw faster. This is expected to change how water moves underground and shift the timing of river flow in cold-region watersheds. The Delgermurun River Basin (DRB) is one of northern Mongolia's major permafrost-affected catchments, where river discharge is primarily governed by snowmelt and seasonal thawing of the active layer. Despite its hydrological and ecological importance, the basin's runoff response to permafrost change remains insufficiently quantified. The DRB is a critical water source for local communities and supports fisheries, livestock watering, and ecotourism, while also serving as the headwater region of the Selenga River Basin. The basin is almost entirely underlain by permafrost, covering 22,710.3 km² (97.5% of the watershed), including continuous, discontinuous, sporadic, and isolated-patches permafrost zones, making it highly sensitive to climate-driven changes in ground thermal and hydrological regimes. This study applies the semi-distributed Soil and Water Assessment Tool (SWAT) to simulate runoff processes in the Delgermurun River Basin under current climatic conditions. Spatial inputs included a 90 m SRTM digital elevation model, ESA WorldCover 10 m land use/land cover data, and soil properties derived from the SoilGrids 250 m database, while soil spatial distribution was defined using the soil map of Mongolia. All spatial datasets were resampled to a resolution of 250 m. A significant methodological improvement involved validating nine major soil types using in-situ data for soil organic carbon (SOC) and bulk density (BD), while soil hydraulic properties (SOL_AWC and SOL_K) were estimated using pedotransfer functions. Daily precipitation, temperature, relative humidity, and wind speed data from two meteorological stations (Murun and Bayanzurkh) for the period 2014-2022 were used in the SWAT simulations, whereas solar radiation data were obtained exclusively from the NASA POWER dataset. The model was run for 2014-2022, with 2014-2015 used as a warm-up period, 2016-2019 for calibration, and 2020-2022 for independent validation. Daily discharge observations from the Delgermurun gauging station for 2014-2022 have been used for hydrograph analysis, calibration, and validation. Model calibration and uncertainty analysis are being performed using SWAT-CUP (SUFI-2). Model performance is evaluated using the Nash-Sutcliffe efficiency (NSE), the coefficient of determination (R^2), and the percent bias (PBIAS). Initial simulations at the Delgermurun gauging station showed low model skill ($R^2=0.11$, $NSE=-0.48$, $PBIAS=73.7\%$), indicating that conventional SWAT parameterization substantially underestimates runoff in this permafrost-affected basin, highlighting the need for permafrost-specific model adaptation.

Keywords: Permafrost, runoff, SWAT, water-balance, cold-hydrology



ESA CCI+ PERMAFROST-VALIDATION USING INTERNATIONAL AND NATIONAL PERMAFROST MONITORING NETWORKS

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Special emphasis in the Climate Change Initiative (CCI) programme of the European Space Agency (ESA) is placed on validation of the CCI Essential Climate Variable (ECV) products using in situ data from international and national monitoring networks in cooperation with the involved communities. In phase 2, Permafrost CCI+ produced time series from 1997 to 2023 of yearly circum-Arctic permafrost maps on mean annual ground temperature (MAGT) at different depths down to 10 m, Active Layer Thickness and Permafrost Probability. We describe here the ongoing data compilation and standardisation effort deriving the validation data set for Permafrost_cci MAGT products. We compiled a new circum-Arctic collection on ground temperature temporal records from the main communities' (permafrost, meteorology) pre-existing in situ ground temperature records. We assembled ground temperature within a wide range of depths from shallow measurements to 10 m depth mainly from the Global Terrestrial Network for Permafrost (GTN-P) managed by the International Permafrost Association (IPA) and from further international and national measurement networks, including the Russian meteorological measurement program Roshydromet (RHM). Despite the measurement networks provide partly standardised data sets, they are no easy-to use time-series depth data suitable for validation. We optimised the ground temperature data collections by error-checking, depth and data metadata standardization and derived the mean annual ground temperature (MAGT). This newly compiled, harmonised data collection of MAGT depth-time series from 1997 to 2024 is published in the PANGAEA data repository and as an ESA CCI+ Climate Research Data Package (CRDP) providing the first consistent circum-Arctic data collection with standardized measurement depths. It covers all permafrost zones of the Northern hemisphere. Especially the shallow ground temperature time series represent a very interesting validation and parametrization dataset for climate and land surface models.

Keywords: Ground Temperature, ESA Permafrost, Validation



SIMULATING THE ACTIVE LAYER THICKNESS IN NORTHEAST CHINA FROM THE PERSPECTIVE OF ENERGY BALANCE

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The active layer controls the exchange of water and heat between permafrost and the atmosphere, and its thickness is an important indicator for assessing the state of permafrost in cold regions. The development of surface energy balance models has established a foundation for simulating energy and material exchanges between permafrost and the external environment. Based on the energy balance theory and a simplified permafrost model, this study developed a model that can simulate the depth of soil thawing using remote sensing data. The model was used to assess the active layer thickness in Northeast China from 2000 to 2025 and was verified by temperature monitoring data from over 200 boreholes at 72 sites in the study area. The results were compared with those simulated by the Stefan equation, and the differences and respective applicability of the two models were discussed. This study provides a new model for active layer simulation, which may have potential applications in similar cold regions.

Keywords: Permafrost; Active layer thickness, remote sensing, North east China, energy balance,



MODELLING COUPLED THERMAL DYNAMICS AND HYDROLOGY IN FRACTURED PERMAFROST ROCK WALLS

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When mean annual air temperatures rise towards 0°C , permafrost starts degrading. This degradation destabilises mountain rock walls, generating gravitational hazards (e.g. landslides, rock avalanches), which represent a threat for high-altitude infrastructures and practitioners, but also valley floor through cascading processes. There is thus a need for better anticipation of rock faces and period prone to destabilisation. Therefore, understanding thermo-hydro-mechanical processes of permafrost is important - and in that scope, numerical modelling tools were extensively used in the past decades. One important aspect of rock wall morphology is the presence of fractures: they represent plans where ice and sediment can accumulate, paths for water flow, and preferential failure plans. Therefore, the presence of fractures influences the thermal dynamics and hydrology of permafrost rock walls. However, the extent of this influence remains poorly understood: modelling individual fractures poses numerous numerical challenges, so modelling efforts failed to take their individual role into account so far. The present study aims at filling this gap by modelling coupled thermal dynamics and hydrology in various fracturing situations. For that purpose, we use the FEFLOW modelling software with the piFreeze plugin, which uses the finite-element method to compute heat transfer and water flow (with Richards' equation) - while accounting for the phase changes of water. In order to break free from as many parameters as possible, we consider a theoretical summit with a triangle shape (75 meters wide and 100 meters high; Fig 1) and use theoretical, seasonally-cycling temperature time series as forcing data. We implement in the model various fracture geometries, exploring several parameters: orientation of the fracture (vertical or sub-horizontal), aperture (1 cm to 10 cm), porosity (5% to 90%). After an initialisation stage, which produces a state of thermal and hydrological equilibrium, each model undergoes 10 years of freeze-thaw cycles (Figure 1). All model parameters (e.g. temperature or hydraulic pressure) are measured for all models at 35 measurement points (a sample of these points is shown in Figure 1), which allows to compare accurately the results of each model with those of a "neutral" model, which does not bear fractures.

Keywords: permafrost, rock, walls, fractures, physical, modelling

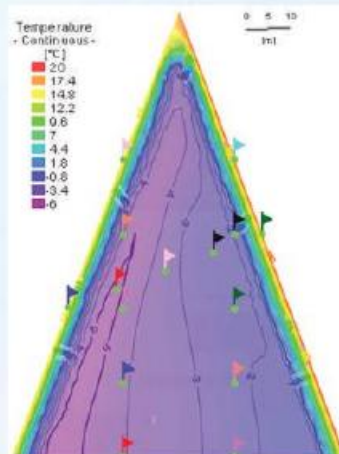


Figure 1: modelled temperature zonation after 10 years of freeze-thaw cycles; some measurement points are represented as colored flags.



PITFALLS AND CONSTRAINTS IN MULTI-TECHNIQUE GEOPHYSICAL INTERPRETATION OF ICE

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In periglacial environments, discriminating between liquid water and ice in the subsurface remains a fundamental challenge, as anomalies in the geophysical record are linked to frozen-ground conditions in an intrinsically non-unique way. Electrical, electromagnetic, seismic, and radar methods respond to coupled effects of lithology, porosity, saturation, temperature, and phase distribution, so comparable anomalies may be produced by contrasting subsurface states. As a result, phase discrimination may be biased by non-phase controls such as salinity, low saturation, and resistive lithologies, while reduced water content can attenuate physical-property contrasts and blur frozen-unfrozen boundaries. Beyond phase discrimination, a consequent and often more demanding objective is the identification of ice occurrence modes once frozen conditions are inferred. Distinguishing between interstitial ice hosted within pore spaces and massive ice bodies remains particularly difficult, as both configurations can generate similar bulk electrical, dielectric, and elastic responses. This challenge is amplified when liquid-water contrasts are absent and the subsurface response is controlled primarily by bulk resistivity and smoothed structural information, limiting the ability of single-technique interpretations to resolve ice geometry. This work investigates the potential and limits of an integrated multi-physics framework combining Electrical Resistivity Tomography (ERT), seismic methods, Frequency-Domain Electromagnetics (FDEM), and Ground Penetrating Radar (GPR) to interpret ice-related subsurface environments. Rather than targeting definitive ice classification, the study is designed to expose interpretational pitfalls arising from non-uniqueness, scale dependence, and trade-offs between phase state, saturation, and lithological control, and to evaluate how these uncertainties propagate into both individual and integrated interpretations. A suite of controlled numerical simulations is developed for each technique to quantify sensitivity to variations in electrical conductivity, dielectric permittivity, elastic properties, porosity, and phase composition. Synthetic ERT, seismic, FDEM, and GPR datasets are generated for conceptual models representative of frozen-ground conditions. Ice occurrence is parameterized along a continuum between interstitial ice within pore spaces and massive ice bodies embedded in coarse or debris-rich materials, including gradual and abrupt frozen-unfrozen transitions. Inverse modelling is performed using standard regularized single-technique inversions and two classes of multi-method integration: structural joint inversion and petrophysically driven joint inversion. Structural joint inversion introduces consistent subsurface architecture across datasets by coupling model structure, while petrophysically driven joint inversion introduces constitutive coupling between electrical and elastic property models through shared state variables describing phase distribution, further reducing non-uniqueness while testing modelling assumptions. Performance is evaluated by anomaly detectability, depth sensitivity, and parameter trade-offs. Within the same workflow, the multi-technique approach is used to validate FDEM as a tool for spatially extensive mapping of frozen ground. Cross-calibration against ERT-derived resistivity structure and independent temperature constraints identifies conditions under which FDEM reliably tracks phase state and those dominated by non-phase controls. Overall, the study shows that multi-physics integration strengthens confidence in liquid water-ice discrimination while delineating the limits of structural and petrophysical coupling when addressing ice occurrence modes.

Keywords: Ice-modelling, multi physics integration, FDEM validation



MAPPING THE OCCURRENCES OF RETROGRESSIVE THAW SLUMPS IN ALL THE LAND NORTH OF 60°N USING H3 GRIDS AND MULTI-SOURCE REMOTE SENSING DATA

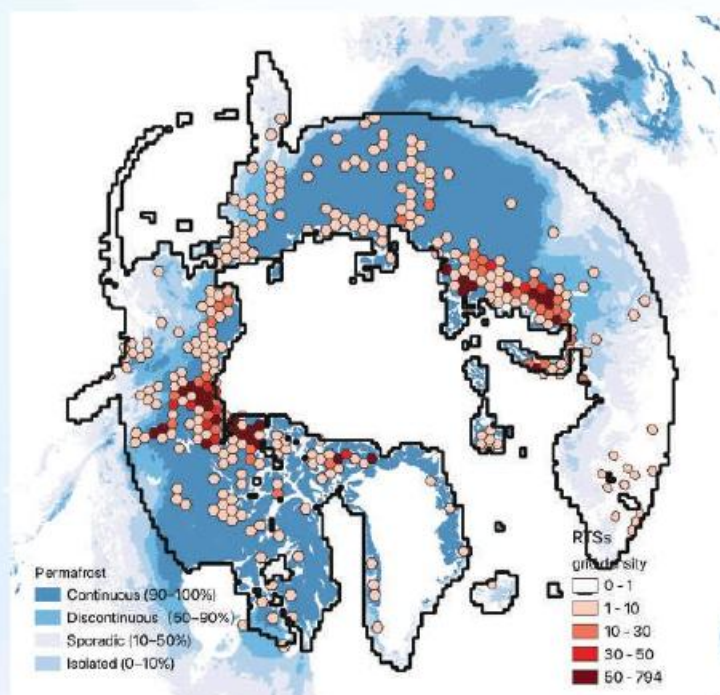
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The spatial distribution and temporal evolution of retrogressive thaw slumps (RTSs) in the entire permafrost regions remain unknown, despite several continental mapping endeavors. Currently, mapping efforts at regional or larger scales typically rely on a single source of remote sensing data, which is incapable of capturing the protracted evolution of RTSs, even if these data span several decades or possess very high spatial resolution. Furthermore, satellite images spanning multiple decades exhibit limited spatial resolution, such as those from Landsat satellites. To address this technical challenge, this study proposes a methodology involving the mapping of RTSs from multi-source/multi-temporal remote sensing data and the subsequent merging of the results using H3 grids. Consequently, RTS occurrences are obtained at a 1-km grid scale. Specifically, this study (1) identified RTSs from multi-source remote sensing, including ArcticDEM, Landsat 7 and 8 spanning the period from 2000 to 2019, and Sentinel-2 images spanning the years from 2018 to 2024, employing AI foundation models and YOLO object detection, (2) merged the mapping results from multiple data sources using H3 grids at the 8th resolution and derived RTS occurrences, and (3) validated the grid-based RTS occurrences through a web-based crowdsourcing system. The outcomes present RTS occurrences represented by unique H3 grids at the 8th resolution (approximately 1 km by 1 km), as illustrated in Fig 1. These grid-based RTS occurrences are sufficiently comprehensive for spatial analysis at large scales and also serve as references for site-specific or local investigations. This study underscores the effectiveness of a grid-based mapping strategy for mapping and monitoring RTS activities from multi-source/multi-temporal remote sensing data.

Keywords: Retrogressive thaw slump, remote sensing, AI foundation models, H3 grid





ICING DYNAMICS OF THE CHULMAN PLATEAU: A 25-YEAR REMOTE SENSING PERSPECTIVE

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The relevance of a comprehensive study of cryogenic forms in Southern Yakutia is driven by the scarcity of data and the lack of research on icing dynamics and related paragenetic processes. Since icing dynamics depend on a complex of geological and physiographic factors, studying their spatial distribution and variability over different periods allows us to assess the degree of influence and interrelationship of these factors. This study improves our understanding of the Chulman Plateau icing belt's distribution patterns. The information obtained serves as a basis for more accurate past change reconstructions, future risk forecasts, and assessments of natural components' susceptibility to anthropogenic impact. The aim of this work is to identify trends and patterns in changes in the area and number of icings on the Chulman Plateau over the past two decades. Icing spatial distribution and dynamics on the Chulman Plateau were assessed using multi-sensor satellite imagery (Landsat-5, Landsat-8, Sentinel-2) from 2000 to 2025. The methodology included interpreting icing contours, analyzing their variability, constructing spatial distribution maps for five time slices, and cataloging all objects with key parameters recorded (location, slope aspect, area, elevation boundaries) at five-year intervals. Analysis of long-term data revealed patterns and factors determining the icing spatial variability on the Chulman Plateau. It has been established that icings predominantly form in the same locations due to the confined nature of groundwater discharge zones. Interannual variability in icing formation manifests primarily as significant fluctuations in their area across the plateau. Medium-sized icings fed by groundwater respond to precipitation and winter temperatures, resulting in noticeable year-to-year changes in their area. Large icings fed by deep subpermafrost waters are resilient to short-term climate changes, and their area remains more stable. The study results indicate a reduction in the total icing area from 147 to 134 km² over 25 years. Thus, remote sensing data enabled the determination of icing dynamics on the Chulman Plateau during the first quarter of the 21st century. The obtained data demonstrate the sensitivity of icing to contemporary environmental changes and provide a foundation for forecasting and further investigation of the response of the region's cryogenic systems.

Keywords: Icing dynamics, remote sensing, groundwater



LITHOLOGICAL AND GEOCHEMICAL CHARACTERIZATION OF THE ACTIVE LAYER IN PERMAFROST DEPOSITS OF THE LOWER OB REGION

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Climate change in the Arctic characterized by warming at high latitudes occurring at twice the global average rate is driving the degradation of permafrost. The initial response to these climatic changes is observed in the active layer, the upper horizon underlain by perennially frozen ground that undergoes annual freeze-thaw cycles. This study aims to provide a lithological and geochemical characterization of the active layer of permafrost deposits in the Lower Ob region. Furthermore, based on key geochemical proxies, it seeks to evaluate the intensity of physical weathering and the redox conditions. The research was conducted within the Ob-Poluy interfluvium, located 95 km southeast of Salekhard. The terrain is predominantly flat. Cryogenic conditions are defined by sporadic (isolated-island) permafrost distribution. The region belongs to the temperate zone. The vegetation cover consists of larch-lichen open woodlands interspersed with areas of shrub tundra. The investigation of the lithological and geochemical properties of the active layer was carried out using a combination of field and laboratory methods. Fieldwork, undertaken on July 15, 2025, included sediment drilling, core description and information of surrounding landscape features and sampling. Laboratory analyses determined the particle-size and elemental composition of the deposits, as well as moisture content, and the concentrations of organic matter and carbonates (LOI). To reconstruct sediment formation conditions, specific geochemical ratios were applied: the Rb/Sr ratio was used to assess the intensity of physical weathering, while the Fe/Mn ratio served to verify the redox conditions. The obtained data allowed for the subdivision of the studied sediment sequence into nine layers, primarily composed of silty loams. A notable characteristic of all layers is the predominance of coarse silt fractions, attributed to the prevalence of cryogenic weathering processes. The deposits exhibit high moisture content, averaging 30%. The average organic matter content is 3%, showing a general decrease with depth. An exception is layer six, where a sharp increase in organic content indicates a significant change in depositional environment. The distribution of carbonates throughout the profile is relatively identical, with a slight decreasing with depth. Rb/Sr ratio show a strong correlation with the distribution of silt fractions, confirm the significant role of cryogenic weathering in sediment formation. Application of the Fe/Mn ratio enabled the identification of two layers formed under reducing conditions. The first is within the upper part of the active layer, where reducing conditions develop due to increased biological activity. The second is located below the permafrost table (from 130 to 185 cm depth), which may be a consequence of cryogenic accumulation of iron during the initial formation of the permafrost. The integrated lithological and geochemical analysis reveals the dominant control of cryogenic processes on the formation of the active layer in the Lower Ob region. Rb/Sr and Fe/Mn ratios provide the rate of physical weathering intensity and identified specific paleo-redox environments within the permafrost sequence. The study was conducted within the framework of the State Project No. 121051100164 and No. 1210514000831. The authors thank the staff of the NCIA for their assistance in organizing, drilling operations.

Keywords: Geochemistry, lithology, Lower Ob region



EVALUATING CLIMATE FORCING UNCERTAINTY FOR PERMAFROST MODELING IN THE SELENGE RIVER BASIN

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Local and regional-scale climate knowledge is essential for modeling ecosystem responses, assessing vulnerabilities, and designing adaptation strategies. Atmospheric reanalyses provide homogeneous, high-resolution datasets to address this need, yet their performance at fine scales remains uncertain in topographically complex and data-scarce regions. This limitation is particularly critical for permafrost studies in marginal zones, where temperatures near 0 °C make the frozen ground highly sensitive to minor climatic perturbations. This study examines daily near-surface air temperature, precipitation, and snow fields from the UAF Weather Research and Forecasting (WRF) model and three widely used reanalysis products ERA5-Land, MERRA2, and NCEP-NCAR for their suitability in permafrost-related impact studies over the Selenge River Basin. The basin spans ~447,000 km² across northern Mongolia and southern Russia, encompassing portions of the Khangai and Khuvsgul mountains, with elevations ranging from 600 m to over 3,000 m. It exhibits a heterogeneous permafrost distribution, with continuous and discontinuous zones covering about 29.5% of the area. Our analysis focuses on atmospheric variables governing permafrost thermal regimes and active layer thickness (ALT), including annual temperature means and amplitudes, Degree Days of Thawing (DDT) and Freezing (DDF), thawing/freezing season lengths, precipitation sums, and snow depth. To evaluate the ability of each gridded product to represent regional climate, these variables were compared against station observations using metrics such as Mean Absolute Error (MAE) and Root Mean Square Error (RMSE). To address observational gaps, we assessed spatiotemporal consistency among reanalyses and calculated ensemble spread as a proxy for uncertainty. Results reveal systematic biases and significant inter-dataset variability, particularly in cold-season conditions, which can significantly impact the results of model-based regional permafrost assessments. Observed discrepancies between the datasets were largely driven by complex topography. These findings underscore the critical influence of climate forcing selection on permafrost modeling and provide a foundation for analyzing past and future changes in permafrost-related Socially Important Hydroclimatological Variables (SIHCV). Ultimately, this work supports the development of decision-centric adaptation frameworks to enhance community resilience in the Selenge River Basin.

Keywords: Permafrost modeling, atmospheric forcing uncertainty



HIGH-RESOLUTION RECONSTRUCTION OF PERMAFROST GROUND TEMPERATURE FROM 1981 TO 2022 USING A PHYSICS-INFORMED DEEP LEARNING MODEL

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Accurate prediction of permafrost ground temperature is crucial for climate forecasting, ecological conservation, water resource management, and engineering hazard prevention. In this study, we developed a coupled model that integrates the permafrost physical model (GIPL2) with the machine learning model (LSTM). This hybrid approach overcomes the limitations of standalone physical and machine learning models, enhancing the accuracy of permafrost temperature simulation and prediction. The coupled model reconstructed quasi-observational daily ground temperature time series at multiple depths for 145 permafrost boreholes across the Northern Hemisphere from 1981 to 2022. Validation results show a daily-scale RMSE of $0.75 \pm 0.70^{\circ}\text{C}$ and an annual-scale RMSE of 0.31°C . The reconstructed temperature time series reveal that permafrost warming trends are closely linked to permafrost zonation. Climate-related permafrost (Climate-driven, Climate-driven/ecosystem-modified, and Climate-driven/ecosystem-protected) shows higher warming rates and greater temperature changes compared to ecosystem-driven and ecosystem-protected permafrost. Future research should leverage high-resolution permafrost temperature data to further investigate the climate response of permafrost, with a focus on critical thresholds, such as the formation and closure of taliks, and their implications for permafrost stability and climate feedback mechanisms.

Keywords: Permafrost, climate change, Arctic



GROUND ICE MAPPING IN THE NORTHERN HEMISPHERE PERMAFROST REGION

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The functioning and vulnerability of permafrost are largely determined by near-surface ground ice content. However, high-quality, grid-based ground ice maps for the Northern Hemisphere are currently unavailable. This study presents the first 1-km resolution grid-based ground ice map within 5 m below the permafrost table across the Northern Hemisphere. The map integrates an unprecedentedly amount (1,178 boreholes) of field measurement for volumetric ice content (VIC) and multisource geospatial data, especially paleoclimate, remote sensing data, surficial geology units, using Copula-Embedded Bayesian Model Averaging (COP-BMA) techniques with multiple machine learning models and 200 ensemble simulations. The validation indicates relatively low errors ($R^2=0.86$, $RMSE=7.08\%VIC$, $bias=0.02\%VIC$), while the uncertainty, represented by the 95% prediction interval (PI), is $16.08\% \pm 3.55\%VIC$. The map indicates that the total ice storage of near-surface permafrost across the Northern Hemisphere is approximately $54,600 \text{ km}^3$ ($47,800\text{--}62,300 \text{ km}^3$), about twice the value from the International Permafrost Association map. This difference may be due to, but is not limited to, advancements in mapping techniques, the integration of additional measurement data, and improved spatial resolution. High VIC ($>80\%$) is predominantly concentrated in low-lying plains, wetlands, and marshes. In contrast, mountainous regions, including the Qinghai-Xizang Plateau and Mongolian Plateau, exhibit lower VIC, typically ranging from 20% to 40%. The new ground ice map exhibits a spatial pattern that is largely consistent with previous maps while providing enhanced spatial detail. This high-resolution map serves as a benchmark for tracing permafrost changes and assessing impacts on climate, hydrology, ecosystems, and infrastructure in permafrost regions.

Keywords: Ground ice



ADVANCING LAND CRYO-HYDROLOGICAL MODELING IN THE PAIKU CATCHMENT (SOUTHERN QTP) TO IMPROVE UNDERSTANDING OF FUTURE HYDROLOGICAL CHANGES

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Global warming is occurring more rapidly at high elevations, driving rapid environmental change on the Qinghai-Tibet Plateau. Climatic shifts have triggered significant hydrological changes, including altered river and groundwater discharge, glacier retreat, and lake level fluctuations. The latter reflect shifts in catchment water budgets, though their drivers remain unclear. Permafrost covers 41% of the Qinghai-Tibet Plateau (QTP), while seasonally frozen ground spans 55%, and both have warmed rapidly in recent decades. These thermal shifts in the ground affect catchment hydrology; thus, it is crucial to assess how cryospheric warming reshapes the plateau's water cycle—both in recent decades and under future projections. To address this question, our approach centers on land-based numerical modeling of cryo-hydrological processes at the catchment scale, using the CryoGrid community model. Our effort is inherently multidisciplinary, bridging climatology, hydrology, and ground/subsurface physics. As such, we rely on field monitoring and remote sensing to parameterize and validate our simulations. We present distributed simulations of ground thermo-hydrological processes covering the Paiku watershed over the last decades and discuss their implications for catchment-scale hydrological changes. Our model simulates the surface energy balance, snowpack dynamics, infiltration, runoff, and ground thermo-hydrological regime while accounting for phase changes. Our simulations, validated with field measurements and remote sensing data, show increasing trends in evapotranspiration and liquid water availability in the ground, which are coupled to higher lateral hydraulic connectivity. This results in reduced surface runoff relative to subsurface flow, as well as enhanced infiltration and subsurface storage. We are happy to present this work in the form of a poster to discuss possible improvements to our framework and the potential implications of our results for scientific discussion.

Keywords: Cryo-hydrology, numerical simulations, remote sensing



SEASONAL ACTIVE-LAYER THICKNESS DYNAMICS AT THE ORRAVATNSRÚSTIR PALSA MIRE COMPLEX, ICELANDIC HIGHLANDS

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Palsa mires, peatland ecosystems characterised by hummocks or plateaus with a permafrost core, are among the most threatened habitats in Iceland. These landforms play important roles in biodiversity support and carbon storage, yet ongoing climate warming is accelerating permafrost thaw and leading to palsa collapse, with cascading ecological consequences. Despite their vulnerability, there is a lack of detailed long-term assessments of permafrost degradation in Icelandic palsa mires. This study examines the Orravatnsrústir palsa mire complex in the Icelandic Highlands, a site surrounded by a heavily eroded barren desert landscape where palsas occur in small clusters. We aim to improve our understanding of permafrost conditions at this site by analysing seasonal active-layer thickness (ALT) dynamics using a combination of high-resolution uncrewed aerial system (UAS) surveys and in situ observations. Aerial optical and Light Detection and Ranging (LiDAR) data, supported by Real-Time Kinematic Global Navigation Satellite System (RTK GNSS) measurements, were collected during two field campaigns in July and September 2025 to generate detailed orthomosaics and digital elevation models (DEMs). On two representative palsas, Circumpolar Active Layer Monitoring (CALM)-based 20 × 20 m monitoring grids with 2 m spacing were established, and ALT at each grid point was repeatedly measured throughout the thawing season. These multi-temporal datasets enable mapping and assessment of seasonal thaw depth development and spatial variability. By combining in situ ALT data and UAS-derived DEMs, we assess the impact of micro-topographic controls and possible changes in topography on ALT and its seasonal development. Meteorological data from the nearest weather station are integrated to examine how atmospheric conditions influence ALT development. This study provides a high-resolution assessment of seasonal ALT dynamics in an Icelandic palsa mire system and offers early insights into the processes driving palsa degradation under climate warming.

Keywords: Palsas, active layer, microtopography, UAS, in-situ



DEVELOPMENT OF A DIAGNOSTIC METHOD OF ALPINE PERMAFROST FOR OPERATIONAL PURPOSES: A NUMERICAL MODELLING APPROACH

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Alpine permafrost plays a critical role in high mountain environments, affecting slope stability, infrastructure, and natural hazard dynamics. Its spatial distribution and temporal evolution are highly sensitive to climate, snow cover, and terrain properties. The PhD project presented here aims to develop, test, and evaluate numerical modelling approaches for Alpine permafrost, extending two decades of fundamental progress toward more operationally oriented tools for geotechnical assessment and hazard management. The methodology starts from existing capabilities in Alpine permafrost diagnostics. Direct temperature measurements and geophysical surveys provide an initial framework for characterising ground thermal conditions and constraining one-dimensional models. These approaches allow describing thermal regimes and subsurface properties despite substantial uncertainties, nonetheless providing a convincing starting point for the development of more advanced modelling. Building on these methods, the project initially focuses on evaluating how sensitive permafrost simulations are to changes in initial conditions. Bedrock terrains near 0 °C are particularly sensitive to small variations in ground temperature and ice content, which are often poorly constrained due to the sparse availability of borehole data and the heterogeneity of fractured alpine substrates. By reconstructing plausible historical temperature profiles and exploring multiple initial ice distributions, we evaluate their influence on simulated thermal evolution over decadal timescales. This remains an exploratory step, essential for identifying the range of possible trajectories rather than producing definitive operational forecasts. A second component assesses the influence of model geometry. While 1D simulations offer rapid insights at specific locations, they cannot account for lateral variations in topography, snow deposition and solar radiation. 2D and 3D models better represent overall processes. Through a comparison of 1D, 2D, and 3D configurations, the project explores when added dimensionality meaningfully changes the simulated thermal regime and when simpler geometries suffice, clarifying the implications of multidimensional modelling in complex alpine terrain. The project also incorporates snow and hydrological processes, with a stronger emphasis on snow thickness, duration, density, and their spatio-temporal variability, which exert a dominant control on the ground energy balance. While meltwater effects are considered, as its infiltration into fractures and porous material modifies heat transfer, the primary goal is to explore how snow processes influence subsurface thermal regimes across different topoclimatic settings and time periods. Scenario-based simulations over ~20-30 years (operational timelines) are used to explore possible trajectories of permafrost evolution. Due to uncertainties in short-term climate projections, the methodology relies on recent climatic sequences to build optimistic, intermediate, and pessimistic scenarios. These simulations serve as exploratory envelopes of potential thermal changes and related instability processes. Finally, the project opens toward alternative data sources that may complement or replace costly extended field acquisitions, such as borehole monitoring. These include electrical resistivity soundings, orthophotos and DEM metrics, and spring-water electrical conductivity and geochemistry. Such datasets offer promising avenues to characterise ground conditions, reducing field constraints. Overall, this PhD project combines sensitivity analysis, multidimensional modelling, snow-hydrology considerations, spring water properties, and scenario exploration to develop a comprehensive and flexible framework for Alpine permafrost studies, laying the groundwork for operational applications in high mountain environments.

Keywords: Alpine permafrost, numerical-modelling, multy method approach, operational purposes



IMAGING PERMAFROST ACTIVE LAYER THICKNESS UNDER FOREST

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Permafrost is a major but still poorly quantified carbon reservoir, and it is highly vulnerable to the rapid warming observed at high latitudes. As temperatures rise, the seasonally thawed “active layer” is expected to deepen and reorganize spatially. This thickening accelerates carbon release into the atmosphere and affects hydrology, geochemical cycles, vegetation distribution, and ground stability. Yet, Active Layer Thickness (ALT) is only measured at sparse northern monitoring stations. As a result, its spatial variability remains largely unknown, especially beneath boreal forests, which severely limits model evaluation. Spaceborne InSAR, thanks to its all-weather and high-resolution capabilities, has shown some sensitivity to ALT through ground deformation. However, previous studies have been mostly restricted to non-forested areas, because vegetation reduces the coherence needed for reliable motion measurements. To address this limitation, we broaden the applicability of InSAR by exploiting SAR polarimetric information to retrieve ground motion even under forest cover. In parallel, we separate the thermodynamic contribution to ground deformation from the hydrological one during the refreezing period using a land surface model. This allows us to isolate the component directly linked to ALT. Applying this approach to a one-year TerraSAR-X time series over the Yakutsk region, we produced the first high-resolution ALT map under boreal forest. This map reveals unexpected fine-scale spatial heterogeneity, structured along anisotropic patterns likely tied to soil, vegetation, and microtopography. Its weak agreement with ALT simulated by the ISBA land surface model, commonly used in climate simulations, shows that current climate models remain highly uncertain over northern regions in the absence of spatially resolved ALT information beneath forested areas. This new method, fully compatible with current and upcoming satellite missions, opens the way to large-scale ALT mapping. It provides a critical tool for improving climate models and for monitoring the progression of global warming across high-latitude environments.

Keywords: InSAR, permafrost, ALT, heterogeneity, climate



SPATIOTEMPORAL VARIATIONS OF PERMAFROST EXTENT IN MONGOLIA DURING 1950-2022

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Permafrost in Mongolia is located in the transition zone between high-latitude and high-altitude permafrost regions of the Northern Hemisphere, with large temperature differences and complex subsurface characteristics. In this study, the reliability of the skin temperature data from the ERA5-Land product covering Mongolia is assessed via site observations. The ERA5-Land skin temperature dataset shows a cold bias, which is more pronounced in the cold season. Following calibration based on elevation differences, significant improvements are observed at both the annual scale (92 % improvement in RMSE (root mean square error) and 98 % improvement in MBE (mean bias error)) and the seasonal scale (78 % improvement in RMSE and 82 % improvement in MBE). Additionally, the spatial variations in the surface freezing index (SFI) and surface thawing index (STI) are most pronounced in the central and northeastern Mongolia. The SFI exhibits a significant decreasing trend of $7.16\text{ }^{\circ}\text{C}\cdot\text{d}/\text{year}$, while the STI shows a significant increasing trend of $4.49\text{ }^{\circ}\text{C}\cdot\text{d}/\text{year}$. Furthermore, the permafrost extent in Mongolia is simulated from 1950 to 2022 using the frost number (Fn) model and the temperature on top of permafrost (TTOP) model. The validated results indicate that the accuracy of the Fn model is relatively high, with an overall accuracy of 0.9 and a Kappa coefficient of 0.47. The permafrost extent in Mongolia has declined from $734.7 \times 103\text{ km}^2$ in the 1950 s to $480.1 \times 103\text{ km}^2$ in the 2010 s, with a prominent decrease of $3.2 \times 103\text{ km}^2/\text{decade}$ after 1994. According to the variations in permafrost extent during past 72 years, the Khovsgol and Khentii Mountain ranges have experienced significant permafrost degradation.

Keywords: ERA5 Land, freezing-thawing index, Permafrost extent, Mongolia



1B: LONG-TERM COLD-ENVIRONMENT PERMAFROST CHANGES

Conveners: Kazuyuki Saito¹, Shunji Kanie², Mamoru Ishikawa², Takahiro Abe³ & Yoshihiro Iijima⁴

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Current permafrost thermal states reflect millennia of interactions among physical, thermal, biogeochemical, and ecological processes under varying climates. This session welcomes paleotomodern studies that reconstruct frozenground formation across inland, coastal, submarine, periglacial, and subglacial settings, using proxies, models, and field observations. We also solicit updates since EUCOP6 and ICOP2024 on new insights, methodological advancements, and future research needs to understand longterm permafrost evolution under accelerating global change.





RECENT PERMAFROST RETREAT IS VERY LIKELY UNPRECEDENTED IN THE COMMON ERA

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Permafrost, a defining feature of high-latitude landscapes, has been rapidly degrading in recent decades due to ongoing global warming. One of the clearest indicators of this degradation is the loss of permafrost area. While recent retreat is well documented, few studies have placed extent changes in the context of pre-industrial natural variability. Here we show, using multiple simulations from the Paleoclimate Model Intercomparison Project Phase 3 (PMIP3) and 4 (PMIP4) and reanalysis products, that the recent permafrost retreat is very likely unprecedented in the last 2,000 years. Across datasets, we estimate a permafrost area decrease of 0.7 to 2.5 million km², with the largest losses concentrated along the southern margins of discontinuous permafrost. These regions are found to hold between 43 and 138 PgC of soil organic carbon, now vulnerable to potential microbial decomposition. The resulting carbon emissions could have already amplified global warming by 0.2 °C, with implications for the pan-Arctic environment and the stability of global climate.

Keywords: Permafrost area, permafrost carbon, paleoclimate

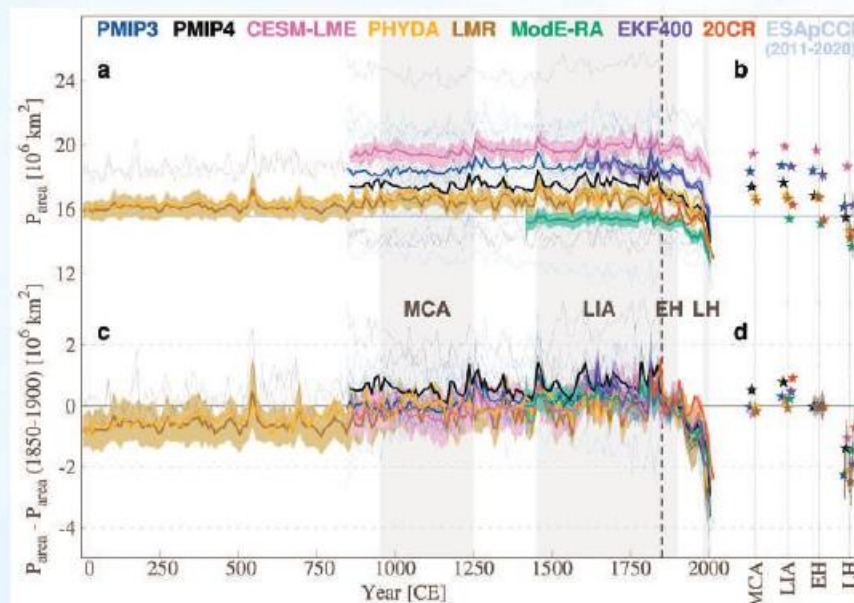


Fig 1. Permafrost area (P_{area}) evolution during the Common Era (CE). (a) Northern Hemisphere decadal P_{area} (million km²) estimates in 1-2014 CE for the different data sources shown in the legend. P_{area} values were obtained using PROB permafrost definition (probability of having permafrost below 0.5). (b) Mean P_{area} values (stars) and 95 % confidence intervals (bars) for the Medieval Climate Anomaly (MCA, 950-1250), Little Ice Age (LIA, 1450-1850), Early Historical (EH, 1850-1900), and Late Historical (LH, 1981-2000) periods. (c) Same as (a), but for P_{area} anomalies relative to 1850-1900 CE. (d) Same as (b), but for mean anomalies relative to 1850-1900 CE. In (a) and (c), the reference periods are highlighted in gray. The ESAPCCI estimate, marked with a pale blue line in (a, b), corresponds to the mean value of the product in 2011-2020 and is shown as a reference.



ENVIRONMENTAL SHIFTS FROM THE LGM TO THE HOLOCENE RECORDED IN SULFUR ISOTOPE GEOCHEMISTRY OF ICE WEDGES

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Ice wedges serve as valuable archives owing to their unique formation processes allowing them to preserve past environmental changes over millennia. Recently, sulfur isotopes in permafrost systems have gained attention as effective proxies for understanding biogeochemical processes associated with redox conditions, hydrological regimes, and permafrost development and thaw. Despite this growing interest, the application of sulfur isotopes to permafrost systems for reconstructing long-term environmental change remains limited. In this study, we measured $\delta^{34}\text{S}$ of dissolved sulfate and particulate organic matter (POM) in ice wedges formed during the Holocene and the Last Glacial Maximum (LGM) in Central Yakutia, East Siberia, to assess temporal variations in sulfur isotope compositions and their implications for past environmental and biogeochemical processes. First, dissolved sulfate from LGM ice wedges shows $\delta^{34}\text{S}$ values of 7-12‰, while Holocene wedges exhibit values of 16-24‰. Given that sulfate aerosols preserved in inland ice wedges are primarily derived from the erosion and weathering of basement rocks, the observed depletion of up to 10‰ during the LGM indicates a shift in sulfate sources. Although the surrounding region is largely underlain by marine sedimentary rocks, including ^{34}S -enriched carbonates and evaporites, the enhanced dust transport associated with Yedoma formation during the LGM likely delivered sulfur from ^{34}S -depleted igneous and metamorphic terranes, thereby diluting the ^{34}S -enriched local signatures. This interpretation is further supported by variations in rare earth element (REE) patterns and total inorganic carbon (TIC) contents in mineral particles within the ice wedges. Additionally, in Holocene ice wedges, POM is either isotopically similar to or more ^{34}S -depleted than dissolved sulfate, consistent with sulfur isotope fractionation associated with sulfate assimilation by plants. In contrast, LGM ice wedges show a broader range of sulfur isotope compositions, including notable ^{34}S enrichment in POM. This enrichment suggests that the restricted drainage and a shallower active layer during the LGM could have enhanced anoxic soil conditions and thereby microbial sulfate reduction, which enriches ^{34}S in the residual sulfate. Overall, the sulfur isotopic composition of both dissolved sulfate and POM in ice wedges captures climatic and environmental changes from the LGM to the Holocene, highlighting the potential of sulfur isotopes as tools for reconstructing the long-term evolution of permafrost landscapes.

Keywords: Ice-wedges, sulfur isotopes, LGM-Holocene, proxy



A 600,000 YEAR SPELEOTHEM-BASED HISTORY OF MONGOLIAN PERMAFROST

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Mongolia has lost much of its permafrost area in recent decades, leading to significant environmental and hydrological changes. As these changes continue, there is an urgent need to understand the environmental factors governing the stability of Mongolia's permafrost. Reconstruction of environmental conditions during past interglacials can help disentangle anthropological and natural forcings behind changes to permafrost extent, and offer potential regional analogues for near-future climate scenarios. However, detailed reconstructions of Mongolia's climate are scarce, and almost none extend beyond the last ice age. Here, we use speleothems from three caves in the Khuvsgul region of northern Mongolia to infer changes to Mongolia's permafrost cover over the past ca. 600,000 years. Speleothems (cave carbonates, e.g. stalagmites) cannot form under continuous permafrost, so intervals of speleothem growth, which can be determined by U-series dating, represent periods of degraded or absent permafrost. Speleothems also preserve water inclusions and biomarkers that can be used to reconstruct precipitation source and ground temperatures, making them powerful archives of hydroclimatic and thermal changes over long-time scales. Our record of 60 U-Th dates reveals extensive speleothem growth prior to MIS 11 (~420,000 years ago), suggesting much-reduced permafrost coverage in the region. Temperature reconstructions based on TEX86 indicate that regional multi-annual mean ground temperatures prior to MIS 11 were as much as 6°C warmer than today. Fluid inclusions from interglacials prior to the Holocene are isotopically lighter than Holocene ones, suggesting an altered hydrological regime during warmer-than-present intervals (e.g., MIS 5) or when Arctic sea-ice cover was reduced (e.g., MIS 11, MIS 13). We hypothesise that prior to MIS 11 increased snowfall insulated the ground, leading to warmer ground temperatures. The higher snowmelt contribution to groundwater (and dripwater) caused isotopically-lighter fluid inclusions. We compare our results to data from Siberia and Canada, where extensive speleothem growth in high northern latitudes occurred prior to MIS 11. This indicates that continuous permafrost in the northern hemisphere was far more restricted compared to today. Our study offers a direct observation of increased snowmelt during this period of widespread permafrost degradation, suggesting that increased wintery moisture supply to continental Eurasia in a warmer world can lead to large-scale Northern Hemisphere permafrost loss.

Keywords: Speleothem, cave, interglacials, paleoclimate, Khuvsgul



COLD-SEASON PRECIPITATION ISOTOPE-TEMPERATURE RELATIONSHIPS AT YAKUTSK, CENTRAL YAKUTIA: IMPLICATIONS FOR PALEOCLIMATE RESEARCH

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In this study, we examine the relationship between stable water isotopes in precipitation ($\delta^{18}\text{O}$ and δD) and air temperature in Yakutsk, Central Yakutia, using observations at daily, monthly, and seasonal timescales. Our goal is to improve understanding of how precipitation isotopic signals preserved in ice wedges can be interpreted for paleoclimate reconstruction. The cold season is defined as October to April, during which precipitation falls predominantly as snow and persistently subzero air temperatures allow the accumulation of a seasonal snowpack. Event-based (daily-scale) measurements of $\delta^{18}\text{O}$ and δD in atmospheric precipitation were collected intermittently from February 2018 to November 2022. Only cold-season precipitation events ($n = 101$) were included in this study and analyzed together with mean daily air temperature (MDAT) and precipitation amount. The δD - $\delta^{18}\text{O}$ regression exhibits strong internal coherence ($R^2 = 0.984$) and regression parameters close to the Global Meteoric Water Line (GMWL). Both $\delta^{18}\text{O}$ and δD show moderate positive relationships with MDAT, while daily d-excess values ($7.0 \pm 7.0 \text{ ‰}$) indicate substantial variability in moisture source conditions at the event scale. To link these observations with the Global Network on Isotopes in Precipitation (GNIP) dataset, daily values were aggregated to monthly scales, yielding 51 cold-season months from the same station over the period 1978-2022. Monthly mean air temperature was calculated using two methods: averaging all days within each month (tm-full) and averaging only days with precipitation-event (tm-prec). For the cold-season months, tm-prec exceeded the tm-full in 80% of cases, by an average of $1.5 \text{ }^\circ\text{C}$, indicating that precipitation-forming conditions differ from calendar-averaged temperatures. We also found that the temperature difference was larger during the mid-cold season than during the early or late cold season. The monthly mean δDm - $\delta^{18}\text{Om}$ relationships remains consistent with the GMWL, while isotope-temperature correlations are systematically stronger for tm-prec than for tm-full. Monthly d-excess variability decreases ($5.1 \pm 6.1 \text{ ‰}$), reflecting reduced noise resulting from temporal aggregation. Seasonal $\delta^{18}\text{O}$ s and δD s values were calculated for the cold seasons ($n = 11$) using precipitation-amount weighting, and corresponding seasonal air temperatures derived using the same approach. Missing monthly isotope data were filled using multiple gap-filling techniques, and the consistency of seasonal regressions across these methods demonstrates that gap filling does not control the observed isotope-temperature relationships. At the seasonal scale, isotope-temperature correlations weaker ($R^2 = 0.626$) compared to shorter timescales, with residual uncertainties of $\sim 2 \text{ }^\circ\text{C}$. The seasonal precipitation-weighted isotope-temperature relationship agrees well with that observed for modern elementary ice veins and air temperature. This agreement indicates that ice wedges record event-weighted cold-season precipitation formed under physically relevant temperature conditions, rather than calendar-averaged climate means. The results provide a scale- and process-based constraint on the interpretation of stable water isotopes in ice wedges and offer a framework that can be tested in other cold-region settings.

Keywords: Modern precipitation, isotopes, isotope temperature calibration



METHANE IN THE HOLOCENE ICE WEDGES OF THE WESTERN SIBERIA AND EASTERN CHUKOTKA

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Ice wedges are widespread in the Russian North and affects modern cryogenic processes, such as heaving, frost cracking, thermoerosion, and thermokarst. The theory of cyclical development of ice wedges, which includes stabilization, development, and degradation, is widely accepted and can be observed in a detailed examination of polygonal-vein, thermokarst-cave, and segregation ice. Determining the direction of development of ice wedges systems is necessary to assess the danger of developing cryogenic processes that may threaten engineering facilities. It is necessary to conduct cryolithological studies and determine the ratio of repeated-vein ice, segregation ice, and thermokarst-cave ice. Cryolithological or geochemical methods (based on methane content) can be used to separate one type of ice from another in a section. To assess the methane content in ice wedges, three areas were selected for subsequent comparison and sampling using the HeadSpace method: a polygon peat bog near Labytnangi (2025), the Lorino outcrop on the coastal plains of the Chukchi Peninsula (2022), and the river lade in the Baydaratskaya Bay (2024). All the ice under consideration is less than 2 meters in height and range from 1 to 3 meters in width, with vertical stratification. Processing of samples obtained from ice wedges and host sediments was carried out at the instrument base of the I.S. Gramberg Federal State Budgetary Institution VNIIOkeangeology using a Shimadzu GC 2014 gas chromatograph. In addition, the selected ice was examined using polarization lenses to clarify their structure and the specific arrangement of air bubbles containing gases. There is an increased methane content in the host organic sediments, so special attention was paid to soil descriptions in the outcrops. For example, in a polygonal peat bog, the methane content in the host peat is up to 1500 ppmv, while the underlying high-ice loams do not exceed 50 ppmv. In the ice wedge itself, the methane content varies from 20 to 250 ppmv and depends on the amount of peat inclusions directly in the ice: the more inclusions, the higher the methane content. The ice wedge samples considered in this work are of the same age, the Holocene, so we can evaluate the different conditions that were observed in three different sites at the same time using a combination of methods: methane content analysis, isotopic analysis, and detailed cryolithological descriptions. The study was carried out as part of the State Task "Evolution of the Cryosphere under Climate Change and Anthropogenic Impact" No. 121051100164 and with the support of the Russian Science Foundation (grant No. 23-27-00123). The authors thank A.V. Dunaev and Z.M. Rogova for their assistance in selecting and processing the materials.

Keywords: Ground ice, methane, ice wedges



IMMEDIATE ON-SITE RNA EXTRACTION REVEALS THE IMPACT OF TRANSPORT AND STORAGE TEMPERATURE ON RNA INTEGRITY AND MICROBIAL GENE EXPRESSION IN PERMAFROST

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Permafrost hosts living microbiomes dormant or active containing psychrophilic bacteria, yeasts, and even multi-cellular organisms such as rotifers and nematodes. Previous studies have reported that unicellular organisms can undergo cell division at temperatures as low as -15°C (1). Living cells contain not only DNA but also RNA, proteins (including enzymes), and metabolites. Owing to the ability to amplify small amounts of material using PCR, together with advances in sequencing technologies, DNA and RNA analyses remain central approaches for studying microbial communities. In particular, RNA transcripts encoding specific proteins may be expressed transiently in response to environmental changes. Thus, the presence of RNA can indicate metabolically active cells, and the quantification and sequencing of messenger RNAs provide a snapshot of gene expression within a microbial community, from which functional activity may be inferred. While DNA can persist for decades at -20°C , the gold standard for long-term RNA storage is -80°C . This requirement may be especially critical for permafrost samples, which can contain microbes that are able to sustain metabolic activity at temperatures close to -20°C . However, the logistical challenges of transporting liquid nitrogen (-196°C) or dry ice (-78.5°C), combined with limited access to -80°C freezers in the field, restrict soil metatranscriptomics to easily accessible locations. To overcome field-based limitations, we developed a transportable “suitcase lab” that enables immediate on-site extraction of both DNA and RNA from up to 24 soil samples daily. Using this system, RNA was extracted on-site from permafrost and active-layer soil sampled from a peat plateau at Milepost 41 along the Denali Highway, USA. The effects of cold storage at -20°C and -80°C for two days, as well as warming to $+4^{\circ}\text{C}$ for six days, were evaluated using metatranscriptomics analysis. RNA extraction and analysis remained feasible after 2 days at -20°C ; however, RNA quality and yield were significantly reduced in the permafrost samples, suggesting a cold-shock-associated response. We further compared transcriptional responses between active and permafrost layers following cooling to -20°C and warming to $+4^{\circ}\text{C}$, providing insights into microbial responses relevant to climate change.

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Keywords: Microbiome, RNA, metatranscriptomics, cold response, thawing



DEEP DOWN THE SQUIRREL HOLE: DIET AND HABITAT OF A PLEISTOCENE GROUND SQUIRREL IN WESTERN BERINGIA

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Permafrost is not only a crucial environmental factor in the Arctic, but also an excellent medium for the preservation of organic matter. In particular, syngenetic, ice-rich permafrost, the so-called Ice Complex, in which sediments are incorporated into the permafrost more or less simultaneously with their deposition, represents an exceptional paleo-ecological archive. Duvanny Yar is type locality for the Late Pleistocene Ice Complex in Western Beringia and is known for spectacular finds of remains of now-extinct large mammals as well as for the revitalization of ancient plant material preserved in Pleistocene ground squirrel nests. During fieldwork in 2015, such a fossil nest was discovered at Duvanny Yar, containing tens of thousands of extremely well-preserved seeds and fruits gathered by ground squirrels according to the size of the nest and to form and size of preserved droppings. Previous studies of mitochondrial DNA from fossil souslik remains preserved at Duvanny Yar revealed that Pleistocene ground squirrels at the site correspond to the modern Arctic Souslik *Urocitellus parryi*. AMS radiocarbon dating of *Carex myosuroides* fruits from the nest yielded an infinite age of >49,000 years BP, which, together with the stratigraphic context, places the find in the early or middle Weichselian/Wisconsinan cold stage (MIS 3 or 4) and considerably extends the known period of souslik occurrence at Duvanny Yar into the past. The aim of the presentation is to shed light on the dietary preferences of Pleistocene Arctic ground squirrels and to draw conclusions about the habitat, vegetation, and paleoenvironmental conditions in Western Beringia during the formation of the Duvanny Yar Ice Complex. The sampled plant material was dried in the field and subsequently dry-sieved in the laboratory using standard test sieves with mesh sizes between 2 and 0.25 mm, then screened under an Olympus SZX16 stereomicroscope and hand-picked for macrofossil identification. Altogether 24 plant taxa could be identified mainly comprising species with large or putatively nutritious seeds and fruits such as grasses (*Festuca*, *Poa*, *Puccinellia*), sedges (*Carex myosuroides*), legumes (*Hedysarum hedysaroides*) and other forbs like *Eritrichium*, *Cerastium maximum*, *Silene samojedorum*, *Potentilla arenosa*, and *Polemonium boreale*. All detected plant species are characteristic of Arctic grassland vegetation and mainly occur in tundra-steppes (*Kobresietea* communities), which are restricted in modern tundra to open, dry and exposed extrazonal sites like pingos or rocky elevations. Neither such habitats nor tundra-steppe vegetation, nor Arctic ground squirrels themselves, are found locally at Duvanny Yar today. As Arctic sousliks require deep, dry soils for their burrows, their presence at Duvanny Yar during the Late Pleistocene is already an indication for a greater than today thickness and considerably lower moisture content of the active layer. Open habitat availability is crucial for Arctic sousliks to avoid predation. Their mere presence, together with the exclusive occurrence of dry grassland plant species in their nest, substantiates distinctly drier and more continental climatic conditions during the Late Pleistocene.

Keywords: Pleistocene mammoth steppe, paleoecology, vegetation, ice complex



ARCTIC-SUBARCTIC YAKUTIA'S PERMAFROST-CLIMATE DYNAMICS FROM 1965 TO 2023

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Global climate change has significantly increased during the last six decades. Changing from stable climates to current warming has strongly affected on permafrost landscapes and infrastructure in cold zones. Arctic and subarctic areas have shown unique reactions to these changes. Ten administrative districts the Republic of Sakha (Yakutia), spanning 1.6 million square kilometers, included into the Arctic zone of Russian Federation. Arctic tundra and subarctic landscapes with few larch forests and sparse northern taiga woodlands characterize these districts. Arctic climates and permafrost change over space and time. We can identify three climate regions within the tundra: the New Siberian Islands, northern Central Siberia, and northern Eastern Siberia. The subarctic zone has four districts: Olenek, Yansk, Indigir-Kolyma, and Verkhoyansk-Chersky. Global warming's effects vary district. The years 1965-1987, 1988-2004, and 2005-2023 represented three periods with different development qualities. The climate in these periods was comparability homogenize: 1965-1987 represents the pre-warming climate, 1988-2004 the start of warming, and 2005-2023 the current warming climate. Based on these differences, permafrost-climate regions were identified, and they each have a unique reaction in their landscapes and permafrost to global warming. The New Siberian Islands and northern Eastern Siberia show the biggest change in mean annual air temperature, around 3°C, while the Yana district shows the smallest, around 2°C. The subarctic regions are less sensitive to climate change than the Arctic tundra. The Arctic and subarctic regions warmed more from 1930-1940s than from 1988-2004, which is their climate change characteristic. Near Tiksi town on the Laptev Sea coast in Yakutia's Arctic, the MPI SB RAS monitoring site offers the longest permafrost temperature observation record. This area is in the foothills of the Primorsky Ridge's eastern side. The temperature borehole, which is 30 meters deep, is on a low ridge, 49 meters above sea level. The permafrost temperature here rose about 2,3 °C at a 10 m depth from 1993 to 2023, according to long-term records. However, the change was uneven across depth and between years. The temperature of permafrost started rising faster by in the mid-2000s. According to CALM data, the interannual changes in active layer thickness in the Arctic zone of Yakutia directly reflect the 2005-2023 warming. Understanding permafrost changes under modern climate will be improved by studying periods in modern climate development.

Keywords: Permafrost, climate, arctic, subarctic, Yakutia



MOISTURE ORIGIN OF ICE WEDGES IN CENTRAL YAKUTIA

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We analysed 209 samples from ice wedges collected at outcrops on the Vilyuy River (Tyalychyma, Khomustaakh outcrops), the Aldan River (Mamontova Gora outcrop), and the Leno-Amga interfluvium to observe the isotopic composition of oxygen-18 and deuterium in MPI-AWI Stable Isotope Laboratory using Picarro L2140-i. In Central Yakutia, the average deuterium excess values of ice wedges in the Late Pleistocene exceeded 7.8‰. The isotopic composition of air precipitation was sampled in Yakutsk (62.03°N, 129.73°E) between autumn 2017 and winter 2025 (329 samples) varies from −1.9 to −46.9‰ for $\delta^{18}\text{O}$ and from −58.5 to −366.1‰ for δD . The lightest isotopic composition is characteristic of the cold season, with a gradual lightening from the beginning to the end of the season. Accordingly, in warm seasons, a gradual heaviness of the isotopic composition was observed, with the heaviest composition observed in July-August. To determine the probable origin of the moisture, 72–120-hour backward trajectories were calculated for each precipitation event recorded in Yakutsk using the HYSPLIT model. Comparison of data with other points — Irkutsk (52.29°N, 104.28°E), Magadan (59.57°N, 150.81°E) showed consistent differences when moving eastward (Irkutsk-Yakutsk-Magadan): an increase in the proportion of precipitation from the Pacific Ocean. Calculated deuterium excess values for atmospheric precipitation during observation period varied within a fairly wide range, from +21.4 to −48.6‰. At the same time, the cold period was characterized by deuterium excess values of more than 10‰, which may indicate the predominance of cryogenic metamorphism of the isotopic composition. For the warm period, the deuterium excess values are significantly less than 10‰, which probably suggests a significant influence of evaporative fractionation on the formation of the isotopic composition. Therefore, ice wedges in Central Yakutia formed in Late Pleistocene without moisture deficiency; the source of winter atmospheric precipitation during that period was probably air masses from transitional seasons coming from the Pacific Ocean.

Keywords: Ice wedges, HYSPLIT, Central Yakutia



FORMATION MECHANISM OF COMPOSITE WEDGES FROM THE BATAGAY MEGASLUMP'S OUTCROP (NORTH-EAST SIBERIA, RUSSIA)

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In 2023, the cryolithological study of Batagay megaslump was conducted, including petrographic, isotopic, and chemical analysis of wedge structures. The main aim was to investigate the formation mechanism of wedge structures in connection with paleoenvironmental conditions. Batagay outcrop contains two types of wedge structures - ice wedges and composite wedges. Composite wedges are the product of thermal-contraction cracking as well as ice wedge. However, the issue about the material infilling a crack has not been clarified. The current study of composite wedges' structure has indicated crystals of segregated ice between and within sand veins. The average crystal sizes for composite wedges are smaller than those for ice wedges in Batagay outcrop. In the main part of the composite wedge, small crystals between the thinnest sand micro-veins, that forms microlenticular cryostructure, have long-axis ranging from 0.16 to 0.80 mm (Fig. 1). Such tiny average crystal sizes have not been encountered in the ice wedges. The composite wedges were formed by thermal contraction cracking with subsequent infilling of the cracks with unfrozen sediments, not with meltwater which produces ice wedge formation. There are no ice veins that could have been formed by infilling the cracks with meltwater in the structure of composite wedges. Lenses of segregated ice were formed by pore water from the unfrozen sediments that filled the crack. The pore water separated and migrated to the freezing fronts (two walls of the crack) forming mainly vertical microlenticular cryostructure. The isotopic composition indicates extremely continental, relatively dry, and low-snow conditions during the composite wedges' formation, such that thermal contraction cracks could be infilled by unfrozen sediments from an active layer. The high mineralization confirms evaporation in thin snow cover that caused fractionation processes and an increase of deuterium excess.

Keywords: Composite wedge, ice-petrography, isotopic composition

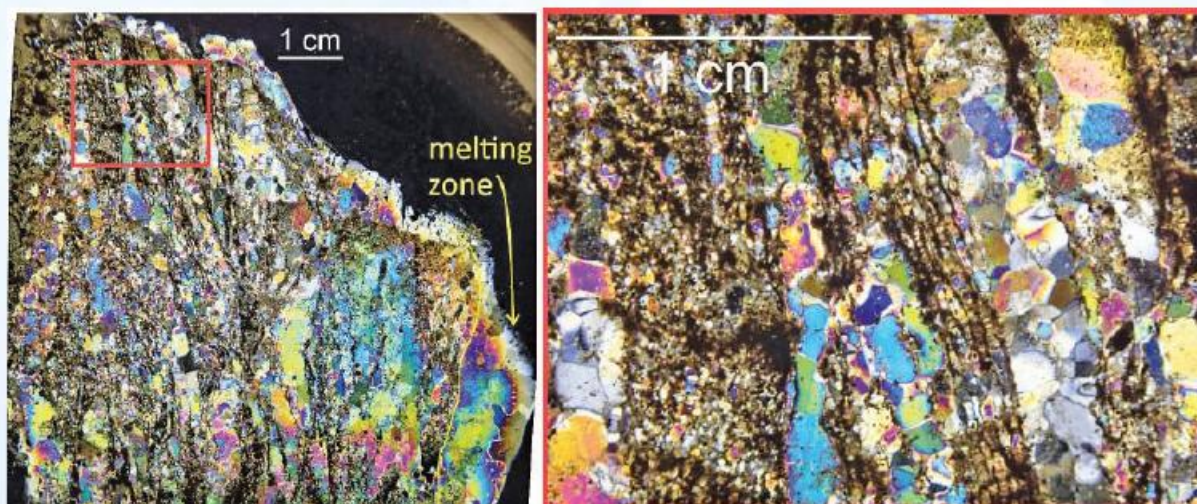


Fig 1. Petrography of composite wedges in vertical section and close-up showing the inner vertical microlenticular cryostructure formed by crystals of segregated ice.



HOLOCENE DEVELOPMENT OF A THERMO-EROSIONAL VALLEY ON KURUNGNAKH ISLAND, LENA RIVER DELTA

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As arctic regions experience climate warming, degradation processes such as thermal erosion increasingly affect the geomorphology, hydrology, and ecology of vast permafrost landscapes. These processes involve the formation of distinct landforms, such as thermo-erosional valleys. Especially in the ice-rich Yedoma permafrost of Siberia, thermal erosion has created widespread thermo-erosional valley networks during the Holocene, but our understanding of their impact on affected deposits remains very limited. Here, we investigated the Holocene development of a thermo-erosional valley in late Pleistocene Yedoma deposits on Kurungnakh Island (Lena River Delta, Siberia), based on near-surface stratigraphy and surface characteristics. We analysed five permafrost cores up to 184 cm long, taken on the floor, slope, source region and adjacent Yedoma upland of a thermo-erosional valley. The stratigraphic analysis included computed tomography (CT) scans, cryostratigraphic classification, radiocarbon dating, volumetric ice content, grain size distribution, robust endmember analysis, total organic carbon (TOC) content, TOC/TN (total nitrogen), stable water isotopes ($\delta^{18}\text{O}$, $\delta^2\text{H}$, d-excess), pH and electrical conductivity. Additionally, we account distributed measurements of active layer thickness (ALT) and water table depth (WTD) within the study area. The deposits were mainly of Holocene age, reaching 11,399 cal yr BP on the Yedoma upland and about 834 cal yr BP in the valley floor. For a sediment lens within the wedge ice contained in one slope core we specified an age of up to 22,220 cal yr BP. All samples exhibited high volumetric ice contents (>52 vol%), and except for the valley floor, all cores contained massive wedge ice. Stable isotope data showed more depleted values in wedge ice and a negative relationship between $\delta^{18}\text{O}$ and d-excess at specific depths of the valley floor, suggesting freezing fractionation. Polymodal grain size distributions and five robust endmembers indicated multiple sediment transport processes. Fluctuating grain size distributions, TOC contents, and TOC/TN ratios in the valley floor core reflected alternating depositional and erosional phases. Together with ALT and WTD measurements, these findings suggest a stable, well-drained Yedoma upland, in contrast to the slopes, which show evidence of erosion and re-deposition throughout the Holocene. The young valley-floor deposits, along with high ALT and low WTD, indicate ongoing thermo-erosional valley development in a variable energy environment with alternating processes and magnitudes of sediment accumulation during the late Holocene. Overall, the valley, particularly its slopes and source region with shallow sediment covers above relic wedge ice, remain highly vulnerable to continued warming and extreme climatic events. Multi-year data and deeper cores could provide further valuable insights into the temporal evolution of this fragile permafrost landscape.

Keywords: Thermal erosion, Yedoma, Siberia, stratigraphy



MULTIPROXY STUDY OF TIBETAN & PUTORANA PEAT RECORDS ELUCIDATES HIGH-LATITUDE HOLOCENE PALEOCLIMATE, ECOLOGY AND LANDSCAPE CHANGE.

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This study focuses on the organic-genetic sediments from two high-latitude regions: the Qinghai-Tibet Plateau in China and the Putorana Plateau in Russia. Utilizing a comprehensive multidisciplinary approach, it systematically explores the paleoclimate dynamics, environmental evolution processes, and landscape evolution mechanisms. The research integrates various technical methods, including AMS ^{14}C dating, carbon dynamics analysis, ground temperature monitoring, microscopic spatial distribution characteristics of soil protozoa, and groundwater level reconstruction based on shelled amoebae. Additionally, it emphasizes the introduction of alternative indicators such as pollen analysis, spore research, and peat accumulation rate to reveal the temporal sequence and ecological response of regional paleoenvironmental changes. The aim of this study is to deepen the understanding of the paleoclimate system in high-latitude regions and to provide crucial data and theoretical support for regional environmental evolution in the context of global change.

Keywords: Qinghai Tibet Plateau, paleoclimate, AMS ^{14}C



FOREST SPECIES DISCRIMINATION TO REFINE ACTIVE LAYER THICKNESS ESTIMATION

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The advent of new low-frequency spaceborne SAR missions, such as SAOCOM and BIOMASS, operating at L- and P-band, opens new perspectives for characterizing vegetation in support of Active Layer Thickness (ALT) inversion. ALT, defined as the maximum seasonal thaw depth corresponding to the downward propagation of the 0 °C isotherm, is one of the most widely used and robust indicators of climate-driven changes in permafrost regions. Because the active layer hosts the majority of biogeochemical processes governing carbon mobilization, microbial activity, and greenhouse gas emissions, variations in ALT directly modulate the magnitude of permafrost carbon feedbacks. Vegetation exerts a strong control on ALT through its influence on organic layer development, soil moisture, shading, and, critically, soil thermal properties. These vegetation-mediated mechanisms can either attenuate or enhance ground thaw, generating pronounced spatial variability in ALT under otherwise comparable climatic conditions. This highlights the necessity of explicitly accounting for vegetation-soil interactions when interpreting ALT dynamics and projecting permafrost responses to ongoing warming. To address this challenge, a dual-frequency SAR framework is introduced to discriminate hemi-boreal forest species using complementary information from L- and P-band observations. Owing to its deeper penetration and enhanced interaction with woody components, P-band data exhibit strong sensitivity to forest vertical organization, whereas L-band backscatter is comparatively less affected by internal structural heterogeneity. Ground topography is first retrieved from P-band data using a polarimetric subspace decomposition in order to mitigate topographic biases. The forest vertical backscatter contribution is then isolated using a Gaussian scattering model. The resulting vertical profiles display marked contrasts across forest stands and polarimetric channels, revealing a strong dependence on species-specific structural organization, notably between pine- and spruce-dominated forests. In contrast, the reduced sensitivity of L-band to vertical heterogeneity enables a more robust inversion of forest height through an empirical structure function. By combining these complementary sensitivities, a unified dual-frequency workflow is proposed to enhance forest species discrimination.

Keywords: Active Layer Thickness, biomass, species



LITHOLOGICAL AND GEOCHEMICAL INDICATION OF SEDIMENTATION CONDITIONS OF SEDIMENTS WITH MASSIVE ICE IN THE NORTH OF WESTERN SIBERIA

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Massive ice beds are a large underground body of ice, reaching several tens of meters in thickness and length from a few meters to several kilometers. There are several different positions regarding the origin of this ice. Some researchers believe that massive ice beds is the remnant of a buried Pleistocene glacier. Others suggest that massive ice beds formed during the freezing of water-saturated sediments in the Late Pleistocene. Massive ice beds is not expressed in relief, so establishing its genesis is an important task for modern cryolithology and paleogeography. Solving this task will allow us to link massive ice to specific genetic types of sediments, and then map the territory based on the likelihood of the existence of massive ice. Northern Western Siberia is the main region where massive ice is found. We had field studies of massive ice in 2022, 2024, and 2025 years at three key sites: the Marre-Sale polar station area on the western coast of Yamal, the Ural coast of Baydaratskaya Bay near the mouth of the Oyuyakha River, and the Vas'kiny Dachi field station in Central Yamal between the Seyakha and Mordyyakha rivers. All three outcrop of massive ice expose terrace III sediments (25 to 40 meters high). We did cryolithological analysis of the massive ice, establishing its bedding, the nature of its contacts with sediments, and the ice structure. In the laboratory, we used X-ray fluorescence analysis (XRF) to determine the bulk content of chemical elements in sediments containing massive ice and in several frozen ice samples. We determined the grain size distribution of sediments to identify lithofacies in the sections and compare them with tracers (chemical elements). Similarities were found in the geochemical composition of sediments from the Ural and Yamal (Marre-Sale) shores of Baydaratskaya Bay, as well as for the Central Yamal region. The Ural shore is characterized by coarser sediments and better particle sorting, which can be explained by the higher energy of streams near the Polar Urals and Pai-Khoi folded structures. The Marre-Sale section (Western Yamal) exhibits smaller particle sizes, but shows a more frequent rotation of sands, sandy loams, and loams, differentiated by organic interlayers. Even smaller particle sizes (loams and clays) are characteristic of the Central Yamal region. Unlike the Ural coast, in the coastal sections of Western Yamal, the highest concentrations of terrigenous elements (Fe, Al, Ti) are confined to loamy interlayers and likely indicate quiescent lacustrine sedimentation conditions. The highest percentage of silicon (Si) is observed here in cross-bedded sands and likely indicates dynamically active sedimentation conditions with the removal of all terrigenous components. Almost no Cl was detected in the sediments (except for the underlying sediments in the Marre-Sale area), indicating a predominantly continental origin. Similar geochemical composition of sediments and solid material within massive ice beds in key sites indicates their intrasedimental origin. The study was supported by the Russian Science Foundation project №25-27-00480.

Keywords: Yamal, permafrost, XRF analysis, massive ice



**1B: LONG-TERM COLD-ENVIRONMENT PERMAFROST CHANGE
POSTER**



GEOCHEMICAL AND LITHOLOGICAL CHARACTERISTICS OF ACTIVE LAYER AND ICE COMPLEX OF PERMAFROST IN THE EASTERN SIBERIA, RUSSIAN ARCTIC

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The active layer (AL) is the uppermost layer of permafrost that thaws every summer. It is highly sensitive to climate change. As the mean annual air temperature rises, the thickness of the AL and the duration of the seasonal thaw period increases. The mean ground temperature at the top of the permafrost also rises. This causes an increase in the content of unfrozen water, which is a solvent and medium for chemical reactions. As the depth of seasonal thawing increases, previously perennally frozen material becomes involved in geochemical processes. The study of geochemical composition of syngenetically frozen deposits of the Ice Complex (IC) is crucial for understanding the transformation of matter in the AL, corresponding to the age of these deposits at the given stratum horizon. It consists of rhythmic freezing of the AL sediments from below as a result of climatic fluctuations with simultaneous sediment accumulation. In turn, comparing the geochemical composition of the and syngenetically frozen deposits will allow us to trace the patterns of sediment transformation under the influence of climatic changes in the late Neopleistocene and Holocene. The study covers 8 sites located in Central and Northern Yakutia: The Kurungnakh-Sise island, the Bykovsky peninsula, the Muostakh island in the Lena River delta region; the Cherskiy settlement in the lower reaches of Kolyma River; the Olenek, Yarolyin and Zhilinda sites located in the Anabar and the Olenek River basins; Tegyultya in the Amga River valley, Central Yakutia. In the AC, samples were taken from a depth of 30 - 60 cm, mainly from soil horizon B. In the IC exposures they were taken from lower, middle and upper levels of the thickness. The geochemical composition of the samples was obtained with Energy-Dispersive X-ray Spectroscopy (Spectroscan-Maks). Each sample was tested for the presence of chemical compounds: SiO_2 , Al_2O_3 , Fe_2O_3 , TiO_2 , K_2O , CaO , MgO , P_2O_5 . The grain size analysis of 9 samples was conducted using laser particle sizer Fritsch Analysette 22. The results of the grain size analysis show that coarse silt is the most prevalent fraction in all samples, with a mean percentage of 47.7%. The fraction of fine silt is slightly lower (mean 29,9%). Sand fractions are present in small quantities (mean 2,4%) dominated by fine and very fine sands. The examined samples exhibit very similar geochemical compositions. The main compounds are SiO_2 (mean 54,7%), Al_2O_3 (mean 12,4%), Fe_2O_3 (mean 2,9%), K_2O (mean 2,5%), CaO (mean 2,4%), and MgO (mean 1,6%). The sample from the Yarolyin site is excluded due to elevated values of CaO (16.4%) and MgO (6.9%). The gathered results allow us to trace a certain pattern on the distribution of geochemical and granulometric compositions in the samples studied from various regions of Eastern Siberia. In turn, the obtained geochemical and granulometric markers suggest that cryogenesis processes in the AC significantly transform the original composition of sediments.

Keywords: AL, IC, grain-size analysis, cryogenesis



LATE PLEISTOCENE (MIS 3/MIS 2) AND HOLOCENE (MIS 1) CLIMATE DATA RECONSTRUCTION IN THE NORTHEAST SIBERIAN ARCTIC USING PALEOECOLOGICAL AND MODELING DATA

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Rapid climate change in the Siberian Arctic threatens major ecosystem shifts in the near future. Understanding how past climate variations affected ecosystems in this region helps assess the consequences of ongoing changes and provides a reference frame for their speed and magnitude. We integrate geochronological, paleoecological, and modeling data to reconstruct climate variables (MAP, MAAT, MTCO, MTWA) in the northeastern Siberian Arctic since MIS 3. Paleontological records from several Arctic locations indicate substantial temperature shifts during these periods. For our study, we used published paleoecological data from sites along the Laptev Sea coast and beyond. The pollen-based climate reconstructions rely on modern Northern Hemisphere pollen datasets and were generated using the modern analog technique (MAT), applying the MAT function to pollen percentages of selected taxa. Climate reconstructions based on insect records use the Mutual Climatic Range (MCR) method. A distinctive feature of steppe-tundra environments is the coexistence of species with contrasting climate preferences. We observe a similar pattern: the ground beetle *Bembidion umiatense* (MTWA 7.5–10°C), the weevil *Isochnus arcticus* (MTWA 2.5–10°C), and the weevils *Stephanocleonus eruditus* (MTWA 12–19°C) and *S. fossulatus* (MTWA 12–21°C) occur within the same assemblages. We therefore consider the most likely temperature to be “about 12°C,” reflecting the strong warm requirement of *Stephanocleonus*, while cold-adapted beetles can regulate their comfort range in permafrost by moving deeper into the ground. The warmest conditions correspond to the Early Holocene, while the coldest interval occurred during early MIS 2. The insect fauna indicates a sharp expansion of Arctic tundra habitats during the LGM, followed by subsequent warming. To derive absolute pre-industrial values (PIobs), NOAA GlobTemp anomalies were added to observed means derived from ERA5 reanalysis. Proxy-based climate reconstructions were then compared with CMIP6 PMIP experiments (15 models for 8 ka and four models for 21 ka). For MIS 3, AWI paleoclimate simulations spanning 38 ka to the LGM will be used. Model data were calculated for >20 locations with pollen records, covering ~2,000 km east-west and ~1,000 km north-south. Proxy and model results are illustrated for the Mamontovy Khayata site on the Bykovsky Peninsula, Laptev Sea coast

Keywords: Paleoproxy, modelling, climate data, Westberingia

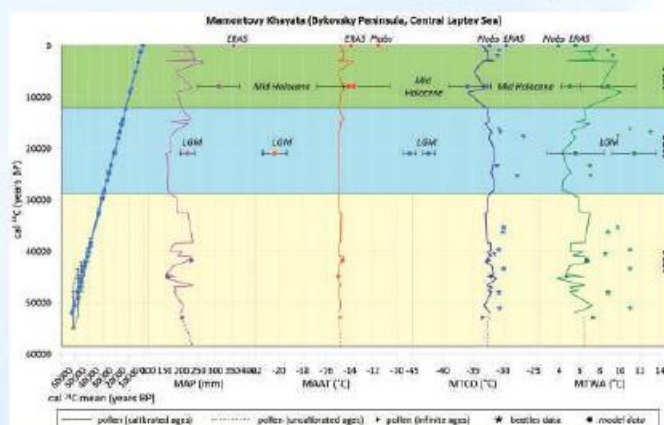


Fig. 1 Ages and reconstruction of mean annual precipitation (MAP), mean annual air temperature (MAAT), mean temperature of coldest month (MTCO), and mean temperature of warmest month (MTWA) using pollen, insect, and modelling data from the Mamontovy Khayata site.



THERMOKARST DEVELOPMENT AND RELATED VEGETATION SUCCESSIONS DETECTED FROM INSAR AND OPTICAL SATELLITE IMAGES

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Thermokarst is a typical process that indicates widespread permafrost degradation in yedoma landscapes. Central Yakutia, located in eastern Siberia, has experienced extensive landscape changes, including surface subsidence due to thermokarst development, over the past few decades. The development of thermokarst affects hydrological processes, ecosystems, and human society, accompanied by vegetation succession and degradation. Recent advances in L-band Interferometric synthetic aperture radar (InSAR) technique enable more accurate detection of ground surface displacement associated with thermokarst. A satellite constellation system, such as observations from multiple satellites, also enables the acquisition of frequent cloud-free images and detects temporal changes in the thermokarst landscape. This study detected the early-stage thermokarst and related vegetation succession using multitemporal satellite images of ALOS-2/PALSAR-2, PlanetScope, and RapidEye. We focus on the changes in the normalized difference vegetation index (NDVI) of grasslands associated with thermokarst development around the Churapcha area in eastern Siberia. The results showed that the NDVI of thermokarst grasslands in early stages was higher than that of dry grasslands without thermokarst development. The differences in NDVI were large during the summer growing season from June to August. Analysis of the time series NDVI over the past 20 years showed an increasing tendency in NDVI in early-stage thermokarst grasslands with a history of anthropogenic land use. These results indicate that increases in soil moisture and soil temperature may affect rapid vegetation growth and succession at the early-stage thermokarst landforms. Further study is necessary to verify the results using field observation over a wide area of eastern Siberia.

Keywords: Thermokarst, vegetation succession, InSAR, NDVI



THE BATAGAY MEGASLUMP: CRYOLITHOLOGY, CHRONOLOGY, AND CURRENT DYNAMICS OF THE WORLD'S LARGEST RETROGRESSIVE THAW SLUMP

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The world's largest retrogressive thaw slump (RTS) near Batagay settlement in the Yana Upland, East Siberia demonstrates the enormous consequences of rapid permafrost thaw including substantial terrain change affecting vast areas (87.6 ha in 2023), high dynamics with annual headwall retreat rates of up to 15 m per year and the considerable mobilization of previously freeze-locked material incl. organic carbon (Fig. 1). Associated with headwall retreat and floor deepening, the Batagay RTS mobilized a total ground volume of ca. 35 million m³ since its initiation in the 1990s. Since 2014, the mobilized volume amounts to about 1 million m³ per year; about 2/3 melted ground ice and 1/3 thawed permafrost deposits. The release of organic carbon as DOC and TOC from both components amounts to 4000-5000 tons per year. While growing, the Batagay RTS provides access to ancient permafrost. As age information of ancient permafrost is essential for understanding permafrost stability and interpreting past climate and environmental conditions over Pleistocene glacial and interglacial timescales, optically-stimulated luminescence (OSL) dating of quartz and post-infrared-stimulated luminescence (pIR-IRSL) dating of feldspar as well as accelerator mass spectrometry-based C1-36/C1 dating of wedge ice and radiocarbon dating of organic material have been applied. The cryolithological inventory of the Batagay RTS differentiates into the Lower Ice Complex (MIS 17-16 to MIS 13-12) overlain by the Lower Sand Unit (late MIS 7 to MIS 6), the Upper (Yedoma) Ice Complex (late MIS 5 to MIS 3) and the Upper Sand Unit (MIS 3-2). Two woody beds below (undated) and above (MIS 5e) the Lower Sand Unit represent erosional discordances marking warm episodes of taiga forest development prior to the Holocene (MIS 1) cover. Both, sediment and ground ice components of the Batagay ancient permafrost archive were currently employed to constrain the local permafrost chronology and to reconstruct past environmental and climate conditions including studies on ancient DNA, stable isotopes, organic-matter and specifically biomarker stocks and characteristics, greenhouse gas formation in ground ice and polar jet stream dynamics based on dust preserved in wedge ice. The present contribution aims to summarize current understanding and major insights from extensive studies of the modern terrain dynamics, the cryolithological structure and the paleoarchive of the Batagay megaslump. Future research to disentangle further environmental information from this unique permafrost degradation feature will be outlined.

Keywords: Rapid permafrost disturbance, thermal denudation



Fig. 1 UAV-based view of the Batagay megaslump; about 890 m wide and 55 m deep in April 2019.



LATE QUATERNARY ENVIRONMENTAL DYNAMICS ON THE BALDWIN PENINSULA (WEST ALASKA) BASED ON PERMAFROST AND GROUND ICE ANALYSES

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We studied Pleistocene to Holocene permafrost and climate dynamics on the Baldwin Peninsula, West Alaska, at the Alaskan side of the Beringian land bridge, a former land mass connecting Siberia and North America. Our field investigations were conducted mainly on coastal outcrops and a lake drainage erosion gully during the expeditions “West Alaska 2024 and 2025”. Site 1, called the Schaeffer site, is a drained lake basin and associated fresh drainage gully, about 5 km East of the City of Kotzebue. The thermo-erosional gully formed when the lake drained in 2022 (Jones et al., 2023) and deeply incised into ice-rich permafrost deposits, exposing a Holocene cover deposit (MIS 1) overlying late Pleistocene Yedoma Ice Complex deposits (MIS 4-3). At the base of the coastal bluff, below the drained lake site and near the outlet of the gully, glaciofluvial deposits and overlying fine-grained ice-poor silty deposits were exposed. Site 2, Cape Blossom, forms a large coastal bluff at the southwest coast of Baldwin Peninsula and is characterized by Holocene cover deposits (MIS 1), late Pleistocene Yedoma Ice Complex deposits (MIS 4/3/2), but also older interglacial, glaciomarine, and glaciofluvial deposits (likely of MIS 5e and older age) including a massive ice body with transparent ice at the bottom of the section. Both sedimentary sequences display larger gaps during MIS 2 and 3. At these two main sampling sites, cryostratigraphic characteristics of frozen sediments and ground ice (ice wedges, representative of winter-season paleo-conditions, and intrasedimental ice, representative of whole-year averaging conditions) were described in detail and sampled. First results are complemented by studies of further sites i.e. in a nearby Holocene thermokarst basin (site 3). Radiocarbon and luminescence dating techniques provide chronological control of the stratigraphy. Here, we present a comprehensive dataset of field and laboratory data on permafrost profiles and the ground ice contained within. Analyses of stable water isotopes in ground ice, $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in sedimentary organic matter, as well as of sediment, biogeochemical and cryolithological properties were carried out. Stable water isotopes in ground ice are indicative for local palaeoclimatological and palaeoenvironmental change, and display clear differences between glacial and interglacial intrasedimental and wedge ice, indicative of both climate change through time as well as of the seasonality shift implied from the ground ice types. Key sedimentary results are a highly uniform, unimodal grain-size sequence of silty sands in the Yedoma deposits, interpreted as largely of aeolian origin. Carbon contents, C/N ratios, and $\delta^{13}\text{C}$ values clearly differ between glacial Yedoma and interglacial deposits. These new results are compared with findings from other sites in Beringia with similar cryostratigraphic sequences. Jones, B. M. et al. (2023). Integrating local environmental observations and remote sensing to better understand the life cycle of a thermokarst lake in Arctic Alaska. *Arctic, Antarctic, and Alpine Research*, 55(1). <https://doi.org/10.1080/15230430.2023.2195518>

Keywords: Palaeoenvironment, Alaska, ground-ice, stable isotopes



1C: GTN-P: LOCAL OBSERVATIONS TO GLOBAL ASSESSMENTS

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The Global Terrestrial Network for Permafrost (GTNP) maintains a standardized, longterm monitoring network of active layer depth, permafrost temperature, and rockglacier velocity to provide highquality Essential Climate Variable data across highlatitude and highaltitude regions. This session explores advances in data preservation, management, and dissemination, and highlights how GTNP observations underpin regional and global permafrost assessments, Earth System Model validation, reanalysis products, and remotesensing integration. We welcome contributions on sitespecific monitoring results, data assimilation into models, synergy with related programs, and lessons learned from operating in both hemispheres, with a particular focus on the Third Pole region.





LONG-TERM MONITORING OF THERMAL STATE OF PERMAFROST IN MONGOLIA

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Permafrost in Mongolia occupies a climatically sensitive transition zone between continuous permafrost in northern Eurasia and discontinuous to sporadic permafrost in Central Asia, making it highly responsive to both climate warming and human disturbance. Here we present a synthesis of long-term monitoring of mean annual ground temperature (MAGT) in Mongolia based on borehole observations spanning 25-55 years, with intensified measurements since 1996 across the Khentii, Khangai, and Khovsgol mountain regions, which together comprise approximately 80% of the national permafrost zone. Temperature records from more than 40 boreholes, including re-drilled historical sites and newly instrumented profiles, were used to characterize regional thermal gradients, depth-dependent responses, and emerging modes of permafrost degradation. Our results reveal a clear latitudinal pattern in permafrost warming, with long-term MAGT increases at the depth of zero annual amplitude (≈ 10 m) of approximately 0.1 °C per decade in the Khentii, 0.2 °C per decade in the Khangai, and 0.2 - 0.3 °C per decade in the Khovsgol region. Warming trends prior to the early 2000s were generally stronger than those observed in the subsequent period, with a notable slowdown in MAGT increase in the Khovsgol region during the mid-2010s. Thermal signals propagated downward to depths of 40-60 m in fine-grained sediments and 80-150 m in bedrock, indicating long-term adjustment of the permafrost thermal regime to surface forcing. In addition to this dominant top-down warming signal, we identify a contrasting degradation mode in locally specific hydrogeological settings of the Khentii region, where permafrost thaw progresses from depth upward. This bottom-up degradation is associated with groundwater flow and talik development, highlighting the importance of subsurface processes that are not captured by surface climate indicators alone. Human land-use activities, including grazing, mining, transportation, and infrastructure development, further accelerate permafrost warming through disturbance of the surface energy balance and the formation of widespread supra-permafrost taliks. Overall, our synthesis demonstrates that permafrost degradation in Mongolia is governed by interacting regional climate gradients, depth-dependent thermal inertia, and local hydrogeological and anthropogenic controls. These findings underscore the need to explicitly represent subsurface heat and moisture transport processes in regional permafrost assessments and models, particularly in climatically transitional permafrost regions.

Keywords: Temperature trend, gradient, degradation, regional



IMPACT OF PRECIPITATION ON SOIL TEMPERATURE IN MONGOLIAN PERMAFROST REGIONS

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Permafrost warming and thawing are highly sensitive to recent climate change. Although the effect of air temperature on permafrost thaw is well established, the relationship between precipitation events and ground temperature dynamics on the interannual time scale remains poorly understood. Mongolia, characterized by strong climatic sensitivity, has experienced rapid warming over the past six decades, approximately three times the global average, reaching an increase of about 2.4 °C. This warming has contributed to significant increases in the thawing index and decreases in the freezing index, accompanied by an increase in active layer thickness (ALT). This study aims to analyze the impact of interannual precipitation variability on ground temperature in the active layer underlain by ice-poor permafrost in mountainous forest-steppe ecosystems in Mongolia. Published datasets of daily precipitation measurements at 200 cm above ground, daily temperature, and daily surface and 20, 40, 60, and 100 cm soil moisture during the 2008 - 2021 period were used to distinguish hydrological wet and dry years based on seasonal precipitation anomalies. The relationship between precipitation (August) and soil moisture (August - October) was studied to provide time-lagged responses on soil moisture dynamics - precipitation anomalies varied by season and year. Spring precipitation decreased, whereas summer and autumn precipitation increased since 2015. Soil moisture at 40 cm showed minimal seasonal variation in the driest year but increased substantially in wet years, with a lag of approximately one month after significant rainfall events. Moisture levels in wet years remained elevated into November despite surface freezing. Correlation analyses revealed no significant relationship between rainfall and deeper soil moisture during dry years, whereas wet years showed moderate to strong positive correlations ($R = 0.38-0.66$).

Keywords: Precipitation, permafrost, soil moisture



GROUND THERMAL REGIME VARIABILITY IN THE ALTAI AND KHANGAI MOUNTAINS BASED ON FROST NUMBER AND SURFACE OFFSET

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This study presents a comparative analysis of ground thermal conditions in two contrasting mountain regions of Mongolia: Bayanovoo soum in the Khangai Mountains (1945 m a.s.l.) and Tsagaannuur village in the Altai Mountains (2120 m a.s.l.). Using air and ground surface temperature observations from 2023 and 2024, we evaluate frost number and surface offset to assess regional and local controls on permafrost-related thermal regimes. Frost number values derived from air temperature indicate transitional thermal conditions at Bayanovoo, with mean annual values decreasing from approximately 0.49-0.45 in 2023 to 0.43-0.46 in 2024 across ground surface sites. This decline reflects an increasing influence of thawing conditions in the Khangai region. In contrast, Tsagaannuur exhibits higher frost number values, ranging from approximately 0.50 to 0.53, consistent with a cold-dominated thermal regime favored by higher elevation and colder climate. However, a slight reduction in frost number is observed at ground surface sites in 2024, suggesting increasing thermal variability even in the Altai Mountains. Surface offset analysis reveals consistently positive values at all sites, indicating that ground surface temperatures are warmer than air temperatures due to surface insulation effects. At Bayanovoo, surface offset increased markedly from 2023 to 2024 at all measurement locations, including sites inside fenced areas, outside fenced areas, and near a permafrost monitoring borehole, with values exceeding 3 °C at the external ground surface site in 2024. At Tsagaannuur, surface offset also increased at ground surface sites; however, a pronounced decrease was observed at the borehole-adjacent site in 2024, where the surface offset dropped to approximately 0.5 °C. This suggests enhanced ground cooling and stronger coupling between the ground surface and subsurface permafrost conditions. The results highlight the combined influence of elevation, regional climate, and local surface conditions on ground thermal regimes in Mongolia's mountain environments. While the Altai region remains more favorable for permafrost preservation, both regions exhibit signals of increasing thermal sensitivity, emphasizing the importance of multi-site ground temperature monitoring for detecting early permafrost responses to climate change.

Keywords: Permafrost, frost number, surface offset



ESTABLISHMENT OF SIBERIA-MONGOLIA-TIBET PERMAFROST OBSERVATION TRANSECT: PROGRESS & PERSPECTIVE

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There are 16 climate tipping points leading to substantial Earth system impacts, among which 2 of them closely related to permafrost. Establishment of integrated hydrothermal observation network is imperative to understand the response and impacts of permafrost dynamics to climate change and earth system. And the uniform and integrated observations for multi-parameters are critical to figure out the energy-water-carbon processes occurred in permafrost over a large scale. Furthermore, the in-situ observations are imperative for the validation of remote sensing products. The international collaboration team from China, Russia, Mongolia and Japan presents a framework of Tran-Eurasia Permafrost Observation Transect through Russia, Mongolia, and China, where cross the latitudinal permafrost regions (arctic), the transitional permafrost regions (Mongolia), and altitudinal permafrost regions (Qinghai-Tibet Plateau) from the north to south in Eurasian continent. With the effort of more than 20 years, the uniform permafrost observation system has been established in the three typical regions. Those observation will serve for the solution of scientific issues including permafrost distribution, heat and moisture exchange within active layer; energy exchange between atmosphere and earth surface in cold regions; the impacts of permafrost dynamics on ecosystem and hydrology; the risk assessment of thermokarst hazards such as thaw slump; and so on. More permafrost observation sites are necessary to establish the cross-continent observation transect for the above-mentioned core issues and the solution of common interest such as permafrost hydrology, carbon balance, and causing-hazard mechanism, etc. The Uniform observations need to be considered for permafrost mapping and modelling over different spatio-temporal scales. Multi-discipline collaborations are welcome at those sites, especially the atmospheric, ecological, hydrological, remote sensing observations.

Keywords: Permafrost, observation, transect, climate warming



NEW RESEARCH AND MONITORING NETWORK IN THE MOUNTAINOUS PERMAFROST REGION OF THE NORTHEASTERN EURASIA

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Northeastern Eurasia, exhibiting various natural conditions, lies in the continuous permafrost zone and is dominated by mountainous conditions. Though this region is highly impacted by climate change, over the last 30 years the permafrost research was practically absent here, while the data on permafrost date back to the 60-70s of the last century. The aim is to study the current state of permafrost in Upper Kolyma Highlands, the formation of hazardous phenomena associated with the transformation of its characteristics, and project their future dynamics, taking into account climate change and anthropogenic impacts. Since 2020, a geocryological monitoring network and the research station “Anmangynda aufeis” have been established and maintained all-year-around. The monitoring network includes 26 temperature boreholes ranging in depth from 5 to 30 meters, three hydrogeological wells, and two CALM sites. The boreholes are located at elevations ranging from 162 to 1,232 m, covering all landscape types typical of the region. Five boreholes are located in talik zone. Several boreholes are located in the aufeis formation zone at the aufeis glade of the giant Anmangynda aufeis. All sites are equipped with snow measuring rods and camera traps in winter, as well as year-round air temperature sensors. The database of permafrost characteristics of the region has been developed, containing both historical and current (2021-2025) monitoring data from the regional network, meteorological stations, and precipitation gauges, as well as snow cover observations. Accumulated observational data on snow cover characteristics in the mountainous part of the Kolyma River basin already allow conclusions to be drawn about snow cover distribution patterns in this area. Given the shortage of meteorological stations, the obtained results are extremely relevant. The station “Anmangynda aufeis” operates year-round. The following data were collected in 2020-2025: daily snow depth at seven sites; 4-hourly data on ground temperature at different depths at seven boreholes; 4-hourly data on groundwater depth and temperature at three hydrogeological wells; 30-minute meteorological data; liquid precipitation and air temperature data at monitoring stations during the warm period; water level and temperature data, measured water discharges, and surface flow velocity based on video footage at four hydrological stations; and data on thaw depth and snow depth at the CALM site. Comprehensive studies of icing processes have been conducted at the research station. The new knowledge was obtained on groundwater regimes and heat exchange in the zone of giant aufeis formation. Various methods for estimating the volume of giant aufeis, including ground penetrating radar surveys, UAV surveys, and high-precision geodetic equipment were tested and adopted for future applications. The new data is useful for regional and global permafrost assessments, Earth System Model validation, reanalysis products, and remote-sensing integration.

Keywords: Geocryological network, research station, Anmangynda



STATE OF PERMAFROST IN THE SWISS ALPS AFTER 25 YEARS OF COORDINATED OBSERVATION

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The Swiss Permafrost Monitoring Network PERMOS documents systematically the state and changes of permafrost in the Swiss Alps since 2000 based on long-term field measurements. To account for the heterogeneous distribution and characteristics of mountain permafrost, PERMOS developed and implemented a comprehensive monitoring strategy. It relies on three complementary variables: (1) ground temperatures at the ground surface and in the permafrost, (2) permafrost electrical resistivity to infer changes in ground ice content, and (3) rock glacier velocities to reflect permafrost creep. In this contribution, we combine the results from the three monitored variables and present a comprehensive assessment of the evolution of permafrost in the Swiss Alps based on 25 years of coordinated observations. Ground temperatures near the surface and in the permafrost have been rising since the start of the measurements. During this period (2000-2025), ground surface temperatures increased by about $+0.5^{\circ}\text{C}$ per decade with large interannual variability in the last 10 years. Currently Mean Annual Ground Surface Temperature values are above 0°C at most locations. In the permafrost, average temperature increase of $+0.4^{\circ}\text{C}$ was observed at 10 m depth over the last decade (2015-2024), whereas an average increase of $+0.2^{\circ}\text{C}$ was observed at 20 m depth. The warmer conditions led to active layer thickening up to several meters, and with record values observed in 2024 at the majority of the sites. Electrical resistivity measured within the permafrost exhibits a general decreasing trend of up to 5% per year on average (50% per decade) indicative of an increase in liquid water content. This is considered as a direct consequence of ground ice loss and subsequent wetting of the ground. Lastly, the velocity of rock glaciers has generally increased since the beginning of the observations, with marked inter-annual variability related to snow cover, meteorological conditions, and subsequent ground temperatures changes. Overall, we show that the three variables have complementary benefits for long-term observations of permafrost evolution. They all point to a consistent pattern of continued permafrost warming and degradation in the Swiss Alps since the start of coordinated observations.

Keywords: Mountain permafrost, permafrost monitoring, Switzerland



GLOBAL CHANGES IN THE ACTIVE LAYER THICKNESS AND THAW SUBSIDENCE RATES IN THE PERMAFROST REGIONS

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Active layer is an important indicator of the changes in the permafrost regions. Changing climatic conditions, ecosystem transformations, natural and anthropogenic disturbances all have impacts on active layer variability and trends. The widespread, systematic changes in the thickness of the active layer could have profound effects on the flux of greenhouse gases, on the human infrastructure in cold regions, and on landscape processes. The Circumpolar Active Layer Monitoring (CALM) program, established in the 1990s, observes the long-term response of the active layer and near-surface permafrost to changes and variations in climate in both hemispheres and is major contributor of ALT data to the Global Terrestrial Network for Permafrost (GTN-P). The analysis of ALT changes over the last 25 years indicates widespread, but variable ALT increases in the Arctic, Antarctic and mountain permafrost regions. The changes in ALT in mountain permafrost have high variability, but most sites in the European Alps show more than 5 cm/year, while most sites located in Norwegian Mountains, Qinghai-Tibet Plateau and Andes generally show less than 2 cm/year increases. The lowest rates of ALT increases are found in cold continuous Arctic permafrost regions of North America and Eurasia and generally less than 0.7 cm/year, while sites located on discontinuous permafrost show on average more than 2 cm/year. Antarctic sites do not show statistically significant trends. In addition, in areas with ice-rich permafrost thaw subsidence rates may be comparable or even higher than ALT changes. Long-term monitoring and data exchange are needed in order to assess permafrost reaction to changing climatic conditions and to inform relevant stakeholders in order to develop mitigation and adaptation strategies in permafrost regions. We welcome new collaborations and open data exchange with the CALM program, especially from Mongolia, China, Kazakhstan, Nepal, Bhutan, Japan and other countries, which will help to improve global coverage and improve understanding of permafrost changes across diverse world regions.

Keywords: CALM, GTN-P, ALT, thaw subsidence



**1C: GTN-P: LOCAL OBSERVATIONS TO GLOBAL ASSESSMENTS
POSTER**



SYSTEMATIC ERRORS IN LONG-TERM BOREHOLE TEMPERATURE RECORDS IN PERMAFROST

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We investigated some of the systematic errors that are part of the uncertainty budget associated with long-term temperature measurements in permafrost. We evaluate the results of two types of experiments: i) lab experiments focusing on stability of calibrated sensor offsets, and ii) field experiments investigating the effects of borehole installation techniques on accuracy and inter-comparability of records from borehole installations. In the lab, we quantified the errors associated with four types of sensor's behavior that is not addressed by the most often carried out single-point 0°C bias correction: i) non-linear sensor offsets dependent on temperature (multiple-step calibration), ii) long-term drift of the 0°C offset (after six and nine years), iii) drift of the 0°C offset following thermal stress, and iv) hysteresis of temperature values measured by the sensor. We found that a significant, positively-trending drift of the 0°C-offset could be recorded after already 6 years, even for sensors never deployed in the field and thus not subjected to drift-inducing external factors. We also confirmed non-linearity of the sensor offsets for temperatures in the range between -20°C to +20°C. Negative temperatures were affected by larger offsets than positive temperatures, suggesting the need for multiple-step calibration at least at and below 0°C. We conclude that expanding the current best practice recommendations on thermal sensor calibrations, and differentiating them specifically for long-term monitoring vs. for short-term measurements, would constitute a step forward in enhancing the quality and inter-comparability of the data we are acquiring as permafrost community. In the field experiment, we drilled and instrumented four boreholes, 4-5 meters deep, at a site with permafrost present in sediments at approximately 1.5 m depth. The boreholes were instrumented with different casing materials to house and protect temperature sensor strings: two boreholes with high-density polyethylene (HDPE) casing, one borehole with steel casing, and one borehole with no casing (temperature sensors in direct contact with the soil). We evaluate i) the inter-comparability of the measurement from two nominally identical installations (the two HDPE-casing boreholes), ii) the differences between measurements in boreholes cased with highly thermally conductive (steel) vs. non-conductive (HDPE) material, and iii) the effect of casing on dynamic response of the sensors inside the two types of casing vs. in direct contact with the soil.

Keywords: Permafrost monitoring, borehole measurements, errors



LONG-TERM SOIL AND PERMAFROST THAW SUBSIDENCE: EVIDENCE FROM «EASTERN CHUKOTKA COASTAL PLAINS» RESEARCH STATION, RUSSIA

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The climate changes in polar and cold regions lead to rapid shifting of permafrost conditions, in particular, increasing of permafrost temperature, deepening of seasonal soil thaw, and the activation of some exogenous cryogenic processes leading to vertical ground surface displacements. Seasonal surface deformations can be reversible under stationary climate conditions, where the summer thaw subsidence of soils is completely compensated by autumn-winter frost heaving. In cases of extremely warm summer seasons, the depth of seasonal thawing can affect the sediments of the transient layer of permafrost, the part of the soil-cryogenic complex that leads to increased values of summer soil subsidence. The observed warming of the Arctic climate, intensified since the 1970s, forced the increased summer heat flow into the soil that leads not only to permafrost warming, but also a gradual thawing of ice-rich transient and intermediate layer. The isotropic subsidence of the ground surface in permafrost regions has global nature. However, available information about its geography and characteristics is scattered; interannual trends in vertical surface displacements are determined by different methods and observational time series. This study presents the results of long-term monitoring the active layer thickness and vertical surface displacements at the Circumpolar Active Layer Monitoring (CALM) site R-41 Lavrentiya located within “Eastern Chukotka Coastal Plains” research station, Chukotka, Northeastern Russia. The monitoring data were supplemented by shallow coring of active layer and upper permafrost to reveal and characterize the transient and intermediate layers. Due to increased summer heat supply, for the period 2004–2024 the rate of subsidence of the day surface varied from 1.4 to 3.5 cm $^{-1}$, while the rate of change in the active layer thickness (ALT) was from -3.2 to +1.6 cm $^{-1}$. The thaw subsidence occurred without the formation of thermokarst landforms. The study revealed that on the background of relatively stable variations in active layer thickness, a gradual subsidence of the ground surface was observed. The obtained results make it possible to reconsider the results of monitoring the active layer at other CALM sites located on ice-rich deposits, and to develop a set of additional studies to take into account the hidden effect of sedimentation of thawing rocks. The study was financially supported by the Russian Science Foundation Project No. 25-17-00010.

Keywords: Intermediate layer, thaw subsidence



FROZEN GROUND TEMPERATURE ON KEY SITES OF PRILENSKOE PLATEAU, SIBERIA

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The study presents the results of observations of the temperature regime of permafrost deposits on the Prilenskoe Plateau, on the left bank of the Lena River, during the period 2016-2024. Observations were made at six boreholes equipped with two-channel Hobo U23-003 loggers and four-channel U12-008 loggers. Temperature sensors were installed at heights of 2 m, on the surface and at different depths of 0.5 m, 1.7 m, 5 m, 10 m, 15 m and 21 m. Site 15/1 Tabaginsky Cape is located in a mixed forest with birch and larch trees, shrubs, and grasses. Sediments are represented by Yedoma deposits with ice-wedges a thickness of 10 m, and alluvial sand below. Key site is located near abandoned fields that have been exposed to thermokarst at different stages. Site 11/3 Pokrovsk is located on an inter-alas high between two thermokarst lakes. Sediments are represented by Yedoma deposits with ice-wedges a thickness of 17 m, and alluvial sand below. Site Kildyamtsy with boreholes 13/1 and 15/2 is located on the first floodplain terrace of Lena River. Sediments consist by alluvial sands and silts. Vegetation consists of meadow grasses and shrubs. Site Namtsy is located 94 km north of Yakutsk. Borehole 18/4 is located on the surface of an inter-alas high, home to a larch forest where a wildfire occurred in 2018. Sediments consist of Yedoma deposits and are underlain by sand. Borehole 18/5 is located on thermokarst lake bank in larch forest. The warming period lasted from 2016 to 2021, during which the mean annual air temperature (MAAT) increased from -7.6°C (2016) to -5.4°C (2020). Then, between 2022 and 2024, there were a reverse decrease in the MAAT, with values of -7.5°C in 2023 and -6.6°C in 2024. Fluctuations in MAAT are mainly due to changes in winter temperatures. The largest changes in mean annual ground temperature (MAGT) occurred in the active layer for the Tabaginsky Cape, from -1.2°C (2016) to +1.1°C (2020), followed by a decrease again to -0.7°C (2024). At 5 m MAGT on the Pokrovsk changed from -2.0°C to -1.5°C, and at Tabaginsky Cape, from -1.6°C to -0.9°C. At the post-pyrogenic Namtsy a decrease in the MAGT was noted from -2.6°C to -3.0°C. At depths of 10 m, 15 m, and 21 m, MAGT increased by 0.2-0.3°C, ranging from -2.8°C at Namtsy to -1.4°C at Tabaginsky Cape. The warming of MAAT, with some slowdown, caused a warming of MAGT at most observation sites, except for the post-pyrogenic site 18/4, where, due to the burning of the vegetation cover, freezing was stronger, and after succession it became equal to the control site 18/5.

Keywords: MAAT, MAGT, permafrost, Central Yakutia



RAPID LAKE EXPANSION DRIVEN BY ASYMMETRIC INCREASES IN PRECIPITATION AND PERMAFROST THAW ACROSS THE NORTHERN TIBETAN PLATEAU

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Accelerated global warming has profoundly intensified hydrological changes across the permafrost regions of the northern Qinghai-Tibetan Plateau (QTP). The unprecedented rate of temperature rise has substantially increased the frequency and intensity of extreme precipitation events, following the Clausius-Clapeyron relationship (~7% increase in atmospheric moisture per 1°C). This enhancement amplifies precipitation-driven surface runoff (precipitation production effect), which rapidly contributes to lake expansion. In contrast, permafrost degradation—manifested as active-layer thickening and enhanced soil permeability—responds more slowly to warming, producing a lagged infiltration effect (facilitated infiltration effect). The asymmetric increases between precipitation intensification and permafrost thaw lead to a dominant and immediate runoff increase that outweighs the gradual infiltration enhancement. Integrating hydrometeorological observations, satellite data, and process-based modeling, this study quantifies these contrasting mechanisms under accelerated climate warming. Building upon recent findings of combined warming, wetting, and greening in QTP permafrost regions, our preliminary results demonstrate that extreme precipitation enhancement exerts a far stronger and more immediate control on runoff and lake expansion than permafrost degradation. These findings highlight that the rapid lake expansion observed in the northern QTP is fundamentally driven by precipitation-dominated hydrological intensification under accelerated global warming, while the permafrost thaw effect remains secondary and delayed.

Keywords: Lake expansion, extreme precipitation, permafrost



2A: ENGINEERING SOLUTIONS FOR A THAWING PERMAFROST: PREVENTION, ADAPTATION, AND MITIGATION

Convener: *Fujun Niu¹*

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Global warming accelerates permafrost degradation, threatening infrastructure with reduced bearing capacity, thaw settlement, and material degradation. This session invites contributions on prevention and mitigation strategies, including innovative materials, cooling systems, and risk management for infrastructure like roads and railways. Case studies from permafrost regions addressing engineering challenges and solutions are especially encouraged.





A INNOVATIVE THERMOSYPHON TECHNOLOGY FOR STABILIZING PERMAFROST-AFFECTED ROCK SLOPES: EARLY SUCCESSES FROM THE PIZ NAIR SUMMIT STATION

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The Piz Nair summit cable car station, located at 3,030 meters in the Swiss Alps, faces ongoing challenges due to permafrost degradation and associated rock mass deformation. Recent years have seen accelerations in slope movement, impacting the integrity of both the cable car infrastructure and the multi-use summit building. Traditional stabilization methods have proven insufficient in this unique alpine environment, prompting the project team to explore passive cooling technologies. We present the deployment and initial performance of a complex thermosyphon-based stabilization system designed to arrest ongoing deformations and restore permafrost conditions beneath the building. Seventeen thermosyphons, arranged in three strategic groups around the building, were installed in the summer 2025 following detailed site characterization and engineering analysis. The design leveraged 3D geothermal modelling and climate projections to optimize thermosyphon placement. Initial monitoring results indicate that the thermosyphon system is successfully lowering ground temperatures in critical zones, with measurable reductions observed during the first operational seasons. These temperature decreases are projected to decelerate slope creep and enhance long-term stability, and supporting safe operation of the facilities for decades to come. The project demonstrates the feasibility and effectiveness of thermosyphon technology in high-altitude, providing a blueprint for similar stabilization efforts in other vulnerable alpine infrastructure. Beyond the technical achievements, the project highlights the importance of integrating climate adaptation strategies into geotechnical engineering practice. The initial success of the Piz Nair thermosyphon system underscores the potential for passive cooling technologies to mitigate climate-driven risks in mountainous regions, offering valuable lessons for future projects facing comparable challenges.

Keywords: Thermosyphon, passive cooling, Piz Nair



STRUCTURAL HEALTH MONITORING SYSTEM FOR CRITICAL INFRASTRUCTURE AT RISK FROM PERMAFROST DEGRADATION IN GREENLAND

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Permafrost degradation is known to influence landscape changes, including rock mass and sediment movements. As the Arctic is warming at a rate more than twice the global mean, it is expected that permafrost will degrade significantly in the coming decades, posing serious risks to existing infrastructure. To effectively assess these risks to (critical) infrastructure in Greenland, it is essential to establish a clear understanding of what constitutes 'critical' infrastructure in the Greenland context. Based on a literature review and input from stakeholders and local communities, we present a framework and definition of critical infrastructure, specifically tailored to Greenland. Applying this framework, and in collaboration with Nukissiorfiit - the Greenland Utility Company - power lines were identified as a particularly critical infrastructure type. As hydropower plants in Greenland are located far from the communities they serve, power lines inevitably traverse sedimentary permafrost, making them especially vulnerable to permafrost degradation. Therefore, we developed a monitoring system for power line masts in Sisimiut and Ilulissat, laying the groundwork for a Structural Health Monitoring (SHM) system. In addition, the collected data will improve our understanding of the ongoing physical processes contributing to permafrost degradation around the masts beyond the effects of climate change alone. In total, seven power line masts founded on sedimentary permafrost were selected for monitoring, as they had already exhibited signs of instability related to permafrost degradation. A borehole up to a depth of 5 m was drilled near the foundation of each of the selected masts, allowing the collection and analysis of permafrost samples and the installation of a thermistor string for ground temperature measurements. In addition, air temperature, relative humidity and barometric pressure are monitored at each mast, together with the tilt of the foundation. Owing to the proximity of the hydropower plant to the monitored masts in Sisimiut, measurements can be transmitted in quasi real-time. This capability is crucial for the development of a reliable and practical SHM system, considering the remoteness of power lines in Greenland, which strongly affects access for maintenance, inspections, and repair. We identified a correlation between the extent of observed foundation instabilities and increasing ice content and the fine-grained sediment fraction within the permafrost, highlighting the importance of site investigations prior to construction. Furthermore, ground temperature measurements indicate that the power line mast acts as a thermal radiator, cooling the soil in winter and heating it in summer. Combined with the initial thermal disturbance of the soil caused by mast construction and ongoing climatic warming, this effect leads to a local acceleration of permafrost degradation. In addition, there are indications that changes in hydrological conditions, both intra- and supra-permafrost, contribute to the acceleration of permafrost degradation. Future work will focus on continued data collection and analysis, as well as the development of a coupled thermo-mechanical-hydrological model to support the SHM system and improve understanding of the governing physical processes.

Keywords: Critical Infrastructure, permafrost degradation, Greenland



LABORATORY MACROMODELING OF THAWING HALO FORMATION AROUND AN OIL WELL USING ULTRA-THIN LIQUID THERMAL INSULATION

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Thin liquid thermal insulation. This material is applied like a standard paint coating, and manufacturers claim its thermal conductivity is 0.001–0.008 W/m*K. This makes ultra-thin thermal insulation very attractive for the oil industry, one of whose problems is the formation of thaw halos around production wells in permafrost. However, numerous publications refute the significant protective effect of liquid thermal insulation. Currently, there is active debate over both the thermal conductivity values of such materials and the methods for determining them. Most articles describe methods in which the thermal insulation surface is in contact with air. To determine the feasibility of using ultra-thin liquid thermal insulation for oil wells, a special test rig has been developed that simulates oil flow in a well on permafrost. The rig consists of a tray filled with soil (the weight of the soil is approximately 800 kg), containing a model of a production well. The tray is housed in a freezing chamber. The soil contains 55 temperature sensors, installed at varying depths and distances from the well model. Initially, the soil is frozen. Once a predetermined temperature is reached within the soil, fluid flow is turned on (40°C) within the well. The well is equipped with temperature sensors at the beginning, middle, and end of the pipe, as well as a fluid flow sensor. The test rig allows for testing well models with different thermal insulation types and designs. Testing can be performed with insulated pipes in contact with the ground, as well as with a “Pipe-in-Pipe” system, where thermal insulation is applied to the inner pipe and the outer metal pipe is in contact with frozen ground. The report will present the results of five experiments for well models in contact with frozen ground. Each test lasted approximately 1.5 months. Tests were conducted for a steel well without thermal insulation, a well with standard 1 cm and 4 cm thick polystyrene foam insulation, and a steel borehole with 5 mm thick liquid thermal insulation from two different manufacturers. The results were evaluated in three ways: 1. Calculation of the thermal conductivity coefficient of the thermal insulation based on standard formulas, taking into account temperature changes inside the pipe as the fluid moves through frozen ground. 2. Calculation of the thermal conductivity coefficient of thermal insulation using numerical heat transfer modeling methods, taking into account the temperature field formed in the soil after the hot fluid begins to circulate. 3. Comparison of the temperature fields formed in the soil with and without thermal insulation. Based on the test results, a range of thermal conductivity coefficients was established for ultra-thin liquid thermal insulation from two different manufacturers. Furthermore, an assessment was made of the feasibility of using conventional and innovative thermal insulation to protect frozen soil from thawing during oil production.

Keywords: Thawing halo, thermal insulation



THERMAL STABILITY ANALYSIS OF CELLULAR CONCRETE AIR CONVECTION EMBANKMENTS FOR COLD REGIONS

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Crushed-rock air convection embankment (ACE), as a highly open-graded porous medium, has been used to mitigate thaw settlement of pavement structures in permafrost regions. In winter, the unstable air pressure/density gradients drive strong air convection, moving warm air upward and cool air downward to balance these differences, enhancing passive cooling on subsoil. In summer, the air pressure/density gradients are stable, and air convection is weak that can be negligible. Thus, the porous crushed-rock layer becomes a thermal insulation system to mitigate thaw settlement. Numerous numerical and experimental studies reveal that ACE is an excellent technique to provide passive cooling to prevent ice-rich subgrade soil from thawing. A previous study proposed using hollow cellular concrete blocks as a cost-effective alternative material for ACE to solve the problem of crushed rocks shortage in interior Alaska and improved the pavement structures' thermal stability in cold climates. The design configurations of hollow cellular concrete block ACE were further designed to maximize performance benefits and facilitate future implementation and field construction. The results indicated that the thermal stability of the two proposed hollow cellular concrete block ACEs was superior to the conventional pavement structures and crushed-rock ACE. However, the mechanical behaviors of the proposed structures and ice-rich subgrade were still unknown. This study further developed a thermo-mechanical coupling model to evaluate the thermal impacts on the long-term mechanical stability of the selected pavement structures and subgrade soils. The new model is validated using the field measured data in Fairbanks, Alaska. In this paper, a mathematical model was first developed to describe the thermo-mechanical process of six selected pavement structures, including a typical Alaskan flexible pavement in the Northern Region of Alaska, a silty sand/gravel embankment, a crushed-rock ACE, a cast-in-place full cellular concrete embankment, and two precast hollow cellular concrete block ACEs. Then, the mathematical model was validated by comparing the numerical results with the observed data from Alaska. Finally, the long-term stability of the pavement structures is predicted and analyzed. The results show that the two proposed hollow cellular concrete block ACEs could achieve better thermal and mechanical performance than the crushed-rock ACE and other selected cases. The maximum thaw settlement of the proposed hollow cellular concrete block ACE was only 10% of conventional silty sand/gravel embankment, and 15% of crushed-rock ACE. The cost analysis showed that the proposed cellular concrete ACEs had a significant cost advantage over the conventional crushed-rock ACE.

Keywords: Permafrost, thaw settlement, air convection embankment



SPATIOTEMPORAL EVOLUTION AND MITIGATION TECHNOLOGIES FOR RETROGRESSIVE THAW SLUMPS ON THE QINGHAI-TIBET PLATEAU

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The Qinghai-Tibetan Plateau (QTP) is experiencing rapid warming, leading to widespread permafrost degradation and a sharp rise in related geohazards. Among these, retrogressive thaw slumps (RTSs) are among the most destructive permafrost features, posing serious threats to fragile alpine ecosystems and key infrastructure. This study summarizes our recent work on understanding the spatiotemporal development, driving factors, and effective control strategies of RTSs. Using high-resolution satellite images combined with extensive field surveys, we built a detailed inventory containing 2,669 active RTSs across the QTP. Our analysis shows that RTSs do not form gradually but appear in distinct bursts, mainly triggered by unusually warm summers in 2010 and 2016. We found that deep active-layer thawing is the main cause, which first leads to shallow detachment slides that later evolve into large RTSs. After initiation, the average headwall retreat rate reaches 2.4-3.2 m per year, with the fastest growth in the first few years before slowing to a more stable rate. To better predict their potential distribution, we applied a machine learning approach using a Random Forest model to produce the first high-resolution RTS susceptibility map for the whole plateau. Summer temperature and rainfall are identified as the key environmental controls. Currently, about 1.4% of the QTP falls into high or very-high susceptibility zones, and model projections suggest that these areas will expand significantly under future warming scenarios. In response to these growing hazards, we developed and patented new engineering technologies for site stabilization. A flexible retaining structure based on geogrids and anchors was designed to adjust to ground movement and reduce stress on structures. In addition, we created a rapid intervention system that combines efficient drainage and thermal insulation to quickly stabilize slump headwalls in emergency situations. By integrating large-scale monitoring, predictive modeling, and practical engineering designs, our work provides a comprehensive framework for assessing, forecasting, and mitigating RTS hazards. These efforts contribute valuable insights for managing permafrost-related risks under accelerating climate change across the Qinghai-Tibetan Plateau.

Keywords: Retrogressive thaw slumps, permafrost, thermokarst



RESTORATION AND PROTECTION OF DESTROYED TERRITORIES WITH ICE-RICH DEPOSITS IN THE CONDITIONS OF CENTRAL YAKUTIA

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The observed increase in air temperature in Arctic and subarctic regions is significantly higher than the global average, leading to rapid transformation of the natural environment, including permafrost (IPCC, 2019). This problem is particularly acute for areas with widespread ice-rich deposits, particularly those with developed ice complexes, which are particularly vulnerable to thermokarst processes. These processes significantly alter natural and man-made landscapes and hinder the effective development of cold regions by humans. The consequences of the degradation of ice-rich deposits are already being observed, leading to damage to buildings and linear structures, the destruction of agricultural land, cropland, and other areas. This leads to enormous environmental and socioeconomic costs. Thermokarst processes are most active in open natural and man-made landscapes (Fedorov et al., 2017). Such landscapes are characterized by a thin (0-0.2 m) protective layer (the protective layer is the zone between the base of the seasonally thawed layer and the roof of the ground ice). In areas covered by boreal forest, its thickness reaches 0.7-1 m. As a result of modern climate warming, the protective layer, which serves as a buffer zone for permafrost from deeper thaw, is being destroyed, leading to the rapid development of thermokarst processes (Shur et al., 2005). This situation indicates the need for research to assess the feasibility of recreating the shielding layer to restore disturbed areas with highly icy deposits. A set of measures is proposed for restoring areas of the ice complex disturbed by thermokarst processes by recreating the shielding (Zhirkov et al., 2023). Experiment including: - At the end of the summer, it is proposed to mechanically level the subsided surface (grading) using specialized equipment. Reference points are established to monitor the dynamics of the active layer using direct methods. - In late autumn of the same year, before the onset of frost, irrigation is planned to moisten the previously leveled area to optimal levels, at which all moisture in the active layer freezes. In winter, snow removal or compaction is planned to achieve deeper freezing of the wetted soils. Completion of all necessary measures at optimal calculated moisture levels should lead to restoration of the shielding layer. Immediate reclamation measures are required in the spring of the following year to further preserve the restored shielding layer. The research demonstrated the feasibility of restoring thermokarst-damaged lands using a combined thermal protection method. This method involves creating a thermal insulation layer (restoring vegetation) and a heat-intensive layer. This layer ensures optimal heat exchange in the atmosphere-soil system throughout the annual cycle, thereby achieving a minimum active soil layer depth. The use of this new method will not only ensure rapid reclamation of thermokarst-damaged lands but also reduce carbon emissions by reducing the degradation of the upper permafrost layers. Based on theoretical and field experiments, the key patterns of active soil layer formation using various thermal protection options were established, confirming the effectiveness and feasibility of the proposed method for widespread implementation in areas where ice complexes are widespread.

Keywords: Thermokarst, ice complexes, shielding layer



**2A: ENGINEERING SOLUTIONS FOR A THAWING PERMAFROST:
PREVENTION, ADAPTATION, AND MITIGATION
POSTER**



NUMERICAL ASSESSMENT OF SOLAR RADIATION EFFECTS ON THE THERMAL REGIME OF RAILWAY EMBANKMENTS IN THE CRYOLITHOZONE OF RUSSIA

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Designing railway infrastructure in the cryolithozone of the Russian Federation requires comprehensive consideration of numerous natural factors inherent to the construction area. Railway transport development constitutes a strategic priority of the Strategy for Scientific and Technological Development of the Russian Federation. Consequently, many new railway corridors are being planned or constructed in regions underlain by perennally permafrost, which imposes significant constraints on engineering practices and necessitates specialized design approaches. Solar radiation plays a critical role in heat transfer into the body of railway embankments. Accurate quantification of this influence demands integration of diverse data sources, including regulatory documents, archival geotechnical records, engineering-geological survey reports, peer-reviewed literature, climatic databases, and numerical modeling tools. Incorporating a broad spectrum of environmental and geotechnical parameters enhances the reliability of geocryological forecasting, thereby mitigating potential adverse impacts of infrastructure on permafrost stability and preventing unforeseen increases in operational and maintenance expenditures. Railway design in permafrost regions is currently regulated by the national set of rules SP 447.1325800.2024, *Railways in Permafrost Regions: Basic Design Principles*. The annex to this document provides a methodology for preparing input data to predict post-construction thermal regimes of foundation soils, explicitly acknowledging the necessity of accounting for solar radiation incident on surfaces with varying orientations relative to cardinal directions. However, the prescribed calculation procedure does not incorporate embankment slope aspect - an omission that may compromise the accuracy of geocryological predictions. An alternative approach, developed by L. N. Khristalev, introduces insolation-based corrections to surface temperature boundary conditions, with adjustments reaching up to +28.9 °C for south-facing slopes during summer months. These corrections significantly influence the computed thickness of the seasonally thawed layer, potentially triggering talik formation and accelerating permafrost degradation. In the present study, predictive thermal modeling of the railway embankment was performed using two approaches: (1) applying the insolation correction prescribed in the set of rules SP 447.1325800.2024, and (2) implementing the methodology proposed by L. N. Khristalev, further enhanced by incorporating both clear-sky and cloud-condition-adjusted solar radiation data for various regions across the Russian cryolithozone. The results indicate that, under the first approach, a non-freezing thermal regime during the cold season was identified at 9 out of 13 investigated sites. In contrast, the second approach yielded similar non-freezing conditions at 8 sites, revealing only a marginal difference between the two modeling strategies. These findings underscore a critical limitation in the current regulatory framework. Geocryological forecasts for railway embankments in permafrost regions may be erroneously optimistic when slope aspect and its influence on solar heating are neglected. Such oversights can lead to systematic underestimation of thermal loads, resulting in insufficient thermal stabilization measures and, ultimately, operational deformations of the track substructure.

Keywords: Forecasting modeling, railways, solar radiation



ESTIMATION METHODS FOR FROST PENETRATION DEPTH IN PAVED ROADS OF MONGOLIA USING THERMAL CONDUCTION ANALYSIS

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Mongolia is an extremely cold region with an annual mean air temperature below 0 °C and is located at the southern limit of the permafrost zone. In recent years, the impacts of global warming have become increasingly evident in Mongolia, and deformations of social infrastructure, presumed to be caused by permafrost thawing, have been widely observed. In particular, road infrastructure has suffered severe damage, with surface irregularities and cracking becoming increasingly apparent.

The primary reason why such road damage occurs in Mongolia and why adequate countermeasures have not been implemented is the lack of established methods to accurately predict the extent of permafrost thaw beneath paved roads while considering temperature increases associated with climate change. In addition, in cold regions, road subgrades must be replaced with high-quality geomaterials down to the freezing depth; however, no reliable method has been established in Mongolia to accurately estimate the maximum freezing depth required for road design.

Therefore, in this study, monitoring instruments were installed within a paved road in Ulaanbaatar to conduct real-time measurements of freezing and thawing depths. Furthermore, by comparing and examining the measured data with the results of heat conduction analysis, this study aims to develop a method for accurately estimating the maximum freezing depth applicable to road conditions in Mongolia.

Keywords: Thermal Conduction Analysis, Paved Road Хэмжээ



2B: THAW-INDUCED HAZARDS AND ENGINEERING IMPLICATIONS

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Permafrost thaw triggers geohazards like thermokarst, subsidence, and slope instability, threatening infrastructure and ecosystems in cold regions. This session seeks interdisciplinary studies on hazard mechanisms, monitoring (field, remote sensing, modeling), and adaptive engineering solutions, including novel designs and materials. Case studies from the Qinghai-Tibet Plateau and Arctic Asia addressing socioeconomic impacts and policy frameworks are particularly welcome.





PREDICTIVE MAPS OF ACTIVE LAYER THICKNESS IN THE UPPER KOLYMA HIGHLANDS

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In recent decades, permafrost characteristics has been transforming under the impact of climate change. Their projections is required to minimize natural and human-made risks and ensure the economic and social development of permafrost regions. The aim of the study is to project the active layer thickness (ALT) in the mountainous region of the Kolyma River upstreams for the period up to 2099. The hydrological model Hydrograph is a modelling system with distributed parameters, which includes the algorithm describing heat and moisture dynamic in the ground profile. Main types of landscapes were identified for the study area: valleys, mountainous slopes of the northern and southern exposures with vegetation, and rocky-talus slopes without vegetation. The data of thermometric boreholes (2022-2025) situated in those landscapes were used to parameterize and calibrate the model. The projections of ALT were estimated out on a daily basis for the period 2015-2099, and then averaged by the periods. The CNRM-CM6-1-HR model with high spatial resolution (~15*15 km) was used as a climate scenario. The geocryological projections show that by 2040, ground temperatures could increase by 2-3°C in the near-surface ground layer to a depth of 1 m, and ALT will exceed 2 m, leading to a retreat of permafrost roof. By the end of the 21st century, ALT increase is predicted for all landscapes, but it is expected to be occurring extremely unevenly. The most intense dynamics are predicted for swampy larch sparse forests (northern slopes), which are characterized by the presence of high-ice peat deposits in the vertical profile. By the end of the 21st century, ALT will increase from the current average of 0.6 m to 2.2 m. The data obtained was used to develop the maps of ALT which is necessary for assessing the characteristics of permafrost in engineering calculations under conditions of its degradation. Financial support: The research was funded by the Russian Science Foundation (project No. 25-77-10033), <https://rscf.ru/en/project/25-77-10033/>.

Keywords: ALT, projections, climate change



THAW SETTLEMENT MITIGATION FOR BURIED WARM-OIL PIPELINES IN PERMAFROST REGIONS: PERFORMANCE EFFECTIVENESS FROM INDOOR TESTING AND SIMULATIONS

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Thaw settlement remains one of the dominant disasters affecting the long-term operation of buried oil pipelines in permafrost regions. Under the combined influence of global climatic warming and ground surface disturbance, the permafrost surrounding a buried pipeline may progressively degrade, leading to enlargement of the thaw bulb, deepening of seasonal thaw depth, and development of differential pipeline settlements. Mitigation technologies therefore focus on regulating ground temperature, typically through an integrated “active cooling” strategy. As a baseline measure, thermal insulation placed around the pipeline can reduce heat input into the surrounding permafrost; nevertheless, insulation alone often cannot offset long-term warming trends. Active cooling measures utilize natural cold energy during the cold season to transfer heat from the ground to the atmosphere, thereby lowering ground temperature and improving pipeline stability in ice-rich permafrost. Convective cooling systems based on air-ventilation ducts provide an additional and often highly efficient mitigation pathway. U-shaped ventilation ducts have demonstrated strong cooling capacity in field observations, laboratory studies, and numerical analyses; numerical evaluation indicates that the closed thaw bulb in cold seasons can be significantly suppressed, and the maximum thaw depth beneath the pipeline bottom is about 4.8 m after 30 years of operation. W-shaped ventilation ducts further enhance convective cooling via chimney effects and mechanical ventilation; laboratory model tests show a clear seasonal response, with no thaw bulb forming in the cold season and only slow thaw bulb evolution in the warm season. In parallel, crushed-rock pipeline embankments can provide seasonal convective cooling through a porous medium layer. Among these options, the inverted T-shaped crushed-rock embankment is highlighted due to its superior long-term performance: under a closed boundary condition, long-term prediction indicates a 50-year maximum thaw depth of about 0.8 m, whereas a conventional bottom transverse crushed-rock embankment reaches approximately 4.8 m. Overall, effective thaw settlement disaster mitigation techniques should be implemented as site-specific composite packages, with key layout parameters screened against long-term thermal-mechanical performance targets and constructability constraints.

Keywords: Permafrost, buried oil pipeline



TIME-SERIES INSAR DETECTION OF SEASONAL FREEZE-THAW GROUND DEFORMATION AROUND ULAANBAATAR, MONGOLIA

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In the Ulaanbaatar region, repeated freeze-thaw cycles induce ground deformation through frost heave and thaw settlement, posing risks to houses and infrastructure. In rapidly urbanizing Ulaanbaatar, spatial identification of seasonally unstable ground is essential for urban planning and infrastructure management. This study integrates time-series InSAR and field measurements of frozen soil to characterize seasonal ground deformation and to evaluate the capability of InSAR to delineate frost-susceptible zones around Ulaanbaatar, focusing on the seasonal amplitude of line-of-sight (LOS) displacement within an area of approximately 70×70 km. We processed a total of 13 ALOS-2 scenes (ascending orbit, HH polarization, SM3 mode) acquired from 17 July 2017 to 16 September 2024 using SARscape 5.7 and an SBAS time-series workflow. The imaging frequency was approximately once per year until 2022, but increased to three acquisitions in 2023 and four in 2024; therefore, seasonal-amplitude analyses were conducted primarily using the denser 2023-2024 observations. Interferograms were generated with a coherence threshold of 0.3. Topographic phase was removed using the AW3D30 (30-m) DEM. Multilooking and phase filtering were applied to produce displacement at 10 m spatial resolution. Displacement is reported as relative LOS change with respect to an SBAS reference automatically selected by the software (high-coherence pixels/areas assumed to be stable). Seasonal deformation was most pronounced in low-lying areas and valley bottoms, with seasonal LOS displacement amplitudes typically reaching ~ 50 -100 mm. Based on the InSAR results, five deformation hotspots (Site 1: Sanzai road; Site 2: Ar gunt; Site 3: Partizan; Site 4: Airport; Site 5: Mak factory) were selected for field investigation in late March 2025. Field observations at Site 1 (Sanzai road) confirmed pavement deformation and an abandoned house likely impacted by ground instability. Frozen soil sampling and laboratory analyses were conducted at Sites 2-5 (Ar gunt, Partizan, Airport, and Mak factory). Samples were collected from the near-surface seasonally frozen layer (to 30 cm depth) at locations with large ($|\text{LOS}| \geq 50$ mm) and small ($|\text{LOS}| \leq 50$ mm) seasonal amplitudes, and grain size distribution and ice content were analyzed. While soil texture varied among sites (e.g., sandy loam, silty loam, clay), within-site contrasts in grain size between large- and small-amplitude points were minor. In contrast, ice content showed a clear difference: large-amplitude points had higher ice contents (mean 35%, up to 59%) than small-amplitude points (mean 18%, locally $<10\%$). Moreover, because large LOS variations were observed in relatively flat terrain where horizontal motion is expected to be limited, the seasonal LOS amplitudes at such sites are interpreted to mainly reflect vertical displacement associated with frost heave and thaw settlement. In addition, continuous ground temperature and soil moisture monitoring began in October 2025 at Sites 2 and 3 (Ar gunt and Partizan), enabling further validation of the InSAR-derived deformation against local hydro-thermal conditions. Consequently, time-series InSAR supported by targeted field measurements provides an effective screening tool to identify frost-susceptible zones threatening urban infrastructure in and around Ulaanbaatar.

Keywords: InSAR, Frost heave, Thaw settlement



CALIBRATION OF AN ENERGY BALANCE MODEL AT AN ALPINE PERMAFROST SITE WITH THERMOKARST FEATURES AND AN ANTHROPOGENICALLY MODIFIED SUB-HORIZONTAL SURFACE

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As Alpine permafrost thaws due to global warming and more frequent heatwaves, the stability of high-altitude terrains is increasingly at risk, threatening infrastructures. Unlike most of the Alpine hazardous areas, the summit of Mont de la Chambre (2840 m, French Alps), located on a sub-horizontal, anthropogenically levelled surface within a bedrock of sandstone and schists, is not affected by rockfalls or mudflows but thermokarst-like subsidence. Some gaps and collapses are observed, resulting in small but damaging movements on local infrastructures, such as a restaurant and some chairlift facilities. Local climate data (S2M-SAFRAN, Météo France) indicates a mean annual air temperature of -2.5°C over the 1991-2020 period. Permafrost susceptibility maps and geomorphological evidence, including creeping landforms, support the hypothesis of permafrost presence undergoing current degradation. In August 2021, 5 thermal sensors (Ibuttons, Mousers®) were installed at about 10 cm depth and are continuously recording ground surface temperature (GST) at an hourly time step. Measured mean annual GST ranges from 0.2°C to 3.8°C , depending on the sensor, suggesting conditions favourable to sporadic to discontinuous permafrost. This study aims to explore the CryoGrid Community model's capacities to reproduce measured GST and to simulate pluri-decadal ground thermal dynamics at this alpine sub-horizontal bedrock site. We first calibrate the energy balance simulation against measured GST. During this calibration step, we identify the snow deposit fraction (i.e. the fraction of snow accumulated at each snowfall event), the albedo and z_0 (surface roughness) as key variables. The simulated GST with an accuracy of 0.1°C on annual and seasonal means (compared to measured values), and simulates the timing of the snowmelt period at approximately weekly precision over the 5-year monitored period. Focusing then on the heat transfer simulations, the analysis highlights a stronger sensitivity to the initial temperature profile (INT) and ground ice content than to the point-specific surface temperature time series. Five scenarios, ranging from -1°C / 10 % ice content to -2°C / 25 % ice content, were defined and applied identically to the five measurement points. The initialisation strategy prior to the full 65-year run consists of defining five INTs and associated subsurface compositions (rock-ice-air) for each sensor. The model is first spun up over the 1961-1990 period, and the resulting temperature fields are then used as initial conditions for CryoGRID simulations run from 1958 to 2024. The results confirm the presence of permafrost for all scenarios at the 5 measurement points over the entire period and indicate an evolution consistent with observations from comparable Alpine sites. Independent geoelectrical soundings and orthophoto analyses (2005-2023) have been used to complete analyses of permafrost conditions and morphodynamics (subsidence features) of the site. Orthophotos analyses show active subsidence development over the past two decades on the horizontal summit part and northern aspect, with features becoming more numerous and pronounced toward higher elevations within the 400 m below the summit. These latter findings are in coherence with the simulated near 0°C GST simulated showing enhanced permafrost thawing over this period.

Keywords: Alpine permafrost, thermokarst features, energy balance modelling, operational purposes



A TRANSFERABLE DEEP LEARNING FRAMEWORK USING SENTINEL-1 AND SENTINEL-2 DATA FOR LARGE-SCALE THAW SLUMP MAPPING ACROSS THE NORTHERN HEMISPHERE PERMAFROST DOMAIN

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Accelerating permafrost degradation is driving the rapid expansion of thaw slumps (TS) across the Northern Hemisphere. However, scalable and transferable methods for their identification remain limited by heterogeneous remote sensing data, fragmented processing workflows, and poor cross regional generalization. This study presents a hemispheric scale identification framework that seamlessly integrates Google Earth Engine (GEE) for multi-source data preprocessing with a modular PyTorch-based deep learning segmentation pipeline. Leveraging Sentinel-1, Sentinel-2, and topographic derivatives, the framework benchmarks six deep learning architectures paired with five backbone encoders. Input features are optimized via PCA dimensionality reduction and SNIC-based object segmentation to mitigate redundancy and enhance spatial coherence. Evaluations across the Qinghai-Tibet Plateau (QTP), Arctic, and broader Northern Hemisphere reveal that late summer imagery and fused optical-radar features yield superior performance, with the LinkNet-EfficientNet-B7 configuration achieving IOU scores of 0.802 (QTP), 0.770 (Arctic), and 0.776 (hemispheric). Cross regional transfer tests demonstrate robust generalization, with the hemispheric model maintaining IOU >0.63 across domains, outperforming region-specific baselines by 20-40%. This GEE-PyTorch integration provides a reproducible, computationally efficient solution for operational monitoring of thaw induced geomorphic disturbances, advancing large scale permafrost landscape assessment in permafrost regions and directly supporting infrastructure risk evaluation, ecosystem management, and carbon cycle studies across the Northern Hemisphere.

Keywords: Thaw slump identification, deep learning.



ALASKA CASE STUDIES RELATED TO REPAIRING INFRASTRUCTURE DUE TO THAWING PERMAFROST

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In developed areas within the Arctic, one challenge is maintaining permafrost conditions given rising air temperatures and impacts related to infrastructure development. In some cases, it is the development itself or nearby development that adversely impacts thermal conditions. In other cases, the initial engineering design conditions do not match current environmental conditions. When evaluating mitigation strategies for existing impacted infrastructure, it is important to understand and distinguish these underlying issues. Three Alaska-based case studies will be presented, including site conditions, cause of permafrost degradation, and mitigations strategies developed to maintain functionality of the impacted infrastructure. The first case study is of a tower system on a shallow foundation that began to lean due to thermokarst development directly below the foundation. The development of thermokarst features was primarily a result of induced heat from a leaking boiler system followed by poor surface drainage in the area. The second case study is of a heavy industrial structure built on shallow foundations in an area with massive ice and thawing permafrost, where a micropile foundation system was developed to transfer the foundation loads below the existing thawing ground and ice. A rapid thawing rate has been observed due to changes in surface water and groundwater flow paths related to adjacent infrastructure development. In this second case study, the structure was past its expected performance period, but the owner desired to continue operations into the future. Lastly, the third case study includes mitigation strategies to stabilize shallow foundations over ice-rich degrading permafrost by installing thermosyphons to provide passive cooling. Based on the age of the infrastructure, permafrost degradation at this site is primarily related to changes in environmental conditions. Each of these case studies offers a different solution to repair infrastructure directly impacted by degrading permafrost. Key considerations include the permafrost conditions, reason and rate of degradation, and operational goals of the infrastructure.

Keywords: Permafrost degradation, case study, mitigation



PERMAFROST THAW STRAIN PREDICTION: EMPIRICAL METHODS VS. MACHINE LEARNING MODELS

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As climatic warming accelerates permafrost thaw and alters ground stability, accurate prediction of thaw strain is essential for assessing the stability of permafrost-affected soils and mitigating infrastructure risks in cold regions. Reliable prediction tools are therefore vital to support hazard assessment, foundation design, and long-term infrastructure planning. This study evaluates both empirical and machine learning (ML) methods to predict thaw strain as a function of dry unit weight. An S-shaped logistic regression equation was established for individual soil types, including silt, clay, and sand and gravel, as well as a unified formulation applicable across all soil types. In parallel, eight ML models, including Random Forest (RF), k-Nearest Neighbours (KNN), Backpropagation Neural Network (BPNN), Support Vector Regression (SVR), Decision Tree (DT), Gradient Boosting, Extreme Gradient Boosting (XGBoost), and Linear Regression (LR), were trained and assessed using coefficient of determination (R^2), Root Mean Squared Error (RMSE), and Normalized Root Mean Squared Error (NRMSE). Results showed that soil-type-specific logistic models yield better accuracy than existing empirical models and the combined empirical model, with the silt equation providing the best performance ($R^2 = 0.81$, $NRMSE = 0.43$). Among all ML models evaluated, predictive performance is ordered as follows: $KNN > RF > Gradient\ Boosting > XGBoost \approx DT > SVR > BPNN > LR$. The KNN algorithm achieved the best overall performance across all soil types, reducing RMSE by 35% and NRMSE by 36% compared with the empirical all-soils equation, while improving R^2 to 0.85. These outcomes underscore the usefulness of soil-specific empirical equations for interpretability and practical application, while highlighting the greater robustness and adaptability of machine learning models for generalized thaw strain prediction in permafrost soils.

Keywords: Thaw strain, machine learning, permafrost



ADVANCING MINING GEOTECHNICS FOR CHANGING PERMAFROST: THEORETICAL FRAMEWORKS, PREDICTIVE MODELING, AND HETEROGENEITY

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Mining infrastructure in cold regions faces instability as permafrost degrades. Simon Dumais's group addresses this by developing theoretical frameworks to characterize the transition of soils from frozen to thawed states. A core contribution is the refinement of large-strain thaw consolidation theory, utilizing a unified model based on residual stress to predict the hydro-mechanical evolution of ice-rich soils. Complementing this, the group developed empirical models to estimate the saturated hydraulic conductivity of thawed soils using index properties, specifically accounting for soil structure degradation. Beyond material properties, the research advances thermal analysis through modified analytical solutions that quantify advective heat transfer in dam foundations. Furthermore, geostatistical simulations are employed to model spatial heterogeneity, providing more realistic seepage and stability assessments than traditional homogeneous approaches. These tools are essential for designing resilient infrastructure in transitional permafrost environments.

Keywords: Thaw consolidation, mining, heterogeneity



CURRENT STATUS OF ROAD DAMAGE IN PERMAFROST REGION (EXAMPLE OF THE KHANGAI MOUNTAINS REGION)

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Current methods for constructing infrastructure in permafrost regions of Mongolia are ineffective. In particular, roads and buildings are damaged in continuous and discontinuous zones due to permafrost thaw. In order to study the state of road damage in the Khangai Mountains permafrost region, identify the location of damaged points, determine the main causes of road embankment damage, and determine the methods for solving road damage in the future, two representative points were selected in the damaged sections of the road in the discontinuous zone of permafrost, and electrical resistivity tomography measurements were performed at these points, and boreholes were drilled to determine the permafrost thaw layer and soil layer composition. Electric resistivity tomography (ERT) transects were completed in conjunction with the drilling of boreholes in the investigation sites. The ERT surveys were acquired using a Syscal R1 plus with switch pro and 48 electrodes from IRIS Instruments. The spacing of the electrodes and total length of the survey varied by transect, and are mostly 1 m and 10 m depth. A Wenner and Wenner-Schlumberger array were used to clarify the heterogeneities of underground layers. The measured resistivity values range from 60 to 3800 ohm.m. The areas with a resistivity of 60-400 ohm.m are considered sand and gravel, areas with a resistivity of 400-700 ohm.m are considered sand-filled gravel, areas with a resistivity of 700-900 ohm.m are considered permafrost with low icing, and values above 900 ohm.m are considered permafrost with high ice content. Active cooling methods should be used to protect road embankments built on heavily iced permafrost from thawing. All geophysical measurements show that the permafrost below the road embankment has thawed to a depth of 4-9 m. In other countries with permafrost, there are several adaptation and mitigation techniques for infrastructure construction. Local and location-specific factors play an important role in the formation and disappearance of permafrost. The choice of a specific technique depends on these specific factors. Here we present current state of some infrastructure in Mongolia.

Keywords: Active layer, road embankment, ERT



PRELIMINARY GEOPHYSICAL OBSERVATIONS OF PERMAFROST DYNAMICS ALONG THE HUDSON BAY RAILWAY

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Completed in 1929, the Hudson Bay Railway (HBR) was Canada's first major transportation infrastructure built on permafrost. The HBR is the only ground transportation link to several communities in northern Manitoba and connects the Canadian railway network to the Port of Churchill, Canada's only deep-water Arctic port. Ongoing challenges related to permafrost thaw are now being amplified by rapid climate warming. Thaw of ice-rich permafrost soils causes subsidence and track deformations along the HBR, referred to as sinkholes, that require ongoing monitoring and maintenance. Sinkholes are typically located near degrading peat plateaus or at transition zones between permafrost plateaus and fens where lateral thaw is occurring. To better understand permafrost thaw processes and impacts on infrastructure stability, we installed monitoring stations along the northern portion of the HBR in September 2025. Three key sites were instrumented: 1) a degrading peat plateau that has a recurring sinkhole, 2) a peat plateau/fen transition zone that has a recurring sinkhole, and 3) a transition zone where there is no sinkhole, likely due to thermosyphons installed in 1987. Our monitoring stations include automated electrical resistivity tomography (A-ERT) systems that provide daily measurements of subsurface resistivity, enabling detailed interpretation of permafrost conditions and dynamics across each site. Monitoring data also includes measurements of ground temperatures, snow depth, and soil moisture. Here, we present preliminary results from multi-method permafrost monitoring stations that include seasonal freeze and thaw from the first year of monitoring. We describe our data processing workflow, including calibrating A-ERT data using borehole temperatures to delineate frozen bodies and approximate ground temperatures. We also describe the potential for A-ERT data to be integrated into a real-time hazard monitoring tool. These efforts to monitor changing permafrost conditions at key sites along the HBR are an important first step towards understanding seasonal permafrost dynamics, thaw processes, and geohazard risks.

Keywords: Permafrost, railway, geophysics, monitoring, thaw



TABULAR GROUND ICE DISTRIBUTION IN THE YAMAL PENINSULA AS A BASE TO PREDICT ACTIVATION OF HAZARDOUS CRYOGENIC PROCESSES

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Since 2012, when the warmest for the period of observations summer occurred, permafrost thaw processes have sharply intensified in the Yamal Peninsula, resulting in the exposure of massive ground ice on slopes. Yamal Peninsula is known for the widespread ground ice in the form of thick layers (tabular ground ice, TGI), which creates a precondition for the development of relief-forming cryogenic processes associated with its thaw, such as thermocirques (also referred to as retrogressive thaw slumps). At the same time, new hazardous process actively manifested itself in Yamal: the formation of gas-emission craters, which are also limited to areas of TGI distribution. These processes pose a threat to structures in the areas of development in Yamal and significantly alter the landscape structure and its potential for economic use, including traditional natural resource management. Addressing this issue is crucial because the distribution of TGI in Russia is insufficiently understood, as satellite images do not show clear signs of such ice in the section. Corresponding landforms, thermocirques, may serve as indicators of the presence of TGI at shallow depths. Since thermocirques can be identified remotely, it becomes possible to detect additional ice locations. The authors collected a database of publications containing information on TGI locations continually updated. This database serves as a source for the map of TGI distribution. Existing datasets on thermocirque locations combined with the map of TGI occurrence will be used to validate this map. Next step will be the development of methodological principles for identifying shallow lenses of TGI using remote sensing data resulting in compilation of a map of the potential activation of hazardous cryogenic processes associated with TGI thaw. The research was supported by the Russian Science Foundation grant 25-27-00480.

Keywords: Yamal, ground ice, thermocirque, database



IMPACT OF DIFFERENTIAL THAW SETTLEMENT ON VERTICAL SOIL PRESSURE AT THE CROWN OF TRENCH-BURIED PIPELINE: INSIGHTS FROM DEM AND THEORETICAL ANALYSIS

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Differential thaw settlement of permafrost foundations can significantly modify the vertical soil pressure acting on trench-buried pipelines, yet the associated deformation and load-transfer mechanisms remain poorly quantified. To clarify the influence of thaw-induced non-cooperative settlement between the pipeline and its permafrost foundation on soil pressures, this study combines two-dimensional discrete element simulations with analytical modelling for typical trench configurations in permafrost regions. The discrete element models represent a rigid pipeline embedded in coarse-grained backfill, with trench width-to-diameter ratios B/D ranging from 2 to 4 and backfill height-to-diameter ratios H/D from 1 to 4. Non-cooperative thaw settlement (i.e., pronounced foundation settlement with an essentially fixed pipe) is imposed via a prescribed differential settlement profile at the trench base. The simulations reveal a distinctly staged development of soil failure. With increasing thaw settlement, localized shear bands nucleate above the pipe and gradually coalesce into a dominant slip surface that initiates at the pipe shoulder and propagates obliquely toward the ground surface, accompanied by multiple secondary slip surfaces that together form an overall sliding failure mode. The induced differential settlements also generate nearly symmetric major and minor principal stress arches within the backfill. The major principal stress arch is well approximated by a quarter-circle spanning from the trench wall to the pipe crown, and the associated soil arching is identified as the primary cause of the amplified vertical soil pressure at the pipe crown. Building on the numerically identified slip surfaces and principal stress trajectories, an analytical model for the vertical soil pressure at the pipe crown is developed by incorporating soil arching and stress rotation into a Marston-type framework and enforcing horizontal differential equilibrium of an element along the arch domain. The resulting closed-form solution yields a crown-pressure coefficient as a function of relative thaw settlement and trench geometry, and is validated against discrete element results, showing good agreement particularly during the early settlement stages and near peak crown loading. Parametric analyses indicate that, within the explored parameter space, the crown-pressure coefficient increases markedly with relative thaw settlement and B/D , with a maximum amplification of approximately a factor of two, and exhibits an overall stabilizing trend with increasing H/D . Deeper burial facilitates the formation of more complete stress arches and renders crown loading more sensitive to thaw settlement, whereas the crown-pressure coefficient decreases approximately linearly with increasing slip-surface inclination. The proposed model and quantified parameter sensitivities provide a mechanistic basis and practical tool for assessing thaw-settlement-induced hazards and optimizing the design of trench-buried pipelines in permafrost regions.

Keywords: Thaw settlement, soil pressure



**2B: THAW-INDUCED HAZARDS AND ENGINEERING IMPLICATIONS
POSTER**



KINEMATICS OF PERMAFROST THAW-RELATED LANDSLIDE IN EAST QINGHAI-TIBET PLATEAU

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Retrogressive thaw slumps (RTSs), which are among the most rapidly evolving and impactful cryospheric hazards, have been expanding in size and number due to engineering disturbance and accelerated climate warming. However, evaluating the kinematic movement and mass wasting of RTSs throughout their life cycles remains challenging due to limitations of the accuracy of remote sensing techniques and insufficient long-term observations. In this study, we integrated the data from remote sensing, interferometric synthetic aperture radar (InSAR) deformation, unmanned aerial vehicle (UAV), and global navigation satellite system (GNSS) real-time kinematic (RTK) to construct a comprehensive field observation system for analyzing the kinematics and temporal evolution of an RTS on the Eastern Qinghai-Tibet Plateau. The InSAR deformation data show that the life cycle of RTSs includes four distinct stages. The UAV observations revealed the occurrence of rapid morphologic changes after the initiation of the RTS, with a headwall retreat rate of 9 m/year and a volume loss of 485 m³/year. These rates are higher than those reported for other regions on the Qinghai-Tibet Plateau and in the Arctic. Finally, we systematically analyzed the development of RTSs and their response to climate change, thereby refining a six-stage kinematic model that captures the life cycle of RTS evolution under climate forcing. This study enhances our understanding of the kinematics, mechanism, and geomorphology of RTSs, providing critical insights for assessing engineering stability and periglacial geomorphological processes in cold regions.

Keywords: InSAR, thaw slumps, permafrost



PERMAFROST AND SNOW COVER WITHIN URBAN AREAS OF THE RUSSIAN NORTH

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Currently, in most settlements of the Far North, widespread deformation of buildings and structures is being recorded. This problem is most acute in large cities experiencing significant anthropogenic thermal, mechanical, and physicochemical impacts. A key factor determining foundation stability is the heat exchange regime between permafrost soils and climatic parameters. The study aims to analyze the conditions for altered ground surface heat exchange due to the specifics of snow accumulation in the context of current climate trends and diverse technogenic loads. The research object is permafrost soils within urban environments in northern cities. The methodological framework includes: conducting field studies of snow accumulation across various landscape-permafrost conditions, including urbanized areas; numerical modeling of the thermal field state in permafrost under variable heat exchange boundary conditions at the surface; and synthesizing the obtained data to identify patterns in the formation of a mosaic temperature regime in permafrost. As part of the research, the nature of snow accumulation was studied in the Arctic cities of Salekhard, Labytnangi, the Norilsk Industrial District (Norilsk, Dudinka), and the Vorkuta District (Vorkuta). Over 600 measurements of snow cover thickness, its structural features, and thermal state, formed under the influence of regional climatic factors, were performed. In built-up urban areas, the largest snow disposal sites, typically localized within the same intra-block zones, were mapped. The final stage involved correlating the studied snow cover parameters with the thermal state of the underlying permafrost. In large Arctic cities, against a backdrop of increasing natural spatial heterogeneity of snow accumulation, a rise in technogenic load (thermal, mechanical, stress, physicochemical) is observed, determined by the diversity of building types, their height, and other engineering characteristics affecting interaction with foundation soils. It has been established that one of the most critical factors (given the relative stability of others) is the modification of heat exchange caused by snow accumulation. This effect manifests, firstly, in the thermal insulating role of the snow mass, and secondly, in excessive moisture of the territory during snowmelt. On artificially leveled urban sites, meltwater stagnates, accumulating in local depressions, which often include the recessed ventilated crawl spaces of buildings and structures, as well as underground pipeline routes. The intensity of both types of impact can vary on an interannual scale depending on winter snowiness. For the first time, distribution maps of the largest snow disposal sites in the studied settlements have been compiled, and a correlation between their location and zones of concentrated deformations and deviations from the designed operational regimes of urban infrastructure has been identified. The obtained results allow for outlining strategic directions for foundation reinforcement and preventing excessive moisture. Under conditions of relatively stable engineering development, the primary influence on foundation stability is exerted by the snow cover, namely its climatic variability (thickness fluctuations) and mechanical redistribution within the urban environment. It is precisely due to the instability of this impact that the bearing capacity of foundations in northern cities is decreasing.

Keywords: Permafrost, snow cover, climate change



2C: INFRASTRUCTURE, COMMUNITIES, AND PERMAFROST DYNAMICS: RISK, RESILIENCE & ADAPTATION

Conveners: Lin Chen¹, Mingyi Zhang¹, Tatsuya Ishikawa², Zhaohui (Joey) Yang³ & Wenbing Yu⁴

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Thawing permafrost and talik formation undermine the stability of roads, railways, pipelines, and buildings, driving up maintenance costs and threatening communities. This session examines permafrost-infrastructure interactions via monitoring, physical and numerical modelling, and remote sensing, and explores resilient design solutions drainage systems, load-bearing adaptations, and community-informed risk management. We particularly welcome contributions that integrate social vulnerability assessments, economic analyses, and co-developed adaptation strategies to bolster both engineering and community resilience in cold regions.





ENGINEERING MEASURES FOR EMBANKMENTS IN HIGH-ALTITUDE PERMAFROST REGIONS: THEORY ANALYSIS, EXPERIMENTAL INVESTIGATION, AND NUMERICAL MODELING

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Permafrost is very sensitive to temperature changes. The construction of transportation infrastructure significantly alters the surface energy balance and accelerates permafrost degradation. Permafrost thawing and warming adversely affect the long-term stability of embankments. Furthermore, transportation infrastructure in high-altitude cold regions is increasingly threatened by frequent engineering failures under complex environmental conditions, including climate warming and humidification, permafrost degradation, intense solar radiation, long-term low temperatures, and high-frequency freeze-thaw and wet-dry cycles. This study systematically investigated the thermal performance of both passive and active cooling measures, including common embankments, thermal-insulation layer embankments, crushed-rock embankments, thermosyphon embankments, and ventilated-duct embankments. The thermal characteristics of the proposed embankment were analyzed and compared using theoretical analysis, experimental investigation, and numerical modeling. In addition, several novel composite embankments were developed and proposed to improve the long-term stability of embankments under complex environmental conditions. Full-scale field experiments and numerical simulations were performed to evaluate their long-term cooling performance. The findings provide a scientific basis and technical guidance for ensuring safe and sustainable operation of embankment networks in high-altitude cold regions.

Keywords: Permafrost, Embankments, engineering measures, climate



LONG-TERM PERFORMANCE OF MITIGATION TECHNIQUES FOR PROTECTING COLD-REGION TRANSPORTATION INFRASTRUCTURE UNDER COMPLEX ENVIRONMENTAL CONDITIONS

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Permafrost is warming and thawing globally due to climate change and increasing anthropogenic activities. The thawing of near-surface permafrost reduces soil strength and bearing capacity, posing serious risks to cold-region infrastructure, including roads. To mitigate permafrost degradation beneath transportation infrastructure, several engineering techniques, including air-convection embankments and thermosyphons, have been developed and applied in the pan-Arctic region (e.g., the Alaska Highway and the Dempster Highway, Canada) and on the Qinghai-Xizang Plateau (e.g., the Qinghai-Xizang Railway, China). However, most existing mitigation approaches primarily focus on the effects of climate warming and aim mainly to reduce or maintain permafrost temperatures beneath infrastructure. Their long-term performance has not been adequately quantified or systematically investigated under complex environmental conditions, such as snow cover, rainfall infiltration, and groundwater flow. Through in-situ observations, physical models, and numerical modeling, we investigated and quantified the performance of various mitigation techniques under conditions of aeolian sand cover, snow cover, groundwater flow, and projected climate warming. Mitigation techniques include air-convection embankments, thermosyphons, air-duct embankments, and snow-shed embankments. The findings of this study are essential for advancing engineering design and road maintenance practices in cold regions.

Keywords: Infrastructure, mitigation technique, permafrost, climate



GEOPHYSICAL MAPPING OF PERMAFROST DISTRIBUTION IN WEST GREENLAND FROM THE ICE CAP TO THE OCEAN TO SUPPORT LANDSLIDE MODELLING

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Within the last 10 years in West Greenland, the occurrences of shallow landslides are happening at an increasing rate, linked as a direct result of climate change related to higher annual mean temperatures and permafrost degradation. The area of interest covers the longest east-west stretch of land in Greenland ranging from the Ice cap at Kangerlussuaq to the ocean at Sisimiut. According to the Global Permafrost Zonation Index Map, this area is assumed to contain permafrost ranging from continuous to sporadic distribution. To better understand the correlation between permafrost and landslides, we investigated the permafrost distribution with the geophysical method Transient Electromagnetics (TEM) in an almost 200 km long transect from the ice cap to the ocean. The TEM system is a non-intrusive method and works by a transmitting coil that generates a magnetic field which induces a current in the ground. These currents then generate a secondary magnetic field, which decay can be measured in a receiver loop at the surface. The TEM measurements can be used to map the apparent resistivity in the subsurface, where in this case high apparent resistivity is interpreted as permafrost. For this field work, we tested a new walkable TEM system, where two people effectively can map up to 20 km a day with a depth of investigation down to 100 m depending on the subsurface. The result from the geophysical measurements shows a much denser permafrost distribution than what is previously estimated by models, hence the measurements can be used to update permafrost models to get a more accurate picture of the distribution and understand how permafrost transition from inland climate towards ocean climate. With this knowledge, an updated landslide susceptibility map can be generated where permafrost is considered, and together with the latest climate predictions, it can be used to model scenarios for future areas prone to landslides. Such a map can assist the local population to stay safe in a changing environment and aid decisionmakers before planning infrastructure in dangerous areas.

Keywords: Geophysics, permafrost degradation, geohazards, landslides



CRITICAL INFRASTRUCTURE FRAMEWORK TAILORED TO THE ARCTIC

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To date, no definition of critical infrastructure exists that is both suitable and representative of the needs and ways of life of Arctic communities. Increasing geopolitical tensions in the Arctic and the growing risks to infrastructure driven by climate change have never made the need for a clear and unequivocal definition and framework for critical infrastructure in the Arctic more relevant. To address this gap, a suitable definition and framework are established based on (i) a literature review, (ii) public community consultations, and (iii) local stakeholder interviews across several regions of the Arctic. By following the procedure of Systematic Concept Analysis, data from all three sources are integrated, allowing key nuances and regional variations to be outlined. Data collection started with an extensive literature review, including worldwide governmental policy documents regarding critical infrastructure. In collaboration with Nordregio - the International Research Centre established by the Nordic Council of Ministers - data were collected in local communities in the Arctic through a Maptionnaire survey, where participants were able to indicate their answers on maps. The results from this questionnaire provided insights into the daily life of local community members, how permafrost degradation affects them, and how critical infrastructure is interpreted. Additionally, interviews with stakeholders and community members were conducted in Longyearbyen, Sisimiut, Ilulissat, Qaanaaq, Nuuk, Aklavik, and Inuvik, revealing a wide variety of interpretations of the term 'critical' and 'infrastructure'. Overall, the data indicate that there are similarities with frameworks for critical infrastructure from non-Arctic regions. However, significant differences and nuances specifically for the Arctic were identified. The structured method of the Systematic Concept Analysis allowed us to combine all the gathered data and compose a comprehensive overview, including these important nuances and regional variations. More specifically for Greenland, the core-periphery divide between the capital Nuuk and other regions of the country is striking: there is a significant difference in perceptions of what is critical. The ways of life and the needs of Nuuk inhabitants compared to the rest of the country are so different that these regional differences need to be addressed to arrive at a holistic framework. Our data highlight clear examples of the core-periphery divide regarding the degree of criticality, such as the food and water supply, road network, and dog sledding. Owing to remoteness and a less redundant infrastructure network compared to for example Europe, the degree of criticality and the vulnerability of certain infrastructure types differ substantially in the Arctic. In addition, natural, non-traditional infrastructure types specific to the Arctic - including permafrost, ice, and snow - were considered. While no consensus emerged on whether these should universally be considered critical infrastructure, there was broad agreement on their importance, with the degree of criticality varying regionally.

Keywords: Critical infrastructure, definition, framework, Arctic



SEISMIC SITE RESPONSE OF DEGRADING PERMAFROST IN ALASKA

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Permafrost in Alaska is degrading rapidly due to human-induced surface disturbances and rising global temperatures, resulting in significant changes in ground thermal regimes and mechanical properties. These transformations alter how seismic waves propagate through the subsurface, modifying site response and increasing seismic hazards for infrastructure built on degrading permafrost sites. This paper presents a case study of an airport built on permafrost about 80 years ago, focusing on permafrost degradation, seismic response, and observed seismic hazards during the 2002 Denali earthquake ($M_w=7.9$). The study site, i.e., the Northway Airport, is located in a discontinuous permafrost area in Interior Alaska. Geotechnical data from 1973, 1991, and 2005 were compiled and analyzed to reveal permafrost degradation under various surface conditions. Observations from the $M_w 7.9$ earthquake, including liquefaction and lateral spreading displacements, were documented and interpreted. A one-dimensional equivalent-linear approach was employed to analyze the seismic site response of the permafrost site with varying depths of degradation. Results show that permafrost tables have dropped at different rates depending on surface conditions, and that complete thaw of warm permafrost (approximately $-2\text{ }^{\circ}\text{C}$) reduces shear wave velocity by 45%, causing a site-class shift from D to DE. Permafrost thaw also lowers the resonance frequency and peak amplification by roughly one-third. A statewide review further indicates that 55% of Alaska's civilian airports are located in permafrost regions, and two-thirds of these fall within seismic hazard zones of level 3 or higher. Collectively, the findings highlight the substantial seismic risks associated with degrading permafrost and underscore the need to incorporate thaw-induced ground changes into hazard assessments and the design of critical infrastructure in cold regions.

Keywords: Permafrost degradation, seismic site response,



POSSIBILITIES OF BOREHOLE GEOPHYSICS FOR SPATIAL MONITORING OF PROCESSES OF ANTHROPOGENIC IMPACT ON PERMAFROST

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The observed climatic changes caused by natural and anthropogenic factors are most pronounced in the Northern latitudes, where permafrost is the subject of progressive degradation. The efficiency and stability of engineering structures in the cryolithozone is related to the processes of thawing and freezing. These objects themselves, in permafrost conditions, create additional gravitational, thermal and hydraulic loads on the surrounding frozen massif. Man-made changes in the condition of the foundations of such structures require effective monitoring and forecasting. Assessments of possible risks, including environmental ones, are also needed. At the same time, changes in man-made permafrost can be considered as a natural model for monitoring and studying the process of degradation of frozen strata. Geophysical monitoring is based on sharp differences in the physical characteristics of frozen and thawed rocks due to the phase state of water and its mineralization up to forming cryopegs. The discussed geophysical monitoring included spatial multi-frequency radio wave borehole studies of permafrost conditions near industrial facilities against the background of their thermal monitoring. The basis of the method is the dependence of the absorption of radiated energy along the propagation of radio waves on the distribution of effective values of resistivity ρ_{ef} and permittivity ϵ_{ef} . Note that valid observations are only within the first Fresnel zone. It is shown that in order to control changes in electric properties of degrading permafrost and to anticipate its thawing, geophysical monitoring of the state of the soil mass in situ is of particular importance. It is important to emphasize that the area located directly under the object is being investigated without disturbing it. Monitoring of a number of important industrial facilities located in the permafrost zone of Western and Eastern Siberia was done: - 3D monitoring frozen massif at the locations of oil fields using downhole injection of hot water to increase oil recovery;- demonstration of the possibility of studying the degraded permafrost bearing the load of huge tanks for storing diesel fuel without structural destruction (example of the Norilsk Ore region);- identification of cryopegs in the permafrost section at the onshore oil storage site (Sabetta Port, Yamal Peninsula);- investigation of the thawing zone at the base of the bridge crossing supports on the section of the Novy Urengoy - Gubkinsky railway;- studies of the formation and development of seepage processes in the coastal zones of hydraulic structures in Western Yakutia. The possibilities of predicting the development of talik are shown. The obtained geophysical information on monitoring the development of coastal talik was used to construct and test numerical models of the interaction of anthropogenic impacts of hydro units on the “permafrost-reservoir-climate” system. The unsteady task of heat and mass transfer in a fractured porous saturated frozen medium was solved. The model analyzes the conditions that cause the occurrence and development of seepage near the reservoir, such as fluctuations in air temperature, snow cover, seasonal changes in water temperature in the reservoir, changes in the permeability of frozen soil and the internal structure of the frozen massif.

Keywords: Radiowave investigations, impact, permafrost, modelling



UNDERGROUND FOOD STORAGE FACILITIES USING FROZEN GROUND ENVIRONMENT IN MONGOLIA -HISTORY AND SITUATIONS

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The system of food, a vital element of life, is a complex issue conditioned by and impacted by various environmental factors. Underground food storage utilizing natural cold energy (UCS), a long tradition of communities in Beringia closely integrated with their lifeways, is challenged by malfunctions or difficulties in appropriate use, affecting food security and food sovereignty, and community wellbeing. In our interdisciplinary project involving both natural and social sciences, we have been investigating impacts of climate and socio-ecological changes on UCS in the greater Beringia region, which includes Alaska, Siberia, Mongolia, and Japan, through interviews and dialogues between local communities and scientists to illustrate the roles of UCS in supporting the sustainable foods and lifestyles, the causes and factors related to its decline, and consequent losses and damages these changes brought, in different communities in the areas. In this study, we report the results and findings on the two different types of UCSs in Mongolia that we obtained from the surveys conducted in 2024 and 2025 in the vicinity of Ulaanbatar (N47°50', E106°00'. Elevation 1300m asl), and in Tsagaannuur, Khovsgol Province (N51°21', E99°20'. Elevation 1550m. 650kmNorthwest of Ulaanbatar) in Darkhad Basin. Food storage facilities in Ulaanbaatar suburban areas were built semi-underground on north-facing slopes, constructed with ice as the building material, and covered with sod for insulation. The width varies between 20m and 50m, the depth between 40m and 60m, and the height is about 2.5m inside and 5m outside. Most of them were built under the Socialist regime for large-scale use, abandoned after the regime change, and are now largely collapsed. The cellars in Tsagaannuur, in contrast, are small-scale, primarily for family use, and built fully underground, either shallow within the active layer (for refrigeration) or deeper into the permafrost layer (for freezing). Our results demonstrated the geographical and historical similarities and continuity of the Mongolian cases, while showing differences in food types and the purpose of storage from those found in Siberia and Alaska.

Keywords: Underground storage, frozen ground, natural cold energy, social system



**2C: INFRASTRUCTURE, COMMUNITIES, AND PERMAFROST DYNAMICS:
RISK, RESILIENCE & ADAPTATION
POSTER**



WATER CRYSTALLIZATION AS AN ENERGY SOURCE FOR HEATING NON-RESIDENTIAL BUILDINGS

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The paper shows the relevance of the work, which consists in the possibility of using the heat of water crystallization into ice to heat non-residential premises to high negative temperatures close to 0°C . The main objective of the work is to determine the required amount of water and heat exchange area depending on climatic conditions, the size of the room, the materials from which the structure is constructed, and its operating mode. To achieve this goal, thermal engineering calculations and experimental monitoring of indoor temperature conditions, outdoor air temperature, ice volume, unfrozen water volume, water evaporation, ice sublimation and other parameters are used. Experimental observations were carried out in an experienced facility built in Yakutsk in 2018, from 2018 to 2025. The heat engineering calculation determined the main and additional heat losses from the room to the environment. As a result of the research, the following conclusions were obtained. The range of changes in outside air temperatures leads to different heat losses from the room, all other things being equal, and, accordingly, to different amounts of water for heating the building. The maximum average indoor air temperature during the winter period (from October to April) was 17 times higher than the average outdoor air temperature during the same period. To prevent water from completely freezing in heat accumulators, due to changes in outdoor temperature and stabilization of indoor temperature, as well as taking into account water evaporation and ice sublimation, about 20-30% of the additional volume of water from the main volume is needed. The main volume of water required for room heating is determined by the thermal calculation of heat loss from the room. Conclusion - long-term tests of the experimental facility have revealed the possibility of practical application of technology for heating non-residential premises with the heat of phase transitions of water to high negative temperatures close to 0°C . This technology can be used throughout most of Russia and the world. It is also an environmentally friendly, safe, renewable, highly efficient, and low-cost source of energy for space heating.

Keywords: Water, crystallization, phase transition, heat source, heat loss



DISCRETE-ELEMENT-BASED INVESTIGATION OF DAMAGE MECHANISMS OF SUBGRADE SOILS UNDER FREEZE-THAW CYCLES

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To quantify the mechanical responses and damage evolution of highway subgrade soils subject to freeze-thaw cycling, we combined laboratory triaxial tests with discrete element method (DEM) simulations for a representative highway section affected by seasonal frost action in Fuxin City, Liao'ning Province in Northeast China. Disturbed silty-clay specimens were prepared at five soil moisture contents (SMC=12.5%, 15.0%, 17.5%, 20.0%, and 22.5%) and exposed to 0 to 7 freeze-thaw cycles (FTCs) under confining pressures of 100, 200, and 300 kPa. Complete stress-strain curves were obtained from static triaxial compression and numerically model simulated with a calibrated particle-flow code (PFC) to understand frost-induced damage processes at a meso-scale. The results identify an optimal SMC that acts as a threshold between strain softening and hardening. Below this threshold, peak deviator stress rises with declining SMC but declines with more FTCs; above it, specimens exhibit continuous strain hardening without a distinct peak. Increasing confining pressure promotes strain hardening by suppressing internal structural damage, enhancing deformation resistance, and improving soil stability. DEM simulations, calibrated against laboratory results, enable direct examination of meso-scale damage mechanisms, including force-chain degradation and porosity evolution under FTCs. FTCs degrades the internal force-chain network from dense to sparse, weaken the load-bearing soil skeleton, and increase porosity, rapidly over the first four FTCs and then asymptotically, whereas higher confining pressure stabilizes force chains and mitigate porosity growth. The integrated experimental-numerical framework clarifies the coupled controls of FTC number, SMC, and confinement on stress - strain behavior and damage evolution of subgrade soils, providing a mechanistic basis for subgrade stability assessment and frost-resilient highway design in seasonal-frost regions.

Keywords: Freeze thaw cycle, subgrade soil, discrete element method, force chains, porosity evolution



OPERATION AND PHYSICAL ENVIRONMENT OF FOOD STORAGE FACILITIES UTILIZING NATURAL COLD ENERGY

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The stable procurement and preservation of food have been vital for survival, cultural development, and the community's well-being, especially in the cold regions. Traditional food storage methods that rely on natural cold—without electricity—reflect environmental adaptations and are now drawing renewed attention amid modern challenges such as food security, climate change, and sustainable development. This study focuses on such methods: ice cellars (sigl̥uaq in Iñupiaq or buluus in Sakha) in Arctic regions and snow/ice houses (yukimuro/himuro in Japanese). We conducted temperature, humidity, and light-intensity monitoring inside and outside these facilities, as well as interviews with residents, to understand usage practices and problems arising from environmental changes. Ice cellars used by Indigenous communities in Alaska (Gambell, Point Hope, Wainwright) and Siberia (near Yakutsk) were investigated. Yukimuro, mainly found in Yamagata and Niigata Prefectures in Japan, were selected for this research. Preliminary findings show a wide variety in the purposes and usage of these natural food storage facilities. The primary use of food storage was driven by the demands of traditional subsistence, bounded by geographical conditions. Our continuous monitoring of the physical conditions in storage facilities revealed year-round temperature and humidity variations closely related to the owners' operations, the timing of community events, and the local climate. A portion of the underground food storage in Arctic communities is increasingly affected by temperature rise and associated hydrological changes. Our fieldwork confirmed that facility structures and their operations significantly influence internal temperature and humidity. Across the studied regions, a major challenge is the significant impact of changes in snowfall and permafrost degradation associated with recent climate change, which severely affect the operational feasibility of these facilities. These traditional storage methods embody valuable environmental knowledge. Integrating them with modern science and technology offers promising pathways to address contemporary food and sustainability challenges.

Keywords: Ice, cellar, food, storage, degradation



THERMO-MECHANICAL STABILITY OF BUILDING VENTILATION PILE FOUNDATIONS IN SUB-ARCTIC PERMAFROST REGIONS

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In sub-Arctic permafrost settlements, climate change and anthropogenic activities are accelerating permafrost degradation, posing a direct threat to the structural integrity of buildings. Although ventilation foundations have been widely used to mitigate thermal disturbance to permafrost, their long-term performance across varying climatic conditions remains poorly understood. This study systematically evaluates the thermo-mechanical stability of ventilation foundation under different mean annual air temperatures (MAAT=−3.5 °C, −4.5 °C, and −5.5 °C), ground ice contents (ice-poor, ice-rich ice-saturated), elevated heights (0.5 m, 1.0 m, 1.5 m), and ventilation modes (year-round ventilation and warm-season closure), using fluid dynamics and non-isothermal fluid-structure interaction models. The simulation results showed that the ventilation, convection, and shading effects of the elevated layer can effectively block the thermal erosion of the ground by indoor heat source, and delay the degradation of permafrost. Raising the height of the elevated layer can enhance the cooling effect on the ground. A 1.5 m foundation elevation prevented talik formation over 50 years and raised the permafrost table by 3-5 m, exhibited good cooling performance. Furthermore, warm-season closure improved cold energy utilization by 6-15% compared to year-round ventilation, thereby reducing summer ground warming. Notably, thermal asymmetry caused by sunny-shady effect was identified as a primary cause of differential foundation settlement. These findings confirmed that the importance of selecting appropriate elevated heights and ventilation strategies based on local climatic and ground ice conditions to ensure the long-term stability of buildings in climate change.

Keywords: MAAT, ice-poor, ice-rich



QUANTIFICATION OF SNOW INSULATION EFFECT ON THE THERMAL ENERGY BUDGET IN SUB-ARCTIC EMBANKMENT

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Seasonal snow cover impacts thermal energy storage in subarctic embankments, accelerating permafrost degradation and leading to road subsidence. However, the quantification of snow cover impacts on embankment thermal energy budget remains largely unknown, and embankment designs to mitigate snow cover impacts have yet to be established. This study systematically evaluated the snow distribution patterns of 25 geometric designs and the thermal energy budgets of four structural types, including common embankment, crushed rock embankment (CRE), CRE with extruded polystyrene (XPS), and U-shaped CRE, using fluid dynamics and non-isothermal fluid-solid coupled models. The simulation results showed that a steeper slope ratio (e.g., 1:3 vs. 1:1.5) reduced recirculation zone length by 17 m, while a lower embankment height (e.g., 2.5 m vs. 6.5 m) decreased recirculation thickness by 1.8 m through enhanced wind velocities over the embankment. Additionally, the U-shaped CRE exhibited good cooling performance for the embankment subgrade, maintaining underground temperatures at or below -0.5°C , with average convective velocities more than three times higher than those of the CRE and CRE+XPS. Furthermore, winter heat flux at the center of U-shaped CRE reached -15 W/m^2 , while the corresponding values for the other two scenarios were about -5 W/m^2 . Notably, no talik formation was observed in the U-shaped CRE over a 50-year simulation period. These findings confirmed that geometric optimization and U-shaped CRE implementation are effective strategies to mitigate snow-induced thermal impacts. Additionally, the CRE+XPS combination unexpectedly enhances convection, sustaining talik-free conditions for 40 years, with thermal stability second only to U-shaped CRE. the CRE+XPS composite design achieves a thermal semiconductor effect by reconfiguring thermal boundaries and optimizing temperature-gradient-driven airflow paths, overturning the assumption that XPS inevitably suppresses convection. However, this synergy requires strict geometric compatibility between XPS and crushed rock properties. Full coverage of the crushed rock layer by XPS would eliminate convective heat exchange, degrading thermal stability to conventional embankment levels. Thus, the benefits of CRE+XPS are contingent on adhering to specific design thresholds.

Keywords: U-shaped, embankment



3A: HIMALAYAN PERMAFROST IN A WARMING WORLD: DISTRIBUTION, EVOLUTION, AND SOCIETAL IMPLICATIONS

Conveners: Soumik Das¹, Elora Chakraborty¹, Mohd. Ataullah Raza Khan² & Milap Chand Sharma¹

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The Himalaya hosts extensive permafrost vital for mountain hydrology, geomorphology, and community livelihoods, yet remains understudied compared to polar regions. This session convenes research on permafrost mapping, activelayer monitoring, ecosystem responses, hazard processes (e.g., GLOFs, debris flows), and Holocenetofuture landscape evolution under warming trends. We particularly invite work on climatelinkages, socioeconomic risk assessments, adaptation planning, and lessons for infrastructure and waterresource management in mountain communities.





PERMAFROST IN THE HIMALAYA: A REVIEW OF SCIENCE AND POLICY OF THE SUB-SURFACE ICE IN A WARMING CLIMATE

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Permafrost, the thermal state of ground that remains at or below 0 °C for two or more consecutive years, constitutes a critical component of the cryosphere. Despite its significance in controlling hydrological regimes, slope stability, and carbon fluxes, permafrost remains among the least explored components of the Himalayan environment. This review synthesizes recent advances in Himalayan permafrost research, focusing on spatial distribution, thermal regime, geomorphic proxies, hydrological relevance, related hazards, impacts on land-use systems, and emerging policy responses. Recent inventories suggest that permafrost is largely discontinuous and fragmented across the Himalayan region, typically occurring above 4200-4800 m above sea level (m a.s.l.) on shaded, north-facing slopes. Ground temperature monitoring in Ladakh reveals mean annual surface temperatures from -10 to +2.1 °C and active layer thicknesses up to 4 m. Periglacial features, especially rock glaciers, act as primary markers of permafrost and subsurface ice. However, geochronological analyses of these landforms are limited, hindering insights into past permafrost behaviour and palaeoclimate. Recent findings show that permafrost warming is increasingly linked to slope instability, ground subsidence, and changes in runoff patterns. Despite this, permafrost is inadequately addressed in long-term monitoring and regional climate adaptation strategies. Critical research gaps exist in the Himalayan region, such as a scarcity of long-term thermal records, lack of geochronological data, sparse mapping in the eastern Himalaya, lack of geophysical investigations for ice estimation, and minimal integration into water and infrastructure management. Given the accelerating impacts of climate change, systematic permafrost research and policy integration are urgently needed to support climate adaptation strategies, hazard forecasting and sustainable development across the Himalaya.

Keywords: Permafrost degradation, periglacial landforms policy, implications Himalayan permafrost



THE RELATIONSHIP BETWEEN THE UPLIFT OF THE QINGHAI-TIBET PLATEAU (QTP) AND THE FORMATION OF MID-LATITUDE PERMAFROST

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The coupling between the Qinghai-Tibet Plateau (QTP) uplift and mid-latitude permafrost formation is a critical topic in global paleoclimatology and geomorphology. As the world's highest and largest plateau, the QTP's tectonic uplift has drastically modified regional and global atmospheric circulation, while mid-latitude permafrost—predominantly distributed across the QTP and adjacent highlands—acts as a sensitive proxy for paleoenvironmental changes. Yet the systematic link between the QTP's stepwise uplift and the spatiotemporal evolution of mid-latitude permafrost remains inadequately clarified, hindering understanding of tectonic-cryospheric interactions. Specifically, the QTP's uplift reduced near-surface temperatures to the freezing threshold via the “altitude effect”, and modified atmospheric circulation (enhancing Asian monsoon-westerly interactions) regulated precipitation and supplied sufficient frozen water for permafrost development. Notably, the QTP uplift process reconstructed using different proxies remains fraught with controversies and contradictions. Fossil pollen is a useful indicator of mountain elevation, surface vegetation cover, and climate change; these proxies can not only be used to reconstruct the process and details of the plateau's uplift but also reflect the corresponding plant-ecological feedback under permafrost-forming environments, indirectly indicating the permafrost formation process—further highlighting the significance of exploring their coupling relationship. Currently, we have collected numerous Cenozoic sedimentary sequences in the central and northern parts of the plateau and conducted preliminary analyses. The results indicate that these profiles are rich in pollen, and the initial findings show that the paleo elevation of the central QTP's mountains rose from ~2000 m in the late Eocene to ~3000 m in the late Oligocene-early Miocene, reached approximately 5200 m during the middle Miocene (~15-12 Ma), and ultimately exceeded 6000 m today. Our next step is to focus on permafrost-sensitive proxies, such as indicator pollen taxa, dust variability, and other relevant indices, to determine the formation timing and evolutionary characteristics of mid-latitude permafrost, thereby further discussing the relationship between QTP uplift and mid-latitude permafrost development and deepening insights into tectonic-cryospheric interactions.

Keywords: Qinghai Tibet Plateau (QTP), pollen, permafrost



LONG-TERM PERMAFROST EVOLUTION IN THE MIYAR VALLEY, WESTERN HIMALAYA: EVIDENCE FROM CRN, RADIOCARBON, AND OSL CHRONOLOGIES

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Geomorphic expressions of permafrost processes in high mountain environments reflect millennial-scale interactions among climate variability, glacial dynamics, and post-glacial landscape evolution. In the Western Himalaya, the persistence of permafrost is strongly influenced by inherited geomorphic and sedimentary controls. This study reconstructs the long-term evolution of permafrost in the Miyar Valley using a multi-proxy chronological framework integrating cosmogenic (^{10}Be) exposure ages, radiocarbon (^{14}C) dating, and optically stimulated luminescence (OSL) ages from glacial, lacustrine, and periglacial deposits. The calculated dates chronologically constrain the shift from glacial to periglacial process regimes vis-à-vis conditions for phased frozen-ground development during the Late Quaternary. Cosmogenic nuclide exposure ages from a glacially eroded bedrock bench and an erratic perched on ice-marginal morainic formation indicate a phase of glacier aggradation during MIS 6-MIS 5, predating the local Last Glacial Maximum (LLGM). These ages suggest that retreat of the trunk Miyar valley glacier occurred before peak global glacial maximum (gLGM) conditions. Optically stimulated luminescence ages from post-LLGM glacio-lacustrine sediments bracket deposition between MIS 3- MIS2 and MIS 2-MIS 1 transitions, implying that a lake existed within the valley during gLGM conditions. This lacustrine phase is interpreted to reflect sediment trapping behind a valley-blocking dam, plausibly formed by advances of tributary glaciers during the gLGM. Radiocarbon ages from a core extracted from subsequently developed peat bogs and thermokarst-related organic horizons range between ~23 ka and ~3.5 ka, indicating prolonged intervals of surface stability, episodic ground-ice preservation, paced thaw, and sustained permafrost-influenced conditions extending from the late glacial period into the mid- to late Holocene. Together, these chronologies reveal selective preservation of permafrost within topographically confined and sediment-rich valley reaches, with regard to geomorphic processes in coherence with episodic climatic variability, driven by changing monsoon-westerly interactions. The results demonstrate that present-day permafrost distribution in the Miyar Valley is not solely a function of contemporary climate, but reflects long-term geomorphic inheritance, debris production, sediment thickness, valley geometry, and post-glacial sediment reworking. This study highlights the importance of multi-proxy chronological constraints for understanding millennial-scale permafrost persistence and degradation in high-mountain environments under ongoing warming.

Keywords: OSL, CRN, ^{14}C , permafrost, quaternary



A HIGH-RESOLUTION PROBABILISTIC PERMAFROST DISTRIBUTION MODEL FOR SOUTH-CENTRAL AND INNER ASIA

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We present the development of a high-resolution probabilistic permafrost distribution model for South-Central and Inner Asia, with a focus on the Hindu Kush Himalaya (HKH) region. The new model addresses the critical need for improved spatial understanding of permafrost in high mountain environments, where permafrost dynamics significantly influence hydrology, slope stability, and infrastructure resilience. The model leverages remote sensing data, digital terrain analysis, and public inventories of over 50,000 rock glaciers as indirect indicators of permafrost. Five key topographic and climatic parameters: slope orientation, solar radiation, slope angle, latitude, and longitude, are integrated using weighted correlations to estimate permafrost probability at a grid resolution of approximately 43 x 43 meters. The new model was used to estimate the extent of permafrost and we showed that approximately 9.2% (387,300 km²) of the HKH region is located within a permafrost region, i.e. a location where there is at least a very low probability for permafrost to be present. According to the most recent Randolph Glacier Inventory, 54,225 glaciers are present in the HKH Region, with a total area approximately 2.1 to 3.5 times smaller than the extent of permafrost within the region, highlighting its importance. However, glaciated areas have not been excluded from the permafrost estimates, adding some additional uncertainty. In certain locations, particularly at higher elevations, permafrost may exist below glaciers where cold-based ice is frozen to the underlying bedrock. The model provides new insights for risk assessment related to permafrost degradation, landslide susceptibility, design of monitoring networks, and hydrological modeling. It may serve as a foundational tool for future research and mitigation and adaptation strategies in the context of climate change, with recommendations for integrating in situ observations and remote sensing data to enhance accuracy and utility.

Keywords: Permafrost distribution, Hindu Kush Himalaya, South Central Asia



DO REMOTE SENSING ESTIMATES OVERESTIMATE PERMAFROST IN THE HINDU KUSH HIMALAYA? INSIGHTS FROM CHANDRATAL LAKE

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Like glaciers and snow cover, permafrost is affected by global warming. Unlike them, permafrost affects both water availability and infrastructure. Most existing studies in the Hindu Kush Himalaya (HKH) rely on areal estimates of permafrost derived from remote sensing data, while field-based surface energy balance studies that directly confirm the presence of permafrost remain extremely rare. In this study, we evaluate the presence of permafrost in the Chandratat Lake region (4300 m a.s.l., western Himalaya, India) using the surface energy balance-based GEOTop model. The model was forced using in situ soil temperature measurements at 10 cm depth, collected from 11 temperature loggers installed around the lake between September 2020 and June 2024. In addition, bias-corrected hourly soil temperature data from ERA5 (1991–2024) were used to simulate long-term soil thermal conditions and to examine temporal variations in soil temperature profiles with depth over the past three decades. Simulations were performed using high and low soil thermal diffusivity values to capture the uncertainty envelope of subsurface thermal profiles. Field observations were further used to determine snow melt-out dates at logger locations for the period 2021–2023. The results indicate an absence of permafrost in the lake surroundings, as simulated soil temperatures stabilize above 3.35 °C under both high and low thermal diffusivity scenarios. These findings contrast with earlier remote sensing-based studies that suggested the presence of permafrost around Chandratat Lake. We therefore hypothesize that remote sensing-based approaches may overestimate permafrost extent in the HKH region, and strongly emphasize the need for detailed, field-based surface energy balance investigations to reliably assess permafrost distribution in the HKH.

Keywords: Permafrost, energy balance, remote sensing estimates



PROCESS-BASED PERMAFROST MAPPING IN THE COLD-ARID TRANS-HIMALAYAN SPITI REGION USING THE CRYOGRID COMMUNITY MODEL AND HIGH-RESOLUTION TOPOGRAPHY

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Degradation of mountain permafrost under ongoing climate change poses increasing risks to slope instability and other cryosphere-related hazards in high-mountain environments. Permafrost maps must capture local ground thermal conditions and micro-scale variability, imposed by rugged topography and heterogeneous snow redistribution. In the Himalayan region, ground-based information on permafrost remains sparse. Existing mapping efforts have largely relied on disparate rock-glacier inventories, limited in-situ measurements, and statistical models that relate permafrost likelihood to air temperature and potential incoming solar radiation. While suitable for broad regional assessments, these approaches inadequately represent permafrost thermal regimes under heterogeneous snow accumulation, typical of complex high-mountain micro-catchments, where thaw can rapidly escalate into cryosphere-related hazards. The cold-arid Trans-Himalayan Spiti region of the western Himalaya, characterised by steep relief and complex post-glacial landscapes, is particularly underrepresented in permafrost assessments. Slopes in this region commonly comprise fractured bedrock, post-glacial surface debris, heterogeneous snow cover, and hosts diverse periglacial landforms, e.g. hummocks, peat bogs, solifluction lobes, and cryoplanation terraces, resulting in pronounced spatial and temporal variability in ground temperatures. Ground thermal regimes in Spiti are primarily governed by slope angle and aspect, solar radiation, soil moisture, and snow accumulation patterns. Consequently, these slopes may store substantial subsurface ice and exhibit permafrost dynamics distinct from those of steep rock walls or gently inclined debris-covered terrain, with direct implications for thaw-related slope instability and local hazards. To address these knowledge gaps, this study applies CryoGrid community model to simulate transient ground temperature dynamics at representative sites in the Spiti region between ~4000 and ~5200 m a.s.l. The model is calibrated using one year of field observations, collected between June 2024 and July 2025 across contrasting slope geometries and geomorphic formations. Calibration focuses on the key parameters governing surface energy balance and subsurface heat transfer. The modelling framework is generalized to account for spatial variability in slope angle and aspect, surface roughness, ground properties, and precipitation/snow regimes. The resulting simulations are then integrated with high-resolution digital elevation models to generate an initial permafrost map for the Spiti region, explicitly representing hummocky terrain, debris-covered slopes, and inactive rock glacier terrain. The results enhance the understanding of Late Holocene permafrost evolution in cold-arid Himalayan landscapes and provide a process-based foundation for assessing slope stability and cryosphere-related hazards in a rapidly warming mountain environment.

Keywords: Mountain permafrost CryoGrid, Cold-arid, Himalaya, permafrost mapping, ground thermal conditions



GLACIER-PERMAFROST CONTROLS ON GLACIAL LAKE DYNAMICS AND GLOF RISK IN THE LACHUNG BASIN, EASTERN HIMALAYA, INDIA

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Climate change-driven glacial melting and permafrost degradation have intensified glacial lake outburst floods (GLOFs), threatening mountain communities worldwide. Despite extensive studies on glacial lake expansion, the main drivers of rapid lake growth in the Sikkim Himalaya remain debated, as was the case with the South Lhonak GLOF in 2023. The Lachung sub-basin, a major tributary of the transboundary Teesta River, hosts a dense concentration of glaciers, glacial lakes and permafrost landforms, making it a dynamic cryospheric region in the High Mountain Asia. Our study examines glacier dynamics, glacial lake evolution, and permafrost distribution in the Lachung Basin from 1974 to 2025, with emphasis on potentially dangerous glacial lakes (PDGLs). Multi-temporal satellite imagery, aerial data, and field investigations, including unmanned survey vehicle (USV)-based bathymetric surveys conducted up to October 2025, were employed. Our updated inventory identifies 99 glacial lakes in 2023, covering $4.570 \pm 0.29 \text{ km}^2$, compared to 46 lakes ($2.986 \pm 0.10 \text{ km}^2$) as was in 1974. Maximum expansion occurred during 2001-2014 at a rate of $0.057 \text{ km}^2 \text{ yr}^{-1}$, closely linked to accelerated deglaciation. Supraglacial lakes expanded rapidly and transformed into proglacial lakes subsequently. Marked spatio-temporal differences in lake expansion is observed within continuous permafrost zones. The frontal regions of Tenbawa, Illibo Khangse lakes, Lake No. 36-37, and Palochuthang-2 (Fig. 1a) lie in active permafrost areas, where permafrost instability likely contributed to repeated expansion and breaching over the past five decades. The Tenbawa supraglacial lake (5088 m a.s.l.), which triggered a GLOF in 1998, continues to expand unabated. A previously unreported moraine-dam breach on 02 August 2023, driven by cascading impact, is confirmed through satellite and field observations. The lake volume reached $7.51 \times 10^6 \text{ m}^3$ in 2023, with an average peripheral depth of $\sim 17 \text{ m}$ measured in 2025. Surrounding rock glaciers and permafrost extend beyond $\sim 4860 \text{ m a.s.l.}$ whereas measured active layer thickness below surface during post monsoon period was $\sim 1 \text{ meter}$. Further degradation will lead to increasing glacial lake dam instability, magnifying the likelihood of future breaching and debris-flow hazards thereof. Our findings highlight the urgent need for continuous monitoring and installing early-warning systems, where small lakes can trigger high-magnitude cascading hazard. Integrated risk mitigation strategies combining monitoring, hazard assessment, engineering measures, community engagement, and policy support are

Keywords: Eastern Himalaya, supraglacial lake, permafrost, GLOF, bathymetry



3B: MOUNTAIN CRYOSPHERE LANDFORMS IN A WARMING CLIMATE: ROCK GLACIERS AND BEYOND

Conveners: Mishelle Wehbe¹, Yan Hu² & Cécile Pellet²

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Alpine periglacial landforms rock glaciers, icecored moraines, debriscovered glaciers record key climatedriven processes yet remain undercharacterized across mountain belts. This session invites studies on landform dynamics (kinematics, thermal and hydrological regimes), monitoring approaches (remote sensing, geophysics, field observations), and their relevance for water resources, geohazards, and paleopermafrost reconstructions. Contributions that compare multiple landform types, advance inventory protocols, or integrate models across scales are especially encouraged.





ROCK GLACIER INVENTORY IN TSENGEL KHAIRKHAN MASSIF, WESTERN MONGOLIA

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The European Space Agency (ESA) Climate Change Initiative (CCI) Permafrost project and the Rock Glacier Inventories and Kinematics (RGIK) IPA Standing Committee have supported the compilation of many rock glacier inventories (RoGIs) over the past years. In 2023-2025, 12 CCI Permafrost RoGIs were compiled and disseminated (Rouyet et al., 2025, ESSD). In 2024-2025, similar work has started in additional regions in Asia, South America and Europe. All RoGIs have been compiled using the recommended RGIK guidelines and the standardised GIS structure and templates, to consistently map the rock glacier units and describe their morpho-kinematic characteristics using optical and radar remote sensing. This contribution will present the results in the Tsengel Khairkhan Massif, located in the Mongolian Altai (western Mongolia), largely within the continuous permafrost zone. To our knowledge, it is the first detailed inventory of rock glaciers in this mountain range. The study area covers approximately 208 km², with elevation ranging from 2610 to 3943 m a.s.l. and features a variety of cryogenic landforms formed under periglacial conditions. The terrain is characterized by steep topography, cirque and valley systems, and a wide range of slope orientations. Using optical imagery (Bing, Google, and ESRI satellite basemaps), we located and delineated the rock glacier units and interpreted their morphological characteristics. Using multi-temporal Sentinel-1 and SAOCOM Interferometric Synthetic Aperture Radar (InSAR), we documented the averaged creep rate of the landforms and assigned a kinematic attribute to the inventoried units. This information was used to support the categorisation of the rock glacier activity (active, transitional, relict), defined as the efficiency of sediment conveyance (expressed by the surface movement). The work was performed by four operators, working in parallel using a standardised QGIS-based workflow. Team meetings were organised at several steps of the work to discuss the discrepancies and find consensus for complex cases. In total, 63 certain and 111 uncertain rock glacier landforms were identified. In total, 91 moving areas were delineated and classified into velocity classes ranging from 0.01 to 0.30 m/yr. Among the certain rock glaciers, 55 were classified as transitional, 4 as active, 3 as active uncertain, and 1 relict uncertain. A clear predominance of north-facing slopes was observed, likely linked to permafrost preservation under reduced solar radiation. The velocity of the landforms is low which emphasizes the cold conditions in the area. This inventory provides essential baseline data for understanding permafrost conditions and rock glacier dynamics in the Mongolian Altai and offers a foundation for future regional scale comparisons.

Keywords: Rock glacier, inventory, Mongolia



ROCK GLACIER VELOCITY (RGV) INVESTIGATIONS IN THE ALPINE REGIONS OF WESTERN CANADA

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Investigated within this research are the distribution, characterisation, and dynamics of rock glaciers, as well as Geomorphic Features of Interest (GFIs) within the alpine periglacial environments of Alberta and British Columbia, Western Canada. This work serves as a component of the Canadian Rock Glacier Inventory (CanRoGI) initiative, a crucial effort to establish the first unified, nationwide database of rock glaciers. GFIs along a morphological continuum, such as debris-covered glaciers, protalus ramparts, potential embryonic rock glaciers, solifluction lobes, and more are included in this initiative as catalogued features. Given that Rock Glacier Velocity (RGV) recognised as an Essential Climate Variable (ECV) Quantity for Permafrost, this research marks the first deployment of Differential Interferometric Synthetic Aperture Radar (DInSAR) in the investigation of rock glaciers in Canada. Canada is a unique region as the current status of rock glacier conditions is sparse, the resolution and accuracy of previous investigations are inconsistent, and recent studies completed are limited. This work and ongoing initiatives fill a significant gap in regional and global permafrost research. This inventory utilised free, high-resolution optical imagery available within base layers in QGIS, with supplementary datasets from Planet Labs and the National Air Photo Library in absence of clear images. While characterising the rock glaciers, the Rock Glacier Inventories and Kinematics (RGIK) guidelines (BPC v1.0) were utilised along with a slightly modified method for delineation. To reduce subjectivity of upper boundary delineation of rock glacier systems and units, as well as reduce mapper bias in difficult situations, a Flow Initiation Line (FIL) was implemented. Methodology for this research also includes the framework for systematic characterisation and monitoring from the RGIK RGV Baseline Concepts (v3.2) and Practical Concepts (v1.2), which assisted in the detection of ground deformations and surface velocities of the rock glaciers. The focus of this work is rock glaciers, although cataloguing their distribution with the GFIs further enhances the suitability of this dataset for hazard mapping efforts and hydrological studies, as well as degradation and slope instability in these regions.

Keywords: Rock Glaciers, DInSAR, CanRoGI, Canada



7500 ROCK GLACIERS REVEAL 2000 M OF PERIGLACIAL BELT MIGRATION IN THE SWISS ALPS SINCE THE END OF THE LAST GLACIAL MAXIMUM

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Rock Glaciers are the visible expression of the permafrost creep process. Over recent decades, important changes in creep rates have been observed, raising questions about the impacts of climate change on mountain permafrost. The Swiss National Foundation research project RoDynAlps aims to understand the mechanisms behind permafrost creep process over various scales. In practice, the project focuses on rock glaciers located throughout the Swiss Alps. In this context, the present study aims to understand the spatial distribution of rock glaciers and to identify the controlling factors of permafrost creep process at the spatial scale of the Swiss Alps. The standard guidelines developed by the Rock Glacier Inventory and Kinematics (RGIK) consortium are applied to compile a comprehensive rock glacier inventory to our study area. All steps are performed manually, utilizing a high-resolution dataset that includes the most recent Swisstopo Digital Elevation Model (DEM) hillshade (SwissAlti3D), recent and historical aerial ortho-images, and Sentinel-1 and Saocom InSAR data acquired between 2020 and 2023. The very high resolution of these datasets allows for high-precision mapping and the creation of a comprehensive inventory. It enables rock glacier units to be distinguished from both morphological and kinematic perspectives. In addition, the DEM allows the reconstruction of the morphological history of landscapes that are currently forested, thereby enabling the systematic identification of periglacial landforms at much lower elevations than previously documented. The resulting dataset provides an overview of areas affected by permafrost creep since the Last Glacial Maxima in the Swiss Alps. To date, 7,500 rock glacier units have been identified, and the activity of 4,900 of these landforms has been assessed. Among them, permafrost creep has been confirmed by a kinematic assessment for 2,400 rock glaciers. The fronts of active landforms are mainly located between 2,400 and 2,900 m a.s.l. Transitional rock glaciers occur at overall elevation 100 m lower. The average length of rock glacier units reaches 250 m for the transitional class and 280 m for the active class. Transitional rock glaciers are therefore expected to have initiated their development during an earlier and colder climatic phase than their active counterparts, yet they exhibit similar lengths. This raises questions about the respective development scenarios of these landforms. Another 2,500 landforms have been classified as relict, with several of them occurring at altitudes between 500 and 1,000m a.s.l. This indicates an altitudinal migration of the periglacial belt of up to 2,000 meters since their formation. Statistical distribution of the combination of solar radiation and elevation on these landforms also reveals up to three distinct clusters, suggesting the presence of three generations of relict landforms in the Swiss Alps. The final inventory is among the first to apply the RGIK guidelines comprehensively to such numerous landforms, combining very high spatial mapping resolution with a systematic kinematic assessment. The potential applications of this inventory extend well beyond the scope of the present research project.

Keywords: RoGI, Switzerland, distribution, geomorphology



STATISTICAL PREDICTION MODELLING OF ROCK GLACIER DISTRIBUTION IN NORWAY

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Active rock glaciers are indicative of mountain permafrost, while transitional or relict rock glaciers delineate areas of degrading or former permafrost. Rock glaciers inhabit certain niches in mountain areas related to topographic and climate settings. Identifying these topographic constraints for rock glacier existence makes it possible to identify not recognised areas of rock glacier distribution during late glacial or Holocene climate conditions. The identification of such areas can be obtained by fitting statistical prediction models to rock glacier inventories. Such an inventory exists for Norway, and we used explanatory variables including meteorological and topographic parameters to model the distribution of rock glaciers at present. In a second step we used the statistical models to explore the Holocene and late-Pleistocene distribution of rock glacier activity by adjusting the temperature in the model to climatic conditions during the Younger Dryas (YD), the Holocene thermal maximum (HTM), and the Little Ice Age (LIA). Our model suggests that at present, active rock glaciers exist at 300–400, 600–800, and 1300–1500 meters above sea level in Finnmark, Troms and southern Norway, respectively. The climate-adjusted model identifies rock glaciers in 1) low-lying, coastal areas in a YD climate, 2) areas at or inside the YD ice sheet margins in an LIA climate, and 3) at high elevation continental areas during the HTM. From these results, we suggest that predictively active rock glaciers during the YD were probably also initiated during this time period and remained active a couple of thousand years until they turned relict before or during the post-glacial warming or the during the HTM. Rock glaciers that were active during an LIA climate were probably formed in colder periods following the HTM, and rock glaciers associated with an HTM climate have likely existed continuously since the YD, throughout the HTM and until today as either active or inactive landforms.

Keywords: Rock glaciers, prediction modelling, Norway



PERMAFROST IN THE PYRENEES: CURRENT KNOWLEDGE AND FUTURE PERSPECTIVES

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The Pyrenean cryosphere is undergoing rapid change due to climate warming, with significant consequences for hydrology, landscape stability, and human activities. Rising temperatures have drastically reduced snow cover and accelerated glacier retreat, and Pyrenean glaciers are expected to disappear in the near future. In contrast, permafrost an essential but largely invisible component of the high-mountain cryosphere remains poorly understood. Located at the southern limit of permafrost distribution in Europe, the Pyrenees are particularly sensitive to warming, and ongoing permafrost degradation is increasing slope instability, rockfalls, landslides, and moraine collapses, posing growing risks in heavily frequented mountain areas. To address these knowledge gaps, the PERMAPYRENEES project has developed an integrated monitoring strategy that combines field observations with advanced remote sensing techniques. This approach includes geophysical surveys, deep boreholes for continuous subsurface temperature monitoring, thermal sensors installed on steep rock walls, InSAR analysis of ground deformation, reconstruction of past permafrost activity using rock glaciers, analysis of rock thermal properties, and detailed permafrost mapping to identify climate-sensitive hazards. During 2025, four boreholes were drilled in the Bessiberri (2,699 m), Pica d'Estats (2,916 m), Vignemale, and Pessons massifs (2,575 m). Results indicate permafrost conditions at depths of 3 m and 8 m in the rock glaciers of Bessiberri and the Clot de la Menera (Pessons), respectively. At Pica d'Estats (2,960 m), bedrock temperatures did not indicate the presence of permafrost, as deep temperatures stabilized at 1.7 °C a few weeks after drilling despite the higher elevation. No data are yet available from the Vignemale borehole. Six additional boreholes are planned for summer 2026 at selected sites on both the northern and southern slopes of the Pyrenees. These findings are complemented by temperature loggers installed on steep rock walls in several of the highest massifs of the range, which also suggest the presence of permafrost on north-facing slopes above 2,800 m. Overall, preliminary data indicate that sporadic permafrost may occur under a wider range of conditions than previously recognized. Beyond advancing scientific knowledge, the project provides essential data to support hazard assessment, risk mitigation, sustainable land-use planning, and the recognition of high-mountain environments as vulnerable geoheritage in the context of a rapidly warming climate.

Keywords: Pyrenees, permafrost, climate warming, geomorphology



MULTI-ANNUAL AND SEASONAL PATTERNS OF MURTÈL ROCK GLACIER BOREHOLE DEFORMATION: CONTROLS AND IMPLICATIONS FOR KINEMATIC MONITORING.

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Information about rock glacier deformation with depth is crucial for understanding the kinematic processes responsible for variations in rock glacier velocity. The majority of studies on rock glacier kinematics have been limited to surface measurements. Understanding what the surface signal of rock glacier movement represents is important because it is a parameter of the “permafrost” essential climate variable (ECV). Here, we present a unique record of the nearly eight-year-long borehole deformation data at high temporal resolution from the Murtèl rock glacier in the Swiss Alps. This data is accompanied by borehole temperature, surface displacement measured by a GNSS and geodetic surveying, and meteorological data to investigate processes related to the kinematics of Murtèl rock glacier. The extracted velocity time series with depth shows that seasonal variations are only observed in the active layer (AL), while in the ice-rich core and the shear zone velocity remains relatively stable. Interannual variability in deformation is driven by both the AL and the ice-rich core components, while the shear zone shows minimal change over the years. The lack of variability in deformation within the shear zone suggests that water-related controls at depth are absent as the thick and cold ice-rich core above limits water infiltration. The AL, ice-rich core and shear zone components of deformation make up 20%, 24% and 56% of surface displacement respectively. Compared to previous borehole inclinometer data, we find an unusually high fraction of surface displacement happening in the AL at Murtèl rock glacier. The driving processes for this are inferred to be the melting of refrozen ground ice near the base of the AL and consolidation of blocks after the seasonal thaw. There are multiple rock glacier studies that report a fast response in surface velocity to water input from snowmelt or rainfall. In contrast, at Murtèl rock glacier we find that surface acceleration begins two to three weeks after the snowmelt period ends. The largest peaks in surface velocity coincide with the years with the highest ground surface temperature rather than the years with the most snowmelt. We postulate that the deep ice-rich and cold permafrost core of Murtèl rock glacier prevents the pore water pressure in the shear zone to change at a seasonal timescale. The borehole deformation and temperature data suggest that the seasonal cycle in AL deformation is strongly related to thermal processes and the melting of refrozen seasonal ice. Beyond this, three independent approaches for measuring surface displacement were applied and show that the borehole inclinometer and geodetic survey measurements agree well over a multi-annual period. The continuous GNSS surface observations slightly overestimate the seasonal acceleration, but match the general background displacement well. This comparison can act as a baseline for selecting an appropriate method to estimate rock glacier velocity to use as a parameter of the “permafrost” ECV, while acknowledging the potential differences between annual surface velocity and velocity at depth. Our borehole deformation data provide novel information on the vertical distribution of rock glacier deformation at various timescales and related driving processes.

Keywords: Rock glacier, kinematics, GNSS, borehole, processes



CLIMATE CHANGE IMPACT ON THE SEASONAL GIANT ANMAGYND AUFEIS IN MOUNTAINOUS PERMAFROST OF THE NORTHEASTERN EURASIA

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Aufeis (naled, in Russian) is a specific form of seasonal glaciation that is typical for mountainous permafrost environment. The area of aufeis fields can be measured in tens of square kilometres, and the ice thickness may reach 10-12 m. Spring aufeis fields are widespread in the mountain permafrost zone of the North-Eastern Eurasia, they serve as the indicators of permafrost-hydrogeological processes. Giant aufeis field in the Anmangynda river catchment is considered to be representative for vast territories of this region where climate change impacts permafrost environment, and its research has been carried out since 1962. The findings on this object may provide the clue of changes for vaster areas. The goal is to assess the temporal variability of the characteristics of the Anmangynda aufeis field using historical materials and remote sensing data, and to identify the climatic factors governing their changes. The study used data from historical field measurements of the aufeis area and volume, from 1962 to 1990. Aufeis detection in current period was conducted based on the Landsat satellite images, from 2000 to 2017, and Sentinel-2, from 2018 to 2025, late spring images were selected to detect the maximum possible aufeis area. The aufeis area was determined using the calculated Normalized Difference Snow Index with a threshold value of 0.4. The maximum uncertainty in estimating the aufeis area is 1.11 km² from Landsat images and 0.74 km² from Sentinel-2 images, e.g. 15-20% of its actual area. Long-term records of air temperature and precipitation time series were compiled for the period 1967-2025 from the Ust-Omchug weather station. The data on ground temperature was obtained from the Susuman weather station (1977-2013). The results showed that over the historical period (1963-1990), the aufeis maximum pre-ablation area ranged from 4.3 to 6.8 km², with a volume of 5.3 to 11.7 million m³. In the present era (2000-2025), these figures decreased to 3.1-5.4 km² and 4.3-8.2 million m³, respectively. The air temperature and precipitation in this area increased, with the strongest changes occurring in the beginning of winter (October-December). The snow cover is formed earlier and its depth is higher in the last decades. Ground temperature has also increased. Solid precipitation in November and December showed a moderate negative correlation (Spearman's rank correlation coefficient = -0.54 $p < 0.05$) with the aufeis size parameters and it was statistically significant for the period of 2000-2025. The observed reduction in aufeis area and volume align with broader cryospheric changes. As aufeis fields continue to evolve, this study highlights the complexities in their responses and their relevance as the indicators of climate-driven alterations in the cryosphere. Financial support: The research was funded by the Russian Science Foundation (project No. 25-77-10033).

Keywords: Giant aufeis, long term dynamic, climate change, Northeastern Eurasia, cryosphere



FORMATION OF INFILTRATION ICE IN TALUS SLOPES AND ITS INFLUENCE ON RUNOFF OF A PERMAFROST WATERSHED (NORTHEASTERN RUSSIA)

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Rocky talus landscapes are widespread across the mountainous regions of Northeastern Russia. They occupy 8.4% of the Kolyma River basin, the largest basin in Northeastern Russia, and may contribute up to 28.9% of its runoff. In spring, snowmelt water infiltrates deeply cooled coarse rock debris and freezes, forming infiltration ice, which influences runoff through seasonal and interannual redistribution of water. This study aims to quantify infiltration ice formation in talus slopes and assess its contribution to runoff formation in a representative permafrost watershed. The study focuses on the Morozova Creek watershed, which represents a typical talus-slope permafrost watershed in the Northeastern Russia. Continuous hydrometeorological observations in the watershed were conducted from 1968 to 1997. Since 2020, hydrometeorological and ground temperature measurements have been resumed by the authors. Using historical and modern observational data, infiltration ice formation and runoff were simulated for the period 1968-2025 with the physically based hydrological model Hydrograph, which accounts for the phase changes of water and heat exchange in the ground. The simulated annual infiltration ice water equivalent varied between 37 and 68 mm, with a mean value of 52 mm. During the earlier period (1969-1993), mean infiltration ice storage reached 57 mm, while in the later period (1994-2025) it decreased by approximately 14% to 49 mm. The simulated annual runoff ranged from 252 to 697 mm, with a mean value of 415 mm, with no statistically significant long-term trend detected over the study period. The contribution of infiltration ice to runoff was quantified as the ratio of annual infiltration ice storage to total annual runoff. On average, infiltration ice accounted for 13% of annual runoff, with interannual variability ranging from 8% to 23% (Fig. 1). A statistically significant decrease of infiltration ice contribution was identified, with a trend of -0.76 mm per decade. The results demonstrate that infiltration ice in talus slopes represents a significant component of runoff formation and highlight the importance of accounting for talus-slope infiltration ice in hydrological and permafrost models, particularly under ongoing climate change. Financial support:

The research was funded by the Russian Science Foundation (project No. 25-77-10033).

Keywords: Infiltration ice, talus slopes, runoff, permafrost hydrology, hydrograph model

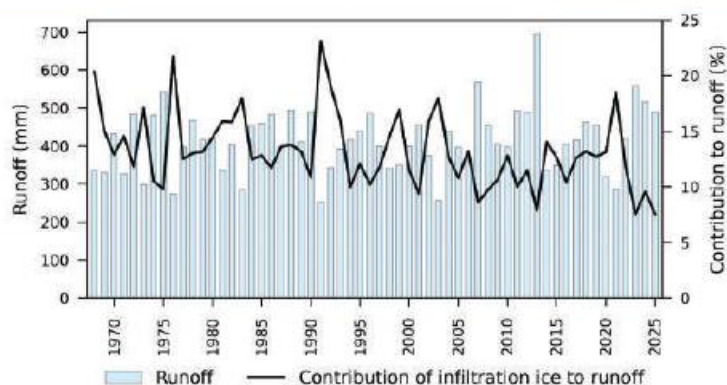


Fig. 1



TRACKING ROCK GLACIER VELOCITY BY GEODETIC SURVEYS: A METHODOLOGICAL CONTRIBUTION TO THE ESSENTIAL CLIMATE VARIABLE “PERMAFROST”

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This study explores geodetic survey methods applied to track the movement of rock glaciers particularly in the European Alps and contextualize these observations with the early phase of monitoring rock glacier dynamics more than 100 years ago. Different in-situ geodetic approaches for measuring both rock glacier velocity (RGV) and rock glacier advance (RGA) are evaluated, offering methodological insights and recommendations. Systematic monitoring of RGV began in the European Alps in 1918, followed by RGA monitoring in 1921. Since 2022, RGV has been recognized as a parameter of the essential climate variable “Permafrost,” highlighting its significance in understanding climate change impacts. Current in-situ techniques rely commonly on either satellite-based positioning or traditional total station measurements. Across the rock glaciers of particular interest in this study ($n=43$), the total number of surveyed boulders varies from 1 to 206. In most cases, only a part of these points is considered as “reference points” used to calculate the RGV value of a given rock glacier unit. The density of these reference points varies between 27.5 and 1143 points per square kilometer, reflecting site-specific characteristics and methodological variability. To ensure reliable long-term RGV monitoring using annual geodetic surveys, the following suggestions are proposed: (a) select rock glaciers suitable for multi-decadal observations; (b) ensure uniform distribution of survey points across the entire glacier unit, either along profiles or well-distributed boulders; (c) maintain consistent timing of annual surveys, preferably in September; (d) average site RGV using all surveyed data points; (e) consider only reliable reference markers for long-term monitoring; (f) include statistical analyses of these markers, with emphasis on the central flowline; and (g) establish secure systems for storing original data, metadata, and derived results. By comparing these methods with other studies, this work emphasizes a standard approach to RGV monitoring, addressing challenges in long-term data collection and reliability while offering solutions for improving methodological consistency. Such efforts contribute directly to the characterization of permafrost as a key climate variable and enhance our understanding of its dynamics in the context of seasonal weather patterns and climate change.

Keywords: In-situ survey, rock glacier velocity



ISOTOPIC COMPOSITION OF GLACIER ICE AND UPLAND RIVERS IN NORTH-WESTERN MONGOLIA AND THE RUSSIAN ALTAI

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In this presentation, we present the results of stable isotope research in high-altitude glacierized areas in North-West Mongolia (Tsambagarav, Tsengel and Tavan-Bogd massifs) as well as in the Russian Altai (Tavan Bogd Massif and South Chuy Ridge). The methodology of this research is based on measurements of the isotopic composition ($\delta^{18}\text{O}$ and δD) of glacier ice, river water, and other sources. The obtained isotopic characteristics were used to understand the features of glaciers' origin and to estimate the fractions of different components in runoff using the hydrograph separation equation. It has been shown that the isotopic composition of glacier ice reflects the local conditions of its origin, while the isotopic signature of river water indicates the fraction of various components, such as meltwater from glaciers, seasonal snowmelt, and summer precipitation. Glacier ice in the arid part of Mongolia is isotopically enriched due to higher fraction of summer precipitation in glaciers feeding. The isotopic composition of the upland river's water in summer reflects the dominance of glacier meltwater in runoff. The practical significance of this research lies in the fact that the obtained isotopic data on glacier ice and other components can be used to estimate changes in runoff in Mongolian and Altai rivers during continuous climate change. These results were also used in research on the water balance of potential outburst lakes.

Keywords: Isotopic composition, Altai, glaciers, runoff



THAW-DRIVEN DISINTEGRATION OF AN ACTIVE ROCK GLACIER: A GEOMORPHIC CASCADE MODULATED BY RETROGRESSIVE SLUMPING, DEBRIS-FLOW SEDIMENT EVACUATION, AND FLUVIAL REWORKING

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Recent studies have shown that active rock glaciers may destabilize through a surge in velocity in response to temperature (and/or rainfall) rise. In this contribution we document the recent evolution of Monte delle Mine rock glacier (Italy), where metric annual displacement rates were followed by the rapid disintegration of this landform through a cascade of geomorphic processes. Methods of investigation include: (1) DInSAR analysis performed on multiple sources of satellite SAR acquisitions (ERS-1, ERS-2, ENVISAT, Sentinel-1, TerraSAR-X, COSMO-SkyMed, and SAOCOM), to track rock glacier LOS kinematics across the last three decades (1992–2024); (2) visual interpretation of sequential aerial photos and satellite (SPOT and Pleiades) optical imagery to track morphological changes (1990–2025); and (3) field and UAV SfM surveys (summer and fall of 2024 and 2025), to quantify topographic change (volumes of erosion and deposition) through time. According to DInSAR information the kinematic evolution of the rock glacier may be broadly subdivided into three phases: (i) until 1996 the rock glacier displaces as a coherent unit at $\sim 10\text{--}15\text{ cm/yr}^{-1}$; (ii) between 1999 and 2004, the western lobe starts accelerating to $>35\text{ cm/yr}^{-1}$ and decouples from the rest, which continues moving at $\sim 10\text{--}15\text{ cm/yr}^{-1}$; (iii) in 2017, displacement of the western lobe approaches $\sim \text{m/yr}^{-1}$, until decorrelation associated with thaw slope failure and fluvial incision becomes apparent in 2023 and 2024. Fieldwork, combined with the examination of satellite imagery and UAV-derived orthophoto mosaics allowed complementing InSAR-based information with geomorphic processes. Accordingly, we find that the western rock glacier lobe began displaying morphological signs of destabilization as early as 2018, with lateral levees undergoing transverse downslope displacement and a thermokarst sinkhole developing over the talus-like front. This thermokarst feature, which hosts the spring of the main fluvial stream draining the catchment, has remained about stable throughout 2022, while the rock glacier lobe continued to displace in destabilized fashion. In early September 2023, large thaw slumps developed at the upper end of the rock glacier surface. By early July 2024, the slumps had grown substantially larger and had become directly connected to the thermokarst feature through headward knickpoint migration, thereby triggering a rapid phase of vertical incision and sediment evacuation via fluvial transport and fine-grained debris flows. Part of this material was redeposited to form a debris ramp immediately downslope of the rock glacier front, while the rest reached the confluence with the Rio Spol in the drainage network of the Livigno valley. By early September 2025, the sedimentary ramp located downstream of the former rock glacier front attained substantial stability, while headward migration of the thaw scarps continues. Today, the active rock glacier formerly feeding a fluvial headwater system, has become a chronic source of debris flows, with immediate practical implications for geohazard potential and the water quality of Rio Spol. Ongoing work aims to reconstruct the pre-2023 climatic forcing, to better constrain the conditions that led to this thaw-driven catastrophic evolution.

Keywords: Rock glacier, InSAR kinematics, thaw slumping, debris flow, fluvial incision



SEASONAL KINEMATIC BEHAVIOR OF ALPINE ROCK GLACIERS

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Rock glaciers commonly exhibit seasonal kinematic behavior (SKB). Establishing what SKB is, such as its timing, amplitude, and variability, is essential for understanding and interpreting the interannual kinematic behavior, i.e., Rock Glacier Velocity (RGV), in permafrost assessment. Here we characterize SKB across the Swiss Alps using multi-year observations from 38 permanent GNSS stations on 21 rock glaciers, complemented by bi-monthly GPS surveys, ground surface temperature (GST) records, and meteorological data. We quantify SKB as normalized seasonal deviations from a running annual mean and assess its consistency through time and variability among sites. Across rock glaciers, acceleration and deceleration begin consistently near the onset of ground thawing and freezing, indicating a common thermal control on timing. In contrast, the amplitude of SKB varies strongly among sites, ranging from ~10% to ~150%, highlighting dominant site-specific controls on the magnitude of seasonal response. Within individual rock glaciers, the SKB envelope is repetitive over multiple years with small variances between years. This is expressed as a variable winter deceleration magnitude scaling with the severity of winter ground surface cooling. Seasonal kinematics show no consistent relationship with summer warmth or snowmelt/rainfall during the acceleration phase, arguing against a primary control by surface water supply alone. These observations motivate a targeted mechanistic direction: identifying processes that transmit seasonal surface thermal forcing into changes at the deep shear horizon. Overall, our results consolidate the scientific basis for using RGV in permafrost assessment by showing that SKB is structured and repeatable, while also demonstrating that site-to-site differences in seasonal sensitivity must be accounted for when comparing rock-glacier responses across regions and years.

Keywords: Alpine, rock glacier, RGV



MONITORING OF UNFROZEN WATER AND POREWATER PRESSURE DYNAMICS IN TWO ROCK GLACIERS IN THE EASTERN SWISS ALPS (GRISONS)

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Unfrozen water within permafrost appears to play a critical role in controlling the creep behaviour in a distinct internal shear layer of rock glaciers. To gain better insights into the hydro-thermo-mechanical interactions in the permafrost body, we drilled and instrumented eight boreholes in 2020 and 2024 on two rock glaciers (Schafberg and Muragl, Grisons, eastern Swiss Alps). The two sites experience similar climatic forcing, since they are located close to each other, but differ in their internal structure and ice/water content. This provides a unique opportunity to investigate porewater-pressure dynamics and the role of unfrozen water in controlling deformation in the shear layer in rock glaciers. Borehole stratigraphy was recorded during drilling, and temperature sensors, a deformation chain (at Muragl only), cross-borehole ERT and piezometer sensors were installed to capture high-resolution vertical profiles of thermal, mechanical and hydrological conditions. To characterize the ground properties that determine the potential unfrozen water to persist within the soil across a range of negative temperatures, we analysed water and sediment samples collected during drilling in 2024 at the Muragl rock glacier for grain-size distribution and hydrochemistry. We are monitoring pressurized unfrozen water at the depth of the shear layer. The short-term variation of porewater pressure in the permafrost body combined with deformation measurements and thermal data reveals a seasonal and interannual variation of temperature, porewater pressure and deformation linked to the onset of snowmelt and the thawing of the active layer. This multi-method perspective improves our understanding of the distribution of unfrozen water at negative ground temperatures in rock glaciers. As warming continues to modify the thermal regime and permeability of the permafrost body, improving our ability to quantify porewater-pressure evolution is essential to understand rock glacier creep.

Keywords: Porewater pressure, borehole, rock glacier, dynamics, Switzerland



**3B: MOUNTAIN CRYOSPHERE LANDFORMS IN A WARMING CLIMATE:
ROCK GLACIERS AND BEYOND
POSTER**



CONSTRUCTING ROCK GLACIER VELOCITY TIME SERIES ON THE TIBETAN PLATEAU USING INSAR

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Rock Glacier Velocity (RGV), the annualised surface velocity of rock glaciers, has been recognised as an Essential Climatic Variable for its role in indicating permafrost status. The construction of RGV time series has been ongoing in the European Alps, Andes and High Mountain Asia. However, the relationship between the kinematics of rock glacier on the Tibetan Plateau with climate remains understudied. These rock glaciers are widespread, diverse but difficult to access due to remote and hostile environments and a scarcity of monitoring stations. To reflect permafrost conditions on the plateau using InSAR-derived RGV, we aim to identify multiple basins on the plateau that contain long-running weather stations and abundant rock glaciers. Active rock glaciers with significant InSAR signals are to be selected using geomorphic features on satellite imagery and using InSAR fringe patterns from wrapped Sentinel-1 interferograms. Since velocity products derived from ALOS-2 serve as essential validation data, a temporal span of ALOS-2 shorter than a month, to minimise phase unwrapping errors, is required for basin selection. The initial RGV time series are constructed from 12-day and 24-day interferograms of Sentinel-1 from 2017 to 2024, processed through the ASF Hyp3 service. Unwrapping errors are corrected using a novel, semi-automated approach to restore the moving area and construct reliable velocity products. Distinct responses to temperature and precipitation changes driven by varied mechanisms of rock glacier motions are expected. Since a rock glacier might have surface sections exhibiting different kinematic characteristics, spatial aggregation is applied to find its most representative area of motion. To validate the timeseries, in addition to ALOS-derived velocities, methods including photogrammetry and offset tracking using high resolution satellite can be applied. These enhancements aim to establish clear relationships between rock glacier surface kinematics and temperature changes, providing insights into regional permafrost evolution in a changing climate.

Keywords: Rock glaciers, InSAR, permafrost



GEOMORPHOLOGICAL MAPPING AND INSAR-BASED KINEMATIC CHARACTERIZATION OF ROCK GLACIERS IN THE BARALACHA LA AREA, WESTERN HIMALAYA, INDIA

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In this contribution we present a rock glacier inventory compiled for an area (~680 km²) around the Baralacha La and Shingo (Shinku) La passes, along the border between Himachal-Pradesh and Ladakh states of India. The study area extends across the drainage divide that separates Lahaul and Zaskar regions in the Western Himalaya. Elevation ranges from 3750 m a.s.l. along the Bhaga River floodplain, up to 6111 m a.s.l. of Mount Yunam. Glacier cover currently accounts for about 20% of the mountain terrain. The climate is semi-arid, with mean annual precipitation decreasing northward in Ladakh, as terrain becomes increasingly sheltered from humid, monsoon air flows. From an applied perspective, the area is of critical interest, as it hosts key transportation routes linking the centers of Leh and Zaskar with Manali, including the proposed Leh-Manali Railway line. Methods follow the workflow proposed by the International Permafrost Association Standing Committee on Rock Glacier Inventories and Kinematics (RGIK), and as such combines geomorphological mapping and InSAR-based kinematic characterization of rock glaciers. The kinematic attribute across rock glacier units is derived from 114 Sentinel-1 ascending and descending, snow-free, summer interferograms acquired between 2019 and 2023, with temporal baselines ranging from 12 days to 1 year. The current version of the inventory tallies 304 landforms, of which 205 are classified as rock glaciers and 99 as ‘uncertain’ rock glaciers. Kinematic characterization is restricted to ‘certain’ rock glaciers. Their front elevation spans from 4080 to 5350 m (median 4770 m a.s.l.). Based on 258 InSAR-derived moving areas distributed within the 205 extended outlines, 141 (69%) rock glaciers display LOS (Line Of Sight) kinematics >1 cm yr⁻¹, 58 (28%) exhibit no motion (or LOS kinematics <1 cm yr⁻¹), and 6 (3%) are kinematically undefined. Distinctively from recent work conducted in southwestern South Tyrol (Bertone et al., 2024), no direct increase in rock glacier velocity and MA (moving area) percent cover is observed with elevation (Figure 1). Similarly, active, transitional, and relict rock glaciers display no separation in elevation-aspect space. Ongoing work aims to investigate further the likely reasons for this lack of altitudinal dependence.

Keywords: Rock glaciers, kinematics, elevation-(in) dependence, Western Himalaya



CANROGI: TOWARDS A COMPREHENSIVE NATIONAL ROCK GLACIER INVENTORY FOR CANADA

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Rock glaciers are essential components of the alpine cryospheric continuum, serving as both key indicators of mountain permafrost and hydrological storage. Despite this, they remain poorly and inconsistently mapped across much of Canada's vast alpine regions. While comprehensive inventories exist for several alpine regions globally, Canada lacks a standardised rock glacier inventorying framework at the national level. Our initiative began with a comprehensive literature review of existing maps and datasets, which revealed significant limitations that underscored the pressing need for a unified and more standardised approach. To address this gap, we developed the Canadian Rock Glacier Inventory (CanRoGI) initiative, which is the first coordinated, nationwide inventory of rock glaciers in Canada. The initiative follows the Rock Glacier Inventory and Kinematics (RGIK) Standing Committees (BPC v1.0) guidelines, leveraging high-resolution imagery and digital elevation models to identify and classify rock glaciers. Crucially, CanRoGI also documents Geomorphic Features of Interest (GFIs) along morphological and activity continuums, seeking to capture the transitional stages between glacier-ice-cored and ice-cemented landforms, as well as their evolution from active to relict states. Current work is inclusive of regions such as Western Canada and the Canadian Arctic, where rock glaciers remain largely undocumented, and the initiative is expanding across all Canadian alpine regions. The resultant CanRoGI dataset will support interferometric SAR (InSAR) time-series analysis and enable future assessments of kinematic activity, permafrost stability/hazards, hydrological investigations, and long-term landscape evolution. It will also significantly contribute to international efforts to standardise and compare rock glacier dynamics in the context of their response to climate change, as well as their role as an Essential Climate Variable Quantity for Permafrost.

Keywords: CanRoGI, Canada, Rock Glacier, Inventory



INTRA-SEASONAL VARIATION IN WATER TEMPERATURE, ELECTRICAL CONDUCTIVITY, AND ISOTOPIC COMPOSITION ACROSS TWO PERIGLACIAL CATCHMENTS IN THE SWISS ALPS

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The hydrology of alpine catchments is shaped by variable contributions from diverse landforms and land covers, such as glaciers, rock glaciers, moraines, talus slopes, and meadows. These landforms influence both the water storage capacity and the timing and magnitude of water release. However, the hydrological processes in rock glaciers and other periglacial landforms, as well as their interactions with groundwater, remain poorly studied. Therefore, this study investigates the influence of different landforms on the hydrology of two neighboring Alpine catchments in the Upper Engadine, Switzerland: Val Muragl and Val Champagna. The main objectives are to (1) characterize the physical and chemical characteristics of water coming from the different landforms in the two catchments, (2) assess the diurnal and intra-seasonal (between July and October 2025) variations in the flow coming from these landforms, and (3) estimate the relative contribution of the different landforms to streamflow further downstream. For this, we measured the water temperature, electrical conductivity (EC), and the abundance of the stable isotopes of hydrogen and oxygen for 25 sites, including water coming from one active rock glacier in each valley and a moraine complex associated with the former Muragl glacier, a lake, and the main river, at a bi-weekly interval. The preliminary results show that the discharge from the rock glaciers and parts of the moraine complex is constantly cold. In contrast, the temperature of water from the other sources in the catchment varies much more. This suggests that portions of the moraine complex still contain ice. The EC was higher for water from the rock glacier and the adjacent scree slopes than for the other sources, indicating older water and/or more intense water-rock interaction in these landforms. The EC increased over the summer and decreased after rainfall events, indicating dilution during rainfall events, with varying diurnal patterns. These findings enable clear differentiation of water from different landforms, especially permafrost-related landforms, and highlight the role of periglacial landforms in controlling both the timing and chemical signature of downstream river discharge. The analysis of the stable isotope data will provide a deeper insight into the hydrological processes within the different landforms and the role of periglacial landforms in shaping Alpine hydrology. In addition, a potential relationship between borehole measurements, i.e. ground temperature and pore water pressure, in the Muragl rock glacier and its discharge will be assessed.

Keywords: Rock glacier, permafrost hydrology, landforms



TOWARDS QUANTIFYING ICE CONTENTS IN MOUNTAIN PERMAFROST ENVIRONMENTS

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In its special report on Ocean and Cryosphere in a Changing Climate (SROCC) from 2019, the Intergovernmental Panel on Climate Change (IPCC) highlights clear knowledge gaps concerning the extent and ice content of permafrost in mountain regions. Assessing ground ice reserves and their changes under a changing climate is important due to implications for, among other factors, mountain biodiversity, geohazards, and water resources. Not least due to their invisibility below the surface and difficult measurement, it is too little known where and how large these water resources are, how they could evolve in the future, and what the potential consequences could be for the surrounding ecosystems and communities. We present results from a study in the Nordic Arctic on the distribution of mountain permafrost, including an improved understanding of its characteristics and an estimation of the ground ice reserves in mountainous regions, presently and under climate scenarios. Concretely, we explore the feature space of mountain permafrost using a range of statistical and machine learning techniques in an uncertainty-aware setting. This feature space consists of topographic and climatic parameters such as topographic masks, elevation models, potential incoming solar radiation, seasonal ground temperatures and snow accumulation. We combine these features with existing inventories of rock glaciers, as these are one of the few visible indicators of mountain permafrost, and in addition particularly ice-rich. Based on such datasets we create a data-driven model to predict the probability of potential rock glacier occurrence as a first estimate of ground ice content. To assess how well such models generalize for regional estimates, we compare predictions and model performance across mainland Norway, Svalbard, and Iceland, thereby evaluating transferability. We further investigate the vulnerability of potentially ground-ice rich areas under climate change by forcing the models with outputs from climate models under multiple emissions scenarios, producing scenario-dependent projections of changes in the likelihood and distribution of potentially ground-ice rich terrain.

Keywords: Mountain permafrost, rock glaciers, distribution modelling



TESTING THE SENSITIVITY OF GROUND ICE PERSISTENCE UNDER VARIOUS UNFAVORABLE CLIMATE CONDITIONS AND GROUND ICE CONTENT WITH NUMERICAL MODELING

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Over the past years, several slope failures revealing ground ice in their scar have occurred in mountain areas where permafrost maps were suggesting low permafrost likelihood. In mountain environment, the thermal offset (i.e. the temperature difference between mean annual ground surface temperature (MAGST) and temperature at the top of permafrost (TTOP)) is hardly quantified. Therefore, unlike lowland permafrost whose maps are based on TTOP, mountain permafrost maps generally represent surface conditions either through a 30-year MAGST, or on permafrost indexes based on the probability of negative MAGST or of creeping landforms to be active. Assessment of permafrost conditions using these maps generally require expert knowledge to interpret the potential permafrost presence against ground condition. While interpretation of these maps for predicted negative MAGST or high index values (> 0.5), is relatively straightforward (permafrost is present in most cases), interpretation of positive MAGST or low index values (< 0.5), revealing unfavorable climate conditions to its presence, is trickier. This difficulty constitutes a real challenge to identify potentially hazardous areas. The existence of permafrost in unfavorable climate conditions is mostly the result of local ground conditions allowing the persistence of permafrost and/or ground ice due to cooling factors. Air circulation such as in scree material is for example a well-known cooling factor, yet still poorly quantified due to the strong heterogeneity of its effect depending on scree porosity, gravitational forces (slope) and strong lateral and vertical temperature gradients. But beyond this near-surface cooling factor, the amount of ground ice is also a key factor of its persistence under unfavorable climate. The greater the ice content, the greater the delay to air temperature signal and the longer ground ice persistence under fairly positive MAGST. In this study, we investigate the relationship between predicted MAGST and ground ice persistence under various ground ice content and distribution scenarios. To do so, we run 1D to 2D heat transfer models forced with various ground surface temperature (GST) time series at daily time-steps (over > 60 years) corresponding to various positive 30-year MAGST (up to 5°C). For those various GST scenarios, we also set up various ground ice scenarios from the near-surface to 100 m depth: ice content from 5% (ice-poor, rockwalls) to 60% (ice-rich, rock glaciers) and homogeneous to heterogeneous (ice layers) distributions. We analyse under which MAGST and ground ice conditions ice persists at different depth among the different models we use. Despite the lack of consideration of complex heat transfers such as air circulation, the results will contribute to a better interpretation of permafrost maps and to identify areas where relict ice potentially persists at depth under unfavorable climate conditions.

Keywords: Mountain permafrost, permafrost map interpretation, ground ice content and distribution, heat transfer modelling



DETERMINATION OF THE ANNUAL ABLATION OF THE DOLOONNUUR GLACIER ON MT. MUNKHKHAIRKHAN USING THE DEGREE-DAY MODEL

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Mongolia is among the ten countries most vulnerable to global warming and climate change. Mid-term observations from the western region indicate that mean annual air temperature increased by 2.08 °C between 1940 and 2017, exerting a strong influence on glacier melt and area shrinkage in high mountain regions. This study estimates the annual melt of the Doloon Nuur Glacier, located on Munkhkhairkhan Mountain in the Mongolian Altai, using a degree-day model (DDM) and evaluates the results against in situ stake measurements. Air temperature data recorded by an automatic weather station between 15 June 2023 and 15 June 2024, together with ablation stake measurements installed on 15 June 2023, were used in the analysis. The cumulative positive degree days (PDD) amounted to 844.8 °C·day over the study period. Applying a degree-day factor of 6.0 mm w.e. °C⁻¹ day⁻¹, the calculated annual melt reached 5.06 m in the lower glacier zone, 4.2 m in the middle zone, and 3.1 m in the upper zone, with a glacier-wide mean of 4.1 m. The modeled melt shows good agreement with the observed mean stake ablation of 3.6 m, with a difference of 0.5 m, supporting the reliability of the degree-day approach for this region. Between 2023 and 2024, the glacier ablation area decreased by 5.3 ha (≈ 5%), corresponding to an estimated ice volume loss of $2.18 \times 10^5 \text{ m}^3$, indicating a clear and measurable impact of climate change on glaciers in the Mongolian Altai. These results demonstrate that temperature-based modeling provides a robust framework for assessing glacier mass loss in Mongolia and offer a valuable data foundation for long-term glacier mass-balance monitoring and climate-change impact assessments in data-scarce mountain regions.

Keywords: Glacier melt, Degree-Day Model



ROCK GLACIER DYNAMICS IN THE SWISS ALPS (RODYNALPS): A COLLABORATIVE RESEARCH PROJECT COVERING DIFFERENT SPATIO-TEMPORAL SCALES

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Past multi-decadal observations in the European Alps have shown that the kinematic behaviour of active rock glaciers has tremendously accelerated, sometimes culminating in phases of destabilization. Simultaneously, some rock glaciers have decelerated. Our current understanding of the permafrost creep process driving rock glacier dynamics - in particular, those driving the deformation occurring in the shear horizon at depth, usually the major contributor to the observed surface displacement rates - is not adequate to explain all observed changes. Within the RoDynAlps project, funded by the Swiss National Science Foundation, we investigate this deformation process at different spatio-temporal scales. Based on up to thirty years of detailed monitoring of rock glaciers in the Swiss Alps, we selected a restricted number of landforms for further investigation. A systematic regional assessment of rock glacier morphology and kinematics offers the opportunity to evaluate the significance of the selection and to detect suitable sites for the reconstruction of multi-decadal time-series using historical aerial photographs. Here, we present the current results of the RoDynAlps project after two years of investigation. So far, out of 7500 identified rock glaciers, we have completed a kinematic assessment for 4900 landforms using InSAR data from the Sentinel-1 and SAOCOM satellites acquired between 2020 and 2023, together with a set of multi-date aerial orthophotos from swisstopo. Among these landforms, 200 have been detected as displaying surface displacement rates equal to or exceeding one meter per year. A further 1000 landforms show creep rates of the order of several decimeters per year. The remaining 1200 are in a transitional kinematic state and characterized by low creep rates, with annual displacement rates lower than 10 cm. To characterize the relation between rock glacier kinematics and air temperature evolution on a multi-decadal timescale, we systematically explored the swisstopo archival orthophotos and high-resolution Digital Surface Model (DSM), and co-registered and harmonized them into a consistent dataset. The resulting DSMs and orthophoto time series allow the reconstruction of horizontal displacement fields and vertical elevation changes, producing a robust, multi-decadal baseline for investigating the development of the kinematic behaviour of selected active rock glaciers since the 1950s. On a local and shorter-term timescale, existing high temporal-resolution GNSS measurements reveal characteristic seasonal kinematic behaviour, with an acceleration linked to snow melt season and continuing to develop until fall. We drilled boreholes in two rock glaciers (max. depth 25 m) with different morphological settings and kinematic behaviour and one borehole with a permanent inclinometer chain and both sites with porewater pressure sensors, temperature sensors, and a surface GNSS system to identify the seasonality of deformation at depth. High year-round unfrozen water content has been detected in distinct layers within the frozen rock glacier body and in the shear horizon. A lack of seasonality in temperature in the shear horizon highlights the influence of seasonally varying liquid water content on the rock glacier kinematic behaviour. This is the first time that a multi-method and multi-scalar approach has been applied to determine the factors driving rock glacier kinematics in the European Alps.

Keywords: RoGI, dynamics, boreholes, photogrammetry, GNSS



FORMATION CONDITIONS OF SLUSHFLOWS

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Slushflow is a sudden and rapid collapse of water-saturated snow masses from gentle slopes and their movement along talwegs taking place during snowmelt periods (Bozhinsky, 2001). As a result of global warming, which is accompanied by increased precipitation, rising temperatures, shorter periods of snowmelt - the amount of slushflows is expected to increase (D'Amboise, 2024). Lack of clear slushflow classification complicates their study and monitoring. Also, this makes difficult selection of required protection measures for existent or planned infrastructure (Hansen, 2024). Attempts to reduce risk and prevent damage from slushflows require considering of a relationship between the formation conditions of slushflows and their socioeconomic consequences (Relf, 2015). Slushflows are recorded less frequently than snow avalanches. This can be related to significantly shorter formation period relative to those of the snow avalanches and debris flows and to specific nature of their propagation. In absence of clear classification, not all slushflows are identified as them. For example, 238 from thousands records in USSR Avalanche Inventory (1984-1991) for the period between 1969 and 1989 match characteristics of slushflows, but no one is named so. The goal of the research is to analyze the climatic and geomorphological conditions resulting in slushflows formation, their geographical extent, their dynamical characteristics and to construct classification suitable for slushflow risk management.

Keywords: Slushflows



3C: MOUNTAIN PERMAFROST MAPPING AND RISK ASSESSMENT: INSIGHTS FROM REMOTE SENSING AND GROUND-BASED OBSERVATIONS

Conveners: Pema Eden¹, Nadine Salzmann^{2,3}, Cécile Pellet³, Sonam Lhamo⁴, DB Gurung¹ & Rebecca Gugerli⁵

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Mountain permafrost is rapidly degrading, with critical implications for slope stability, water security, and hazard exposure. This session showcases remotesensing workflows (e.g. MODIS LST, NDVI, snow cover, albedo, SRTM) and groundtruthing with temperature loggers to generate highresolution probability maps across diverse mountain regions. We welcome applications of these mapping products for risk assessment, earlywarning systems, and adaptation planning in both the Himalaya and other alpine settings.





PHYSICALLY INFORMED MACHINE LEARNING FOR PERMAFROST STABILITY MAPPING IN CENTRAL MONGOLIA: LEVERAGING INSAR AND DOWNSCALED THERMAL REGIMES

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Ground deformation rates are critical indicators for evaluating permafrost stability and degradation. However, field monitoring in the Mongolian Plateau is often constrained by challenging terrain and limited accessibility. Although time-series Interferometric Synthetic Aperture Radar (InSAR) is widely employed to monitor deformation, its effectiveness is frequently compromised in areas affected by geometric distortions or low coherence. To address these limitations, this study proposes a physically-informed machine learning framework combining InSAR with Random Forest (RF) modeling to map permafrost stability in the Chuulut River valley, central Mongolia. First, Small Baseline Subset (SBAS) InSAR techniques were utilized to analyze surface deformation using 85 scenes of Sentinel-1 remote sensing imagery acquired between 2018 and 2021. Second, to bridge the pervasive scale gap between regional climate and local terrain, a statistical downscaling model was developed to refine coarse-resolution thermal indices (1 km) to a 30-m resolution. By establishing a regression relationship between regional thermal indices and high-resolution predictors (elevation, potential incoming solar radiation, and NDVI), we generated topographically consistent 30-m thermal regimes. Twelve conditioning factors were incorporated into the final stability model, including the downscaled thermal indicators (Degree-Day of Thawing and Degree-Day of Freezing), Potential Incoming Solar Radiation, geomorphological variables (elevation, slope, northness, and profile curvature), hydrological and biological proxies (Topographic Wetness Index, NDVI, and Normalized Difference Moisture Index), and disturbance factors (distance to water bodies and roads). Furthermore, the relative importance of these factors was evaluated using Mean Decrease Gini and Mean Decrease Accuracy indices, which identified elevation and downscaled summer thawing intensity as the most significant determinants. In addition, the critical thresholds of these environmental factors were analyzed to identify the specific ranges conducive to permafrost stability. Third, the trained RF model was applied to generate a comprehensive 30-m permafrost stability map. Crucially, this approach successfully predicted stability conditions in regions where InSAR data were unavailable, providing a robust, continuous, and physically consistent assessment tool for permafrost evolution in data-sparse regions.

Keywords: Permafrost stability; SBAS-InSAR; Machine learning.



LONG-TERM INSAR AND STREAMFLOW RECESSION ANALYSIS REVEAL HUMAN ACTIVITIES ACCELERATED PERMAFROST DEGRADATION IN QILIAN MOUNTAIN

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Permafrost underlies about 40% of the Qinghai-Tibet Plateau (QTP), where climate warming and human activities increasingly threaten fragile alpine ecosystems, necessitating long-term permafrost monitoring. Interferometric Synthetic Aperture Radar (InSAR) enables precise detection of thaw-induced surface deformation, while streamflow recession helps reveal subsurface hydrological changes with permafrost degradation. This study performed a first-time joint analysis of decades-long InSAR surface deformation and streamflow recession to assess the trajectory of permafrost degradation in the source region of the Datong River, Qilian Mountain, an area covering $\sim 4,576 \text{ km}^2$ in the northeastern QTP region and subject to intensive mining during the 2000s and early 2010s. A data-constrained Small Baseline Subset (SBAS) method was proposed to improve the Sentinel-1 C-band deformation retrievals through integrating a linear-periodic temporal constraint model and using concurrent ALOS-2 retrieved deformation rate as a reference. A consistent long-term (1997-2023) deformation dataset was then generated through combining multi-sensor C- and L-band SAR retrievals. The results reveal minimal surface deformation before the mining, followed by sustained ground subsidence (-15 to -5 mm a^{-1}) and enhanced seasonal deformation (~ 20 - 60 mm) during and after mining, indicating accelerated permafrost degradation. This acceleration coincides with a marked slowdown in the post-mining streamflow recession rate derived from daily discharge data of the upper Datong River, likely driven by thaw-induced increases in basin subsurface water storage and flowpath connectivity. The concurrent increase in surface subsidence and streamflow recession time constant during the mining and post-mining period provides strong evidence of widespread permafrost degradation driven by anthropogenic disturbances. The accelerated permafrost degradation trends revealed by the integrated analysis of InSAR deformation and hydrological data underscore the long-lasting impacts of human activities on permafrost environments and highlight the potential permafrost ecosystem vulnerability under continued strong warming trends in the alpine region.

Keywords: InSAR, deformation, permafrost degradation, recession



RISK ASSESSMENT OF POTENTIAL GROUND ICE CONTENTS IN THE PERMAFROST REGION OF MONGOLIA

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Mapping of ground ice distribution at regional and global scales remain major challenge. Under a warming climate, thawing of ice-rich permafrost possibly triggers various thaw-induced hazards, which include extensive thermokarst development, ground-surface subsidence, and thaw settlement. These processes pose substantial risks in engineering infrastructure, i.e., damaging roads and buildings, leading to economic losses and environmental degradation. In Mongolia, risk assessments across continuous and discontinuous permafrost zones are particularly critical due to the high sensitivity of degradation of ice-rich permafrost. To address this, we applied the Random Forest (RF) model to predict the spatial distribution of potential ground ice contents. The model was trained with compiled ground ice content data acquired from on-site observations that have been maintained by the Institute of Geography and Geoecology (IGG) since 1968. We referred to archival records of 37 boreholes from the Circumpolar Active Layer Monitoring (CALM) program and 62 boreholes from the internal reports of the Division of Permafrost Research, IGG. To increase the number of data in the Altai and Khentii mountains, we incorporated ground ice content from 13 additional boreholes through Electrical Resistivity Tomography (ERT) surveys into the analysis. The model considered 14 environmental variables, and model accuracy was assessed by comparing the predicted ground ice content with measurements from 14 ERT profiles that were used only for model testing. Permafrost risk was considered to be the arithmetic mean of the predicted ground ice content and permafrost distribution. The trained model demonstrated strong predictive performance, showing a root-mean-square greater than 0.72. Also, validation with the test set of ERT data revealed a correlation of 0.90 (i.e., 90% of prediction accuracy). The areal extent of the highest ice content underlies approximately 7,142.1 km², and very high-risk permafrost zones are mainly concentrated in the northern Khuvsgul mountains and a small part of the Khangai mountains. Based on the permafrost risk assessment, approximately 34-37% of Mongolia's permafrost regions are classified as high-risk. Consequently, when planning future activities such as the construction of engineering structures and roads, it is important to implement measures to prevent or mitigate permafrost thaw. Overall, this study presents the first detailed, field-validated regional map of potential ground ice content in Mongolia, providing essential baseline data for assessing ice content and permafrost risk in this climate-sensitive region.

Keywords: Permafrost, ground ice content, risk, Mongolia



ASSESSMENT OF GLOBAL PERMAFROST MODELS AND ENSEMBLE MACHINE LEARNING FOR HIGH-RESOLUTION PERMAFROST MAPPING IN BHUTAN

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The distribution of permafrost in Bhutan and the eastern Himalaya remains poorly constrained due to sparse ground observations, complex topography, and strong spatial variability in climatic controls, leading to uncertainty for cryosphere research and mountain hazard assessment. This study presents the first high-resolution (12.5 m) probabilistic permafrost map for Bhutan based on a locally calibrated, multi-model ensemble approach. Predictor variables were derived from an ALOS digital elevation model, downscaled Landsat-based land surface temperature (LST), snow proxies, terrain indices, and national soil datasets. A comprehensive rock-glacier inventory comprising more than 1,900 points were used as a proxy for permafrost occurrence and served as the basis for model training and independent testing. The complementary modelling techniques Generalized Linear Models (GLM), Generalized Additive Models (GAM), Random Forest (RF), and Extreme Gradient Boosting (XGBoost), were implemented to capture linear, nonlinear, and interaction effects between environmental predictors and permafrost presence. Model performance was evaluated using independent test data and multiple metrics, including area under the curve (AUC), precision-recall AUC, sensitivity, specificity, and the True Skill Statistic (TSS). Among individual models, XGBoost showed the highest predictive performance (AUC = 0.93), while all models achieved strong discriminatory ability (AUC > 0.86). A performance-weighted ensemble, based on TSS-derived model weights, further improved robustness and spatial consistency, yielding an overall AUC of 0.91 and TSS of 0.68 on independent test data. For contextual comparison, five widely used global permafrost products were evaluated against the same local test dataset. These global models exhibited substantial variability in predicted permafrost extent when thresholded, ranging from 137 km² to 4,034 km², whereas the locally derived ensemble produced a more spatially coherent and plausible estimate of approximately 2,674 km². Spatial disagreement analyses highlight transitional elevation zones and lower-elevation margins as key areas of uncertainty. Overall, this study demonstrates the value of locally calibrated, ensemble-based modelling for improving permafrost mapping in data-scarce, high-mountain regions and provides a critical baseline for future cryosphere monitoring and infrastructure risk assessment in Bhutan.

Keywords: Bhutan, permafrost, rockglacier, permafrost models



SPATIOTEMPORAL VARIABILITY OF GIANT AUFEIS IN THE NORTHEASTERN EURASIA

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The spatiotemporal variability of aufeis is influenced by physical-geographical factors included geocryological conditions and also climate change. Identifying the direction and magnitude of changes in the intensity of aufeis processes makes it possible to detect and forecast trends in the evolution of geocryological conditions within specific geographical clusters. This study presents the results of determining the actual maximum areas of 437 giant aufeis (area > 5 km²) in Northeast Russia (Fig. 1). Area estimates were derived using the Normalized Difference Snow Index (NDSI) applied to Landsat imagery



Fig. 1

for the periods 1973-1975 and 2007-2013, and Sentinel-2 imagery for 2020-2025. As an archival reference, the Cadaster of Aufeis of Northeast Russia (1958) was used, which contains morphometric characteristics of aufeis clearings obtained through interpretation of aerial photographs. The areas obtained from satellite imagery were, on average, 55% smaller than the total areas of aufeis glades reported in the Cadaster (1958). For aufeis covered by satellite imagery for all observation periods, the difference between the actual aufeis area and the area of aufeis glades exceeded a factor of two. These results demonstrate that assessing aufeis extent based on the size of aufeis glades is incorrect. The dataset includes 39 aufeis for which area information is available in the Cadaster (1958) but which show zero area values for one or more observation periods. Among them, 19 aufeis glades are characterized by dense vegetation, which is atypical for aufeis glades associated with intensive aufeis processes. Most aufeis in this group are located within the Penzhina River basin and the Kolyma Highlands in the Magadan region. The decrease of total ice area for all aufeis was estimated as 5.4% over 60 years. To assess spatial variability, Moran's I index was applied, along with a formal grouping of aufeis according to their general change trends. In total, seven clusters were identified based on differences between aufeis areas and aufeis glades reported in the Cadaster (1958). An additional eight clusters were identified when assessing changes across the three observation periods. The most significant cluster, demonstrating a pronounced decrease in aufeis area over time, is located in the Verkhoyansk Range, where the reduction reached 65%. Financial support: The research was funded by the Russian Science Foundation (project No. 25-77-10033).

Keywords: Climate change, aufeis, remote sensing



PERMACLIM 2.0: AN UPDATED MODEL FOR MAPPING PERMAFROST CONDITIONS IN MOUNTAIN REGIONS

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In the current climate change scenario, it is increasingly important to evaluate mountain areas potentially at risk in an efficient and rapid way. Permafrost is one of the main factors determining surface stability in cold regions. The monitoring network of ground surface thermistors in the Italian Alps is limited to some small areas and in several cases the data and metadata are not of easy access. Therefore, modeling is a valid alternative for the prediction of the ground surface temperature (GST). PERMACLIM is a physics-based model, that can predict the GST using easily accessible input data, commonly measured by the Automatic Weather Stations (AWS) located in the Italian Alps, such as air temperature (T_a) and snow depth (HS). The model requires also a digital elevation model (DEM) for the calculation of the topographic features. PERMACLIM 2.0 is the new version, which presents several updates concerning mainly: 1) the use of AWS belonging to the same pluviometric region, 2) an improved temporal resolution to better catch the rapid changes on snow depth, 3) the snow modeling with renovated empirical factors for the simulation of avalanches phenomena, wind transport and snow melting, 4) the calculation of the snow properties like density and thermal conductivity and 5) a radiative correction factor for the calculation of the GST during the summer snow-free period. The model was tested for the hydrological years 2020 and 2022, on the entire upper Valtellina, returning results with a spatial resolution of 10 m. The MAGST maps were reclassified to detect permafrost conditions (Fig. 1) in terms of presence, probability, possibility and absence of permafrost aggradation. Permafrost conditions were absent for the 67.8%, possible for the 8%, probable for the 17.9% and present for the 6.2%. Permafrost aggradation never occurred below 2400 m a.s.l. and above 3500 m a.s.l. permafrost could form in all conditions. The good results obtained suggest using PERMACLIM 2.0 as a new tool to determine permafrost conditions throughout the Italian Alps.

Keywords: Permafrost conditions, mapping, modeling, MAGST

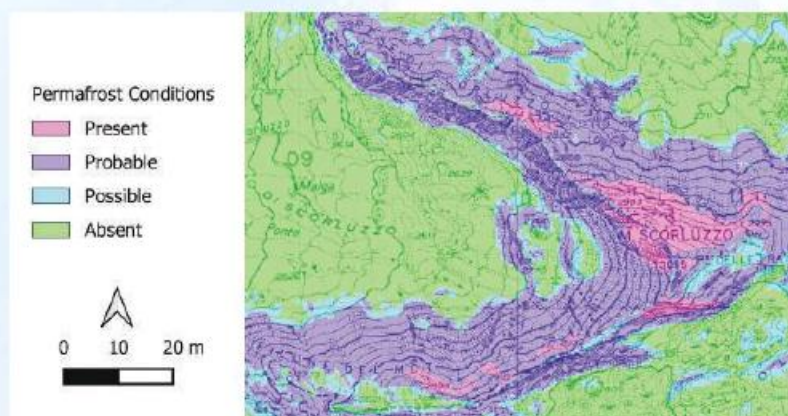


Fig. 1



STORYLINE-BASED PROJECTIONS OF PERMAFROST THAW SUBSIDENCE AND RISKS TO ARCTIC INFRASTRUCTURE

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Permafrost thaw is accelerating global scale warming, with profound implications for Arctic landscape and ecosystems. Consequently, human infrastructure built on permafrost is subject to risk under current projections of warming. Here we present high-resolution (0.1°) projections of Arctic permafrost extent and thaw-driven ground subsidence using the CTSM-EXICE land model forced by four regional climate simulations following the SSP3-7.0 scenario. The simulations represent two contrasting climate storylines: a weaker Arctic amplification (ArcAmp+, NorESM-forced) and a stronger warming pathway (BKWarm+, CNRM-forced). Model robustness was evaluated using multiple atmospheric, soil, and ecosystem variables before focusing on permafrost extent and subsidence impacts. We analyzed permafrost extent using two complementary definitions: soil temperature below 0°C at 3 m depth and an active layer thickness not exceeding 3 m. Across the ensemble, Arctic permafrost area declines consistently toward global warming levels of approximately $2.8\text{--}3.7^\circ\text{C}$ by the end of the century (2070-2099), with a mean reduction of $6.73 \times 10^6 \text{ km}^2$. Faster degradation is projected under the stronger warming BKWarm+ storyline. The lowest mean Arctic permafrost extent across simulations is approximately $3.4 \times 10^6 \text{ km}^2$, consistent with recent CMIP6-based estimates while providing substantially higher spatial resolution. Projected permafrost thaw is accompanied by substantial ground subsidence, particularly in subregions between 60° and 70°N , which are among the most populated and economically significant parts of the Arctic. Ensemble mean subsidence by the end of the century ranges from several centimeters to over 1 m, with localized maxima exceeding 1.5 m in northern Canada and northeastern Siberia. Subsidence accelerates markedly once global warming levels exceed $\sim 2^\circ\text{C}$. To support adaptation-relevant assessments, we further analyze subsidence projections for 12 Arctic cities in northern North America and Asia identified as highly vulnerable to permafrost degradation. Several cities exhibit subsidence levels exceeding thresholds associated with high infrastructure risk. All CTSM-EXICE simulations used in this study are publicly available, providing a consistent, high-resolution foundation for future impact assessments and policy-relevant analyses of Arctic permafrost change.

Keywords: Subsidence, infrastructure, storylines, high-resolution projections



**3C: MOUNTAIN PERMAFROST MAPPING AND RISK ASSESSMENT:
INSIGHTS FROM REMOTE SENSING AND GROUND-BASED
OBSERVATIONS
POSTER**



SPATIAL DISTRIBUTION OF SOIL ORGANIC CARBON AND PEATLAND IN MONGOL ALTAI AND GOBI-ALTAI MOUNTAINOUS REGIONS

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Mongolia is the fifth-largest country by permafrost area, contributing significantly to the global permafrost carbon cycle. However, current estimates of soil organic carbon (SOC) data and peatlands in Mongolia have limited accuracy, creating significant uncertainty in projecting SOC pools and their feedback to climate change. Here, based on 198 soil samples and 19 environmental variables, we modeled and mapped the 0-30 cm SOC distribution in the Mongol Altai and Gobi-Altai regions using three machine learning algorithms: Random Forest (RF), eXtreme Gradient Boosting (XGB), and Gradient Boosting Regression (GBR). Model performance assessment showed that RF outperformed the other algorithms, providing the highest accuracy in both training and testing datasets. Air temperature, precipitation, MSAVI, and elevation consistently emerged as the most important predictors. The results indicated that within permafrost zones, SOC content ranged from 0.9% to 20.7%, with a mean of 5.7%. SOC content within permafrost areas was higher than in seasonally frozen ground, which has a mean SOC content of 1.6%, highlighting the greater accumulation of SOC in permafrost-affected soils. The peatland area covers 4,316 km², or 1.5% of Mongol Altai and Gobi Altai's territory. These findings provide valuable data for the Mongolian mountainous regions and enhance our understanding of SOC and peatland distributions, as well as their controlling factors, in this high-latitude, high-altitude permafrost region.

Keywords: Soil organic carbon, peatland, mapping



PATTERNS OF ICING DEVELOPMENT WITHIN THE ALDAN-TIMPTON WATERSHED (SOUTHERN YAKUTIA, RUSSIA)

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Icings are a typical indicator of groundwater presence in permafrost regions. The Southern Yakutia territory is actively developed. Icing hazard here along linear infrastructure (highway, railroad, pipelines etc.) takes place. Patterns of icing development and distribution for better understanding of icing control approach should be estimated. Based on the interpretation of Landsat 5 and 8 satellite imagery for the period 2005-2025, icings (aufeis) within the Aldan-Timpton watershed have been delineated. A total of 854 icings were identified, with a total areal extent of 363.7 km². The icing belt of the study area is situated within the elevation range of 260 to 1260 m a.s.l. The highest concentration of icings in the 340-580 m a.s.l. (30%) and 600-940 m a.s.l. (50%) intervals is observed. This distribution is attributed to the extensive development of the river network within these elevation ranges, the highest topographic gradients, and the discontinuous distribution of permafrost. Above 1000 m a.s.l., the subalpine and alpine belts prevail. Permafrost is ubiquitous here, and groundwater feeding the icings discharges along tectonic faults. Icings developing below 600 m a.s.l. are located in the valleys of the largest streams. Discharge of icing-forming groundwater in these areas also occurs primarily through fault zones. No direct correlation between the total number of icings and the dynamics of groundwater or climatic parameters was found.

Keywords: Icing, permafrost, groundwater, Landsat imagery



HOW DO ROCK AND DEBRIS SURFACE TEMPERATURES DIFFER ON INTERMEDIATELY-STEEP ALPINE PERMAFROST SLOPES?

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Warming permafrost in the European Alps is increasing slope instabilities, posing a growing hazard in this densely populated region. Accurate knowledge of permafrost distribution is therefore essential. While steep rock faces ($>70^\circ$) and gentle debris-covered slopes ($<37^\circ$) are relatively well studied, intermediately steep slopes ($38-70^\circ$) remain poorly understood despite covering a substantial proportion of Alpine terrain ($\approx 1400 \text{ km}^2$, $\sim 30\%$ of the area above 2500 m a.s.l. in Switzerland). Their complex topography generates strong spatial variability in solar radiation, snow cover, debris thickness, and bedrock fracturing, which strongly influence ground surface temperatures. Our project addresses this knowledge gap by investigating permafrost at six sites in the Swiss and French Alps, all dominated by intermediately steep slopes: Mont Fort (3329 m a.s.l.), Mont Gelé (3023 m a.s.l.), Pointes du Mourti (3563 m a.s.l.), Cabane de la Dent Blanche (3500 m a.s.l.), Schafbärg (3240 m a.s.l.), and Bellecôte (3050 m a.s.l.). These sites span a range of elevations, lithologies, and topographic configurations. Our data acquisition strategy includes 46 rock surface temperature (RST) and 49 debris surface temperature (GST) sensors. Mean annual rock and debris surface temperatures (MARST and MAGST) derived from 23 RST and 30 GST sensors between 26.07.2024 and 25.07.2025 range from -3.6 to $+4.4^\circ\text{C}$ between 2735 and 3522 m a.s.l. (Fig.1). Aspect-related contrasts are pronounced for RST. At Pointes du Mourti, the difference between MARSTs in south and north slopes ($\Delta\text{TS-N}$) of similar altitudes is 7.50°C . Considering all the sites between 2975 and 3300 m a.s.l., $\Delta\text{TS-N}$ MARST is 2.82°C , increasing to 5.12°C between 3150 and 3550 m a.s.l. This dependence is weaker for GST, with $\Delta\text{TS-N}$ MAGST of 1.38°C between 2975 and 3300 m a.s.l. Furthermore, MAGST is consistently cooler than MARST, particularly in sun-exposed aspects (110° - 250°), where $\Delta\text{TMARST-MAGST}$ reaches 3.38°C between 3200 and 3350 m a.s.l. This is due to both prolonged snow cover and the insulating effect of blocky, porous surface layers on debris-covered slopes. In shadier aspects (290° - 70°), $\Delta\text{TMARST-MAGST}$ decreases to 0.46°C between 3000 and 3150 m a.s.l. These results demonstrate highly heterogeneous ground surface temperatures, underscoring the need for dense, site-specific measurements to accurately characterise permafrost in complex Alpine terrain.

Keywords: Alpine, rock & debris surface temperatures



MONITORING ARCTIC CRYOSPHERE CHANGE USING INTERFEROMETRIC SYNTHETIC APERTURE RADAR: PROGRESS, APPLICATIONS, AND CHALLENGES

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The Arctic cryosphere is undergoing rapid and widespread changes in response to global warming, with profound implications for regional environments and the global climate system. Continuous and quantitative observation of key cryospheric components including glaciers, permafrost, snow cover, sea ice, lake ice, and river ice is therefore essential. Owing to its all-weather, day-and-night observation capability and sensitivity to surface geometry and dielectric properties, interferometric synthetic aperture radar (InSAR) has become a cornerstone technique for cryosphere monitoring in high-latitude regions. This review provides a systematic synthesis of the development and application of InSAR for monitoring changes in the Arctic cryosphere. We first summarize the evolution of SAR satellite missions and InSAR-derived digital elevation models that underpin cryospheric observations. We then review major application domains of InSAR, including glacier motion and elevation change, permafrost surface deformation, snow depth and structural variations, thickness changes of sea ice, lake ice, and river ice, as well as grounding-line detection of marine-terminating glaciers. The applicability of different SAR frequency bands is discussed in a general sense, highlighting how wavelength-dependent scattering and penetration characteristics influence InSAR performance across distinct cryospheric elements. For each application, the strengths and limitations of InSAR are critically assessed with respect to coherence conditions, temporal sampling, and signal interpretation, without focusing on method-to-method comparisons. Finally, we summarize existing InSAR-based cryospheric data products and discuss key challenges and future perspectives for improving long-term, large-scale monitoring of the Arctic cryosphere. This review aims to provide a coherent technical reference for cryospheric research and to support the design of future observation strategies in a rapidly changing Arctic environment.

Keywords: Arctic Cryosphere, InSAR, applications dynamics



4A: HYDROLOGY OF PERMAFROST-AFFECTED WETLANDS

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Permafrost wetlands including peatlands, tundra mires, shallow waters, and coastal marshes play pivotal roles in carbon and nitrogen cycling, contaminant transport, and biodiversity support, yet remain vulnerable to thawdriven hydrological shifts. This session invites interdisciplinary research on biogeochemical fluxes, contaminant fate, ecological dynamics, and wetland responses to disturbances like wildfire and permafrost collapse. We especially encourage contributions combining field investigations, laboratory experiments, modelling, and remote sensing to elucidate how changing thaw depth, precipitation patterns, and evapotranspiration alter wetland ecosystem services.





ECOLOGICAL INDICATION OF PERMAFROST FEATURES FOR PURPOSES OF PEATLAND ECOSYSTEM RESTORATION IN MONGOLIA

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Peatlands and permafrost are functionally connected in the landscape. Permafrost is a source of water and maintains suitable conditions for peatlands' existence, while peat material prevents the direct impact of surface temperatures on the permafrost. A hypothesis of a strong connection between the distribution of peatlands and permafrost in Mongolia was proposed earlier, and permafrost loss following peatland degradation has been reported in several regions of the country. Peatland ecosystem restoration initiatives have been implemented in Mongolia over the last eight years. Understanding permafrost distribution and features at the level of individual peatlands is therefore crucial for restoration planning and for monitoring restoration success. The key research and practical question addressed by this survey was whether permafrost and hydrological site features relevant for restoration design can be indicated by ecological parameters observable through relatively simple field methods. The study design included five peatland sites in central and north-eastern Mongolia. Both geophysical and ecological parameters were registered along transects. In total, 26 transects with a combined length of 27 km and 560 testing points were established during the 2024-2025 field seasons. Data interpretation was supported by a large-scale peatland map developed based on semi-automatic classification of field observations combined with satellite imagery. The geophysical survey focused on the presence of permafrost beneath peatlands and within their catchments, permafrost thickness, average seasonal active layer thickness (ALT), frozen ground and bedrock characteristics, groundwater and soil water-table depth, and the chemical properties of groundwater and surface water (fresh, saline, or carbonated). The survey applied a combination of GPR, EMI, and EMR methods, complemented by coring. These methods proved to be mutually supportive under challenging field conditions, including high salinity and carbonisation, shallow peat layers, and heterogeneous bedrock. The ecological survey documented vegetation composition, surface microtopography, moisture conditions, and land-class characteristics at each testing point. Preliminary results show consistent relationships between specific vegetation assemblages, surface wetness patterns, and shallow permafrost or seasonally frozen ground conditions. In particular, microrelief forms, the dominance of sedge-moss communities, and indicators of stable water supply were found to correspond to shallow permafrost and reduced active-layer thickness. These findings suggest that selected ecological indicators can serve as practical proxies for permafrost-related site conditions in peatland restoration planning. We thank the field team for their contribution to data collection under demanding field conditions.

Keywords: Permafrost, peatland, ecological indicators, restoration



HYDROLOGICAL CHANGES ENHANCE CARBON-NITROGEN INTERACTIONS DURING ABRUPT THAW: A MESOCOSM STUDY IN A FENNOSCANDIAN PALSA

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Abrupt permafrost thaw is projected to contribute up to 40% of carbon (C) emissions from thawing permafrost regions, largely due to the rapid development of thermokarst features that fundamentally reshape wetland hydrology. In peatlands, abrupt thaw often shifts relatively dry permafrost plateaus to inundated thermokarst ponds, causing pronounced changes in thaw depth, water table position, and redox gradients. Although hydrological change is known to regulate greenhouse gas fluxes, these transitions are commonly simplified as aerobic-anaerobic shifts, neglecting finer-scale redox and microbial dynamics. We hypothesize that these conditions and dynamics primarily govern C and nutrient cycling during abrupt permafrost thaw. This pilot study provides one of the first experimental demonstrations linking abrupt thaw hydrology to changes in microbial function and greenhouse gas dynamics. In a mesocosm experiment, we simulated abrupt and gradual thaw using 1-m intact peat cores from a palsa in Finnish Lapland, isolating hydrologically driven redox effects on microbial processes and biogeochemical fluxes. Abrupt thaw was simulated by flooding cores to represent thermokarst pond formation, while gradual thaw maintained in-situ moisture with a deepening active layer. We quantified CO₂ and CH₄ production using continuous gas flux measurements from the mesocosms and complementary anaerobic vial incubations. To identify mechanistic drivers of gas production, we performed metagenomic sequencing on soil and porewater subsamples, focusing on changes in microbial community composition and functional pathways associated with C, N, and S cycling. Our results show that the microbial community structure response was highly depth dependent, with significant shifts within the permafrost layer under the abrupt treatment. Despite marked shifts in permafrost microbial communities, most C cycling pathways were similar under abrupt and gradual thaw, while denitrification and sulfate pathways were enhanced under abrupt thaw. This was likely caused by thaw water addition providing more energetically favorable terminal electron acceptors for metabolic pathways such as denitrification, thus inhibiting the terminal stages of C degradation that result in CH₄ production. Coupling of C and N cycling and stimulation on non-methanogenic processes is supported by a 90% decrease in CH₄ production under abrupt thaw simulation. The release of CO₂ as a byproduct of denitrification aligns with CO₂ emissions two times higher under the abrupt thaw compared to the gradual thaw. Our findings highlight hydrological change - beyond thaw rate alone - as a key control on post-thaw biogeochemistry. Abrupt thaw alters redox conditions via electron acceptor availability and introduces new substrates through thermokarst pond inundation, enhancing C-N interactions. As abrupt thaw events are projected to increase in Fennoscandia, incorporating hydrology-driven microbial and chemical feedbacks into ecosystem and Earth system models will be essential. Overall, our results provide a first step toward a new perspective on the tightly coupled cycling of C and nutrients in lowland permafrost soils.

Keywords: Palsa, hydrology, mesocosms, C-N interactions



METHANE PRODUCTION IN THERMOKARST PONDS ACROSS A THAW GRADIENT IN PERMAFROST PEATLANDS OF NORTHERN NORWAY

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Rapid warming is accelerating the abrupt thaw of permafrost peatlands in Northern Scandinavia, leading to the formation of thermokarst ponds and depressions that later transition into permafrost-free mires. This process mobilizes the large, previously frozen carbon pool, making it available for microbial decomposition and leading to subsequent greenhouse gas emissions that may further amplify warming. Although methane (CH_4) has a much higher global warming potential than carbon dioxide (CO_2), the factors governing CH_4 production rates in permafrost landscapes and their post-thaw dynamics remain uncertain. To assess how potential CH_4 production changes with time since thaw, we used the space-for-time substitution approach along thermokarst chronosequences. We sampled permafrost (intact plateau) and thermokarst (pond and mire) cores along thaw gradients at two peat plateaus, Iškora and Áidejávri, Northern Norway, where thaw age at each location was determined from historical and modern aerial imagery spanning the last 65 years. For each core, we sampled the surface, active layer, and permafrost layers in intact peat plateaus, and the corresponding former (thaw and subsided) layers now present in thermokarst cores. Thermokarst pond bottoms were classified as a separate group. Samples were incubated under anoxic conditions at 10°C for a year and CH_4 production was measured monthly. Overall, CH_4 production potential was substantially higher in thermokarst cores than in intact permafrost, but highly variable, ranging from 0.00001 up to 1% of initial carbon per year produced as $\text{CH}_4\text{-C}$. The highest potentials occurred in pond-bottom peat and in deposits from former pond that have transitioned to mire within the past 65 years. Across intact plateau and thermokarst cores transitioned to mires (excluding pond stage), CH_4 production potential increased steadily from intact tundra to peak values in thermokarst deposits formed between 2 and 60 years ago, then declined by 2-3 orders of magnitude in older thermokarst layers formed before the 1950s. To investigate how the in-situ CH_4 production varies with thawing age in ponds, we quantified wintertime CH_4 production in thermokarst ponds on the Áidejávri peat plateau. CH_4 was measured in the ice and, where depth > 0.5 m, in the below ice water column; winter bottom CH_4 fluxes were calculated as the change in CH_4 storage since freeze-up divided by the number of days in the accumulation period. Winter CH_4 bottom flux increased from $2 \text{ mg CH}_4\text{-C m}^{-2} \text{ d}^{-1}$ in a two-year-old pond to $106 \text{ mg CH}_4\text{-C m}^{-2} \text{ d}^{-1}$ in a pond formed 30-60 years ago. Ponds older than 70 years with ongoing sedge colonization also exhibited some of the highest bottom fluxes, whereas older, Sphagnum-dominated ponds showed 4-10 times lower fluxes. Our results suggest that the time since thaw is an important driver of CH_4 production rates, influencing both incubation-derived rates and winter CH_4 bottom fluxes in ponds.

Keywords: Permafrost, peatland, methane, incubations, winter



GEOCHEMICAL COMPOSITION CHANGES OF LACUSTRINE BOTTOM SEDIMENTS IN THE PERMAFROST ZONE OF THE YAMALO-NENETS AUTONOMOUS OKRUG (RUSSIAN ARCTIC) OVER THE PAST 500 YEARS UNDER THE CLIMATE CHANGE IMPACT

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Lake sediments represent a unique depositional environment capable of recording climatic changes. The analysis of their composition makes it possible to extract important information about ongoing natural processes. Geochemical studies of sediments allow us to assess the dynamics of elements entering the lake catchment and to trace how the migration of individual elements changes over time due to climate change, including permafrost degradation. Studying the environmental response to climate change is especially relevant for the Arctic region, where these processes are most pronounced. In this work, the upper layer (up to 1 m) of lacustrine sediments from 23 lakes located on the Yamal Peninsula and in the Yamalo-Nenets Autonomous Okrug (YNAO) of the Russian Arctic was studied. This region is one of the main areas of oil and gas production in Russia and is experiencing significant anthropogenic pressure that gives additional permafrost thawing. For comparison, both lakes in conventionally “clean” territories and lakes located within city limits were included. YNAO is also characterized by one of the highest rates of climate warming, which emphasizes the importance of studying lake systems in this region. Most of the lakes were studied for the first time. Sampling was carried out in July-August 2020, 2023, and 2024. A total of 33 sediment cores up to 1 m long were obtained using a GOIN gravity corer. The lakes are located between 62° and 70° N and belong to different biomes, from tundra to northern taiga. Two types of lakes were examined: oxbow and thermokarst lakes. According to radiometric dating of the Neytinskie lakes group using the Pb-210 method, the sedimentation rate is about 0.8 mm/year, which allows us to estimate the approximate age of sediments. The studied layers correspond to approximately the last 500 years, a period influenced by both climatic fluctuations and increasing anthropogenic impact over the past 150 years. The geochemical composition of the sediments was determined by XRF scanning using a GEOTEK system, which measured a wide range of elements from Na to U with description of 0.2- or 0.5-mm. Correlation and factor analyses, as well as principal component analysis (PCA), were used to identify geochemical associations of elements and the main factors controlling sediment formation. The results show that the input of terrigenous material related to climatic, hydrological, and geological conditions plays a key role. Sediments formed during the past 100 years were compared with elder layers aged 100-500 years. No dramatic restructuring of ecosystems was revealed. However, increased terrigenous runoff leads to higher input of elements such as Al, Si, K, Ca, Ti, and Fe. Lakes in the central and southern parts of YNAO showed signs of eutrophication, including algal blooms. PCA revealed a relatively low percentage of variance explained by the first two components, indicating a complex data structure. The main controlling factors are probably terrigenous runoff, including coastal abrasion, and redox processes. Lakes located in industrial areas are characterized by increased concentrations of heavy (trace) metals (Ni, Cu, Pb, Hg, V, Zn).

Keywords: Arctic lakes, bottom sediments, climate



INVESTIGATING SURFACE AND GROUND WATER FLOW DURING THE WINTER AT KUPARUK RIVER, ARCTIC ALASKA, COMBINING NEAR-SURFACE GEOPHYSICS AND CRYO-HYDROLOGICAL MODELING

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Ongoing climate warming is increasing air and ground temperatures across the Arctic, accelerating permafrost degradation and talik expansion, which directly impact regional hydrological systems. Surface and ground water flow has been observed within Arctic River systems on continuous permafrost; however, the mechanisms of this flow remain poorly understood. This study uses Ground Penetrating Radar (GPR), Transient Electromagnetics (TEM), and modeling to investigate the hydrological flow during the winter at the Kuparuk River on the North Slope of Alaska. GPR measurements were collected in March 2025 using a snowmobile pulling a 160 MHz antenna, reaching a depth of investigation up to ~30 m. Preliminary GPR results suggest a talik thickness between 1 and 6 m below the river, which is hypothesized to facilitate groundwater flow during the winter. We will repeat GPR measurements in April 2026 and collect coincident 2D TEM measurements, which can reach a deeper depth of investigation up to 100 m, providing a better understanding of the subsurface structure. Finally, the geophysical results will be used to create a cryo-hydrological model of this complex river-talik system. This work provides a better understanding of the relationship between permafrost degradation and hydrological flow in the Arctic tundra in the context of a warming climate.

Keywords: Geophysics, talik, river, Kuparuk, Alaska



RECONSTRUCTION OF THE LIFE CYCLES OF TWO DRAINED LAKE BASINS ON THE BALDWIN PENINSULA, W ALASKA

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Drained lake basins and the wetlands that develop in them dominate large regions in Arctic lowlands with ice-rich permafrost. Thermokarst lake formation and subsequent lake drainage and wetland development is in fact one of the main processes shaping the landscape of the Baldwin Peninsula in western Alaska, where drained lakes currently cover more area than lakes. Lake drainage creates shallow topographic depressions with increased surface water retention and wetland formation. Many basins develop into peat-forming wetlands following lake drainage, with ice-wedge polygon networks shaping their microtopography. In Arctic lowlands with ice-rich permafrost, sediment-based palaeoreconstructions can be challenging because of cryoturbation, thermokarst-induced sediment disturbances and mass wasting processes in general. The centres of drained lake basins have less disturbed sediment than their marginal parts or most of their surroundings. In addition, the centres of ice-wedge polygons in these basin centres often have relatively undisturbed peat sequences, which can be highly valuable palaeo-archives, particularly for Holocene time scales. In April 2024, we cored ice-wedge polygon centres in the centres of fifteen drained lake basins. We targeted the upper 2-2.5 m of peat to reconstruct past environmental and landscape dynamics as well as vegetation composition and organic matter storage and decomposition in this highly dynamic region of the Arctic. Here we present first results of sediment and organic matter composition as well as plant macrofossil assemblages in sediment cores from two of these sites. Our results indicate that the cores capture the entire life cycle of the thermokarst lakes from lake inception to drainage followed by wetland initiation. In addition, these palaeoarchives provide a unique view into one of the most common and dynamic landforms of permafrost lowlands relevant for past, current, and future carbon cycling and sequestration.

Keywords: Thermokarst lake, palaeo environment, carbon, nitrogen



HYDROGEOCHEMICAL EVIDENCE FOR SUPRAPERMAFROST GROUNDWATER RECHARGE TO THERMOKARST LAKES ON THE QINGHAI-TIBET PLATEAU

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Thermokarst lakes are widespread across the Qinghai-Tibet Plateau (QTP) and play a critical role in regulating hydrological and biogeochemical processes in alpine permafrost regions. However, the magnitude and mechanisms of suprapermafrost groundwater recharge to thermokarst lakes remain poorly constrained due to complex freeze-thaw dynamics and limited field-based evidence. In this study, we investigate the hydrological connectivity between thermokarst lakes and suprapermafrost groundwater using an integrated hydrogeochemical approach across a representative permafrost landscape on the QTP. Stable water isotopes ($\delta^{18}\text{O}$, δD , and d-excess), major ions, and dissolved organic carbon (DOC) were analyzed in lake water, suprapermafrost groundwater, and precipitation to identify recharge sources and flow pathways. Results show that thermokarst lake waters deviate from the local meteoric water line and exhibit enriched isotopic signatures indicative of strong evaporative effects, while suprapermafrost groundwater displays relatively depleted isotopic compositions with higher d-excess values, reflecting limited evaporation and subsurface flow. Mixing models based on isotopic mass balance indicate that suprapermafrost groundwater contributes substantially to lake water budgets, particularly during the thaw season when active-layer deepening enhances lateral subsurface connectivity. Hydrochemical signatures further support this linkage, as both lake water and suprapermafrost groundwater are dominated by $\text{Na}^+\text{-Cl}^-$ type waters, with coherent spatial patterns in electrical conductivity and ion ratios suggesting common sources and transport processes. Elevated DOC concentrations in suprapermafrost groundwater, coupled with similar aromaticity indices between groundwater and lake water, indicate that lateral groundwater inflow is an important pathway for carbon transfer into thermokarst lakes. Our findings provide direct hydrogeochemical evidence that suprapermafrost groundwater recharge is a key component of thermokarst lake hydrology on the QTP. Enhanced groundwater-lake connectivity under ongoing permafrost thaw is likely to alter lake water balance and carbon dynamics, with implications for regional hydrological processes and greenhouse gas emissions. This study highlights the necessity of incorporating suprapermafrost groundwater processes into models of thermokarst lake evolution and permafrost-hydrology-carbon feedbacks in high-altitude cold regions.

Keywords: Thermokarst lake, suprapermafrost groundwater, QTP



ON THINICE: EMERGING RISKS FROM DRILLING MUD SUMPS IN THE MACKENZIE DELTA DRIVEN BY PERMAFROST THAW AND HYDROLOGICAL CHANGE

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For decades, the Arctic and its resources have played a central role in global economic development. A wide range of industrial activities in pristine and sensitive ecosystems resulted in the accumulation of chemical substances and industrial waste products throughout the region. At various former and active industrial sites, these substances were disposed of in permafrost soil, which was used as an effective natural hydrological barrier to seal off contaminants. In particular, landfills for drilling mud from oil and gas exploration (drilling mud sumps) have left clearly visible marks on the Arctic permafrost landscapes. In the permafrost region of the Mackenzie Delta in Canada's Northwest Territories alone, more than 230 such drilling mud sumps were created between the 1970s and 1990s. With climate warming, the thawing of permafrost threatens the stability of these subsurface landfills and raises concerns about their integrity. This thawing also causes significant changes in the hydrological network of the surrounding permafrost landscape, increasing the risk of disruptive geomorphological processes and creating pathways for the spread of contaminants. Consequently, both terrestrial and aquatic ecosystems face increased risks of contamination, particularly impacting indigenous communities whose livelihoods and health are intricately linked to the maintenance of intact ecosystem functions in the Arctic. To date, the environmental risks associated with industrial contaminated sites in thawing permafrost regions have not been adequately quantified. Our project aims to conduct a comprehensive assessment of the short- and long-term environmental risks linked to the destabilization of industrial waste sites in the Mackenzie Delta due to permafrost thaw. We therefore conducted a detailed investigation of the current thermal and hydrological conditions of eight drilling mud sumps along the Inuvik-Tuktuaktuk Highway, combining field observations, remote sensing, and modeling techniques. Additionally, we evaluate the effectiveness of contaminant containment at these sites and assess potential migration of contaminants through hydrological and chemical analyses. Preliminary results reveal that across a diverse range of climate and landscape conditions, many of the investigated sites exhibit signs of impending failure under current climate conditions. Given the trajectory of ongoing climatic warming, we anticipate further exacerbation of issues related to the failure of drilling mud sumps. It is crucial to address these evolving ecological risks associated with permafrost destabilization in the context of future climate change.

Keywords: Industrial, contamination, permafrost, hydrology



UTILIZING COMMUNITY-RELEVANT PERENNIAL GROUNDWATER SPRINGS TO ASSESS A CRYOHYDROGEOLOGICAL REGIME IN TRANSITION IN NUNAVUT, CANADA

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For those living on continuous permafrost for multiple generations, changes to the winter local waterscape is a novel experience. Traditional expert knowledge, ways of knowing, and assessment of land-based hazards have developed based on a regime of limited lateral groundwater movement during winter. Yet, there is evidence of changing winter groundwater dynamics along traditional overland travel routes in the continuous-permafrost region of Nunavut, Canada. This research study weaves Inuit Qaujimagatuqangit (Indigenous knowledge and ways of knowing) with groundwater and permafrost science to identify and assess local community-relevant landscape indicators of winter groundwater movement. Nunavut is the traditional home of the Inuit who comprise the majority of the population. Winter overland travel primarily consists of snowmobiling and dog sledding. Encountering groundwater springs is a winter overland travel hazard. With local community members, we document and categorize past and present perennial groundwater spring locations in Nunavut. We then analyze groundwater chemistry, temperature, and flow rate. Combined, these results provide integrated understanding of Nunavut perennial groundwater spring characteristics and enhance predictions of future perennial groundwater spring occurrence in response to environmental change. Presently, Arctic climate change prediction models generally do not account for near-surface groundwater processes nor its effects on local community-relevant landscape dynamics such as perennial groundwater spring formation. This research study was co-designed with Indigenous and local-community governments and organizations in Nunavut. Their input further aligned this study's activities with local decision-maker information needs and existing community projects underway. By following an inclusive research model, the study results are of a scale, format, topic, and timeframe relevant for Indigenous and local community resilience planning.

Keywords: Permafrost, Indigenous knowledge, groundwater spring



EXPLORING TALIK DEVELOPMENT BENEATH BEAVER PONDS IN ARCTIC ALASKA

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The northward expansion of beavers into the Arctic is rapidly altering freshwater landscapes through the construction of dams and the formation of new ponds. This expansion has led to a marked increase in the number and spatial extent of small ponds across Arctic lowlands. Beaver ponds modify local hydrology and surface energy balance, potentially resulting in warmer water temperatures. These changes can accelerate permafrost thaw beneath ponds, promote talik development, and potentially enhance emissions of carbon dioxide (CO₂) and methane (CH₄) from previously frozen soils. In this study, we investigate the thermal and biogeochemical impacts of beaver pond formation on permafrost thaw and carbon fluxes using observations from a beaver pond located in the Noatak region of northwest Alaska. We combine field-based measurements of water temperature and pond morphometry with a physics-based lake model that represents ice cover dynamics, heat transfer, and sediment thermal processes. The model is used to simulate seasonal and interannual variations in pond thermal regimes and to quantify resulting changes in thaw depth beneath the pond. A series of numerical experiments was conducted to examine the sensitivity of talik development and greenhouse gas fluxes to variations in ice-cover duration and hydrological inflow. Results indicate that reduced ice duration and increased inflow of relatively warm water enhance heat transfer to underlying sediments, leading to deeper and more persistent talik formation. These thermal changes are associated with increased CO₂ and CH₄ production and efflux from thawing permafrost soils beneath the pond. Our findings suggest that beaver pond expansion may act as an important, yet underrepresented, mechanism linking ecosystem engineering to permafrost degradation and carbon release in Arctic landscapes. Incorporating beaver-driven hydrological changes into permafrost and carbon cycle models may therefore be critical for improving projections of future Arctic greenhouse gas emissions.

Keywords: Lakes, methane, carbon dioxide, modeling



CHANGES IN THE ARCTIC HYDROLOGICAL SYSTEM UNDER A WARMING CLIMATE

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Under the background of rapid global warming, the hydrological regime in the Arctic River basins, where permafrost is widely developed, has changed significantly. These changes not only altered the local ecological environment, but also had far-reaching impacts on the global climate system and socio-economy. Therefore, the study of hydrological processes in Arctic River basins has become a hot-spot issue at the forefront of the international scientific community. Based on a thorough review and critical analysis of domestic and international literature, this paper systematically summarizes the research findings and latest progress on the spatial and temporal changes of the runoff of major Arctic rivers, as well as the driving mechanisms behind these variations. In addition, the patterns and spatiotemporal differences in runoff changes between Eurasia and North America were analyzed in detail. Furthermore, the direct and indirect effects of precipitation changes (e.g., precipitation amount, rain/snowfall fractions) and permafrost degradation on Arctic runoff are thoroughly examined. Despite significant progress in data accumulation and scientific understanding in current Arctic hydrological research, considerable challenges persist, such as the scarcity of ground observations and the difficulty of quantitatively assessing the interactions among climate, snow/permafrost, and hydrological processes. Thus, establishing a robust observation network in the Arctic River basins and developing cold region hydrological models with account for the Arctic specifics are fundamental for gaining in-depth insights into the rapid changes occurring in the Arctic hydrological system. This is also crucial for addressing the risks of water-related disasters and enhancing water resource management in the Arctic region.

Keywords: Hydrological regime, Arctic River basins



COUPLING OF VEGETATION DYNAMICS AND PERMAFROST LANDFORMS IN POST-AGRICULTURAL STEPPES OF TUVA

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Large-scale agricultural abandonment following the post-Soviet socio-economic transition initiated long-term reorganization of steppe and meadow ecosystems across Southern Siberia. In regions affected by sporadic permafrost, vegetation recovery is additionally constrained by seasonal ground freezing, groundwater redistribution, and the development of cryogenic microrelief. This study analyzes vegetation dynamics and ecosystem resilience in the Turano-Uyuk Basin (Republic of Tuva), a cold-arid intramontane depression characterized by strong continentality, basin temperature inversions, seasonal soil freezing, patchy floodplain permafrost, and permafrost-related landforms forming both in floodplains and within steppe landscapes. The analysis is based on long-term satellite observations covering the period 1990-2024. Atmospherically corrected Landsat-5, -7, and -8 imagery and MODIS data were used to derive seasonal and interannual time series of the Normalized Difference Vegetation Index (NDVI) and Vegetation Condition Index (VCI). The study period was subdivided into three intervals (1990-2000, 2001-2011, 2013-2024) to assess temporal shifts in vegetation functioning. Peak vegetation timing was determined using the Greenest Day of Year (DOY) approach. Functional types of vegetation dynamics were identified through cluster analysis of seasonal NDVI curves ($k = 10$), while spatial persistence of vegetation anomalies was evaluated using Getis-Ord G_i^* Hot Spot Analysis with a 150 m neighborhood radius. Field surveys and UAV-based observations were conducted on representative steppe, floodplain, and ecotonal sites. The results indicate that post-agricultural vegetation recovery remains incomplete after 35 years. Autonomous xerophytic steppes exhibit early spring green-up but high interannual NDVI and VCI variability, with peak vegetation activity occurring predominantly between 8 and 23 August. Groundwater-influenced ecosystems including floodplain meadows, halophytic communities, and steppe zones affected by groundwater discharge show earlier and more stable vegetation maxima, typically between 18 July and 8 August. Within steppe plains, groundwater discharge zones are marked by the development of tufur mounds, which represent localized permafrost-related microrelief formed under conditions of seasonal freezing and sustained soil moisture supply. These features exhibit distinct vegetation functioning, characterized by intermediate seasonal dynamics and relatively high recurrence of positive NDVI anomalies (approximately 0.6-0.7). In terms of ecosystem behavior, tufur-associated communities function as transitional (ecotonal) landscape units between autonomous steppe and hydromorphic floodplain systems. Depending on seasonal hydrothermal conditions, their vegetation regime may shift toward either steppe-like or floodplain-like functioning, resulting in elevated spatial and temporal heterogeneity and increased concentration of species and functional diversity. Overall, the spatial and temporal patterns demonstrate that vegetation recovery is primarily controlled by position within the catena system, groundwater depth, and cryogenic microrelief rather than by slope exposure alone. The presence of tufur mounds in steppe groundwater discharge zones highlights the direct coupling between permafrost-related processes and ecosystem functioning. Long-term remote sensing indicators prove effective for diagnosing ecosystem resilience and phytomass sustainability in cold-arid landscapes with patchy permafrost.

Keywords: Tufur, steppe, NDVI, vegetation, dynamics



EFFECT OF TOPOGRAPHY ON GROUND TEMPERATURE AND FUNCTIONING OF ECOSYSTEMS WITHIN OPEN TUNDRA BIOME: CASE STUDY AT THE SEWARD PENINSULA, ALASKA

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Even though permafrost is a cold climate-driven phenomena, several factors decouple air and ground temperature. Within the open biomes, such as tundra or steep, it is snow cover. Heterogeneity of the thickness of the snow pack controlled by wind redistribution and topography determines the presence or absence of perennially frozen ground at the ground surface. To understand the topography effect on the ground temperature regime and functioning of ecosystems, we studied slope terraces, which are a widespread feature at the Seward Peninsula on Alaska. These landforms affect the redistribution of snow during winter and control soil temperature and moisture, influence the vegetation and pedogenesis. To study this mechanism, we performed soil, vegetation, and snow surveys along the transect, biomass productivity assessment, decomposition experiment, and monitoring of the ground temperature and soil moisture. According to our results mean annual temperature at the depth of 1.2 meters in 2019 gradually decreases from 1.9-4.2°C at the rear part to 0.1-0.5°C with the chance of presence of perennial frozen layer at the terrace's edge. Such a pattern in the ground thermal regime is mostly caused by the difference in winter temperature due to snow redistribution. The soil moisture regime might be identified as Ustic at the rear and middle parts and Udic at the front of the terrace. Across the tread of the terrace vegetation changes from the Mesic graminoid-herb meadow in the rear part to dwarf shrub tundra in the middle and ericaceous-lichen dwarf shrub tundra at the front. Aboveground bioproductivity increases from the rear (449.6 g/m²) to the front part (1099.76 g/m²) of the terrace. But, because of the differences in composition of plants communities, annual litter biomass decreases from the rear to the frontal part. The highest rate of litter decomposition during the summer season was recorded at the middle section of the terrace and the lowest - at the front. Processes of the organic stabilization were the lowest at the rear part of the terrace. A combination of all about mentioned factors and processes explain the pattern in soil sequence, in particular thickness of organic horizon. The most developed soil profile can be found at the rear part of the terrace.

Keywords: Permafrost, snow, soils, biomass



**4A: HYDROLOGY OF PERMAFROST-AFFECTED WETLANDS
POSTER**



CHANGES OF SOIL ORGANIC MATTER ALONG THAW TRANSECTS OF PERMAFROST PEAT PLATEAUS IN FINNMARK, NORWAY

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The thawing of permafrost peat plateaus holds the potential for a substantial release of greenhouse gases (GHG) into the atmosphere, due to the potential emission of previously frozen soil carbon, thereby exacerbating climate change. Aside from the environmental conditions, the soil microbial community, and the export of C as dissolved organic carbon (DOC), the quality of soil organic matter (SOM) is expected to govern the release of carbon (C) into the atmosphere. Thus, we characterized the quality of SOM pools by their content of organic elements and signal of stable C and nitrogen isotopes (i.e., ^{13}C , ^{15}N) along thaw transects at currently degrading permafrost peat plateaus in Iškoras and Áidejávri, Finnmark, Northern Norway. The results are evaluated along the thaw transect (chronosequence) to identify compositional changes indicating decomposition of the thawed SOM pools. We investigate the quality of the organic element composition using the established framework of the van Krevelen diagram in combination with further elemental ratios as proxies for quality SOM changes (e.g., carbon-nitrogen ratio). The isotopic signals of ^{13}C and ^{15}N are used to complement the compositional SOM quality changes, as microbial decomposition of organic matter induces isotopic fractionation. Furthermore, the thermodynamic metrics of the SOM pools, i.e., the C oxidation state and the degree of unsaturation, as well as the respiratory quotient of the SOM pools, are estimated using the organic element composition. Preliminary results indicate site-specific compositional changes of the degrading plateaus along the chronosequences, presumably resulting from differing vegetation governed by the respective paleoenvironmental conditions. Generally, the stoichiometric ratios indicate a higher content of N in Áidejávri than in Iškoras, which is consistent along the thaw gradient of the plateau. Regarding the plateau strata, the active layer experiences more distinct compositional and thermodynamic changes than the respective permafrost layer with progressing thaw, especially in Iškoras. The samples are visualized in the van Krevelen diagram alongside essential biomolecular classes, like carbohydrates, lignin, lipids, and proteins. The visual inspection implies a compositional trend towards a lignin-like dominance of SOM pools with progressing decomposition along the thaw gradient. This compositional trend complements the more reduced C oxidation state observed for the thawed SOM pools. Resolving the strata-specific compositional changes along the thaw gradient can give implications regarding the relevance of the C availability for microbial decomposition. The less pronounced changes of the permafrost compared to the active layer along the chronosequence indicate a lower mobilization potential of C with progressing plateau degradation, conversely implying a higher preservation potential of permafrost C with plateau degradation than anticipated for the C in the active layer.

Keywords: Biogeochemistry, carbon, nitrogen, permafrost, wetlands



TEMPORAL CHANGES OF THERMOKARST LAKES IN THE KHUKH AND KHUITEN NATURE RESERVE, MONGOLIA

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Thermokarst lakes are key indicators of permafrost dynamics and the impacts of climate change in cold regions. This study examines temporal changes in the surface areas of thermokarst lakes within the Khurkh and Khuiten Nature Reserve. Multi-temporal Landsat satellite imagery from 1995, 2005, 2015, and 2025 was processed using atmospheric correction and geometric alignment. Water bodies were extracted using the Normalized Difference Water Index (NDWI), and the resulting lake polygons were vectorized to calculate their surface areas in a GIS environment. The analysis reveals significant fluctuations in thermokarst lake extents over the past decades, suggesting interactions among permafrost degradation, seasonal hydrological variability, and local environmental conditions. These results provide a current assessment of thermokarst lake dynamics and offer a scientific basis for future studies on permafrost stability and hydrological conditions in the reserve.

Keywords: Thermokarst lakes, Permafrost degradation



HYDROLOGY AND SEDIMENT TEXTURE DRIVE SPATIAL DIVERGENCE IN MICROBIAL ASSEMBLY AND FUNCTIONS IN A DRAINED LAKEBED ON THE NORTHWESTERN QINGHAI-TIBET PLATEAU

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Extreme rainfall-driven lake breaches on the Qing-Tibet Plateau exposed large portions of lakebeds of Zhuonai Lake in 2011 and offered a natural model for primary succession, yet the spatial heterogeneity imposed by cryogenic environments is rarely studied. By integrating amplicon sequencing (16S rRNA/ITS), shotgun metagenomics, and geochemical profiling in the Zhuonai Lake basin and adjacent indigenous permafrost sites in Kekexili, this study reveals that microbial assembly and functional potential developed into three distinct groups, strongly influenced by the specific coupling of permafrost hydrology and sediment lithology. Specifically, fine-textured depressions act as “Hydrological Refugia” (e.g., Site Z7), where moist condition maintain anaerobic microsites, and favors for *Methanosarcina* and anaerobic functions. In contrast, gravel-dominated lake sediments (e.g., Site Z9) drained and aerated rapidly, shifting conditions from anaerobic to oxic and thereby accelerating the colonization of aerobic, soil-adapted taxa such as ammonia-oxidizing Archaea (*Nitrososphaeraceae*) and bacterial actinomycetal *Rubrobacter*. Meanwhile, high-evaporation areas form “Salinity Traps” that constrain communities to low-diversity, halophilic compositions. We propose a lithology-mediated cryogenic assembly, driven by geochemical filters from permafrost barriers and surface substrates, controls microbial composition and functional trajectories in alpine arid ecosystems.

Keywords: Microbial assembly, permafrost hydrology, sediment texture, Zhuonai lake, functional divergence



DYNAMICS OF HYDRO-ECOSYSTEMS IN PERIGLACIAL LANDSCAPES FROM MULTI-SATELLITE OBSERVATIONS AND FIELD DATA

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We focus on alases - thermokarst depressions that are occupied by grasslands and lakes, and which are an important element of the Central Yakutian periglacial landscape. In recent decades, climatic changes have resulted in important changes in environmental conditions of this region. By using different remote-sensing instruments (Landsat 8, TerraSAR-X, ENVISAT-RA2, and Jason-2) alongside in situ observations we investigate 1) the spatial distribution and water regime of alas lakes and their relationships with climatic and geomorphologic factors, 2) the relationship of the alas' grassland productivity with the water regime and 3) the potential of alas grasslands for local agriculture. We observed several periods of water level increase/decrease and thermokarst lake expansion/decrease. Small thermokarst lakes ($<0.025 \text{ km}^2$), which indicate regions of young thermokarst, comprise up to 11% of the total lake area and experience high (30%) seasonal variations. In situ observations of the grassland dynamics show their synchronous cyclic variability with the lake extent and a general increasing trend for their productivity since 1985. Around 50% of these dynamics can be explained by the amount of pre-winter precipitation with a delay of two years. We explain this delay through the buffering effect of watershed soils. The cyclic variability of alas hydro-ecosystems strongly affects the local agriculture, which is based on horse and cattle breeding. We estimate that these alas grasslands can provide enough forage supply for local communities. However, the real alas yield is several times less than the theoretical value because of grassland degradation that is caused by recent thermokarst and waterlogging in the most productive phytocenosis. This research was supported by the CNES TOSCA Permasensing I and II projects and Institute of Water Problems Project N FMWZ-2022-0001.

Keywords: Hydrology, satellite, lake, water level



4B: PERIGLACIAL DYNAMICS IN HIGH-LOW LATITUDES

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This session examines how past and ongoing climate change drives geomorphological, pedological, and ecological transformations in icefree periglacial environments from Antarctica's subAntarctic islands to Arctic landscapes. We invite studies employing geophysical surveys, groundthermal monitoring, soil and vegetation assessments, and remote sensing to characterize activelayer variability, permafrost thermal regimes, hydrological shifts, and seainteraction effects. Contributions on submarine and subglacial permafrost, novel field techniques, and integrated modelling approaches to understand periglacial system responses at multiple latitudes are especially encouraged.





MONITORING OF ACTIVE LAYERS OF PERMAFROST IN MONGOLIA: LIMITS OF ACTIVE LAYER THICKNESS AS AN INDICATOR OF PERMAFROST STABILITY

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Active layer thickness (ALT) is widely used as a key indicator of permafrost response to climate change; however, its diagnostic power may be limited in climatically transitional permafrost regions where hydrological and thermal processes increasingly decouple surface thaw from long-term permafrost stability. Here, we present a synthesis of long- and short-term ALT monitoring in Mongolia based on borehole temperature observations spanning more than two decades (since 1996) across the Khentii, Khangai, and Khovsgol mountain regions, which together represent approximately 80% of the national permafrost zone. These regions encompass a gradient from relatively cold, stable permafrost to warm, discontinuous and patchy permafrost conditions. ALT was derived from depth-resolved borehole temperature records at more than 40 monitoring sites using temperature isopleths, complemented by high-resolution measurements in the upper 5 m at selected sites near Ulaanbaatar. Across all regions, ALT varied widely from approximately 1-1.5 m to 5-8 m, with mean values of 2.5-4.0 m depending on substrate properties and soil moisture regimes. Long-term trends indicate a general increase in ALT of approximately 2-3 cm yr⁻¹, although rates varied strongly among sites and periods, ranging from negligible change to increases exceeding 10 cm yr⁻¹. Despite these broadly increasing trends, our results reveal pronounced regional contrasts in the interpretation of ALT dynamics. In the Khentii region, characterized by relatively warm and discontinuous permafrost, ALT exhibits high interannual variability and rapid increases that coincide with delayed refreezing, prolonged thaw seasons, and the formation of supra-permafrost taliks in formerly swampy terrain. In these settings, ALT increases increasingly reflect subsurface thermal and hydrological reorganization rather than surface-driven deepening of seasonal thaw alone. In contrast, in the colder and more stable permafrost of the Khovsgol and Khangai regions, ALT changes remain smaller and more tightly coupled to surface climate forcing, with thaw and refreezing occurring within a narrower seasonal window. Our findings demonstrate that ALT alone is an incomplete indicator of permafrost stability in transitional permafrost regions, where talik development and subsurface heat storage can precede, amplify, or decouple ALT changes from long-term permafrost degradation. We conclude that ALT monitoring must be interpreted in conjunction with ground temperature profiles, soil moisture conditions, and freeze-thaw timing to accurately assess permafrost vulnerability. This diagnostic perspective is particularly critical for regions such as Mongolia, which serve as early-warning zones for permafrost regime shifts under ongoing climate warming.

Keywords: Active layer, dynamics, trend, talik



A DECADE (2013-2022) OF PERMAFROST AND ACTIVE LAYER THICKNESS MONITORING IN ANTARCTIC PENINSULA AREA

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Since 2013 the thermal profile of two intermediate deep boreholes (≥ 30 m) located approximately at the same elevation (ca. 30 m a.s.l.) and same distance from the coast respectively at Signy Island ($60^{\circ}43'S$) and Rothera ($67^{\circ}57'S$) were monitored continuously. Here, we will present the trend of permafrost temperature at the zero annual amplitude (ZAA) depth and the active layer thickness (ALT). Moreover, we analysed their relationships with the latitude and with the main climatic factors (air temperature, snow thickness). The temperature at ZAA at Rothera and Signy was substantially stable around $-3^{\circ}C$ and $-1.3^{\circ}C$ respectively. The two sites, both located in continuous permafrost areas, showed different trends for the ALT with a substantial stability ($\beta = 0.07$; $R^2 = 0.4$) at Signy Island while a not statistically significant thinning trend ($\beta = -3.7$; $R^2 = 0.1$) was recorded at Rothera. At Rothera ALT was very variable ranging between only 10 cm up to more than 130 cm while at Signy between 270cm and 360 cm. The ALT variations were statistically correlated with the mean annual, spring and summer temperature of air and ground surface ($R^2 > 0.5$) at Signy, and at Rothera good regressions were observed with summer mean ground surface temperature ($R^2 > 0.7$) and stronger with the ground surface thawing degree days index ($R^2 = 0.9$). The quite strong increase of the snow thickness (ca. 4 cm per year) at Rothera seems to not significantly affect the ALT. The significant stability of the two essential climate variables (ECV): ALT and temperature at ZAA in both sites may be related to the climate considered period, which includes both part of the cooling phase (1999-2016) and a portion of the following strong air warming.

Keywords: Permafrost, climate change, Antarctica



HUMAN DISTURBANCE ON ANTARCTIC PERMAFROST: THE IMPACT OF AN AIRSTRIP CONSTRUCTION

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Recent climate change affects permafrost conditions in cold regions. In Continental Antarctica a recent active layer thickening has been demonstrated at least between 1996 and 2012. Here, we present the impact of the Boulder Clay airstrip, (very close to the Italian Antarctic Research Station “Mario Zucchelli”, Northern Victoria Land, Antarctica) on the surrounding landscape. Specifically, we want to highlight the effects of this construction on the active layer thickness (ALT) considering that the airstrip was built on continuous permafrost during 2016-2020. In detail we present the effects on: a) the surroundings prior and post the construction and b) the modified surface layer of the airstrip compared to the original till. The ground surface temperature measurements in situ and the remote sensing data during 2014-2023 showed that the airstrip produced negligible impacts on the surroundings farther than 30 m, both in terms of ALT and snow cover frequency. However, between the western embankment toe and 30 m, we noticed a detrended ALT increase. The reworked surface promoted warming of the ground resulting in a greater ALT than the surroundings till and consequently to an ALT thickening (average of 1.29 m on the airstrip vs 0.65 m on the uphill surroundings) due to a change of water content, density and thermal conductivity of the embankment fill that turned into a higher edaphic factor. Moreover, the ALT measured in situ in 2024 showed a greater value of 2.3 m compared to the modelled one in 2020-2023 that exceeds the depth of the buried ice within the debris covered glacier. Therefore, if the current trend of climatic parameters is maintained, possible consequences (e.g. thermokarst depressions) are expected on the stability of the construction, especially during summer that is more susceptible because of the human activities.

Keywords: ALT, Stefan’s equation, Antarctica, airstrip



LONG-TERM MONITORING OF ACTIVE LAYER, ICE WEDGES, AND FROST CRACKING CONDITIONS IN NORTHERN VICTORIA LAND, ANTARCTICA (2004–2023)

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A long-term monitoring of ice wedges thermal regime started since 2004 at three sites along an altitudinal transect between 72°S and 74°S in northern Victoria Land, Antarctica. Air and ground surface temperatures did not show any significant trends in two sites (Boomerang Glacier and Mount Jackman), whereas Baker Rocks exhibits contrasting trends. Active layer thickness remains stable at Baker Rocks (48 cm) and at Boomerang Glacier (27 cm), while thins significantly at Mount Jackman (30 cm) of about 7 cm/decade. Active layer thickness is mainly related to summer ground surface temperatures. The mean annual temperature at the top of permafrost remains stable at all sites, except for a slight warming at Baker Rocks. Potential cracking events frequency increases with elevation, but with different patterns at the different sites. At Boomerang Glacier and Baker Rocks, a significant decline was recorded while at Mount Jackman conditions remained stable. It is remarkable that air and ground temperature, cooling rates and thermal gradient exceed the values reported during thermal-contraction cracking events in the Arctic. These records provide long term evidence of ice-wedges cracking dynamics in Antarctic ice-free areas and reveal the stability and thinning of the active layer.

Keywords: Antarctica, permafrost, ice-wedge, active layer



CHARACTERIZING POLYGONAL PATTERNED GROUND ON THE CENTRAL QINGHAI-TIBET PLATEAU: SPATIAL DISTRIBUTION AND CLIMATIC IMPLICATIONS

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Polygonal patterned ground (PPG) is a crucial periglacial landform and a sensitive indicator of climate-driven permafrost change. However, its spatial patterns across the high altitude–latitude permafrost regions of Qinghai-Tibet Plateau (QTP) remain poorly characterized. This study investigated the spatial distribution of PPG in the Wudaoliang (WDL) region of the central QTP using drone imagery, geomorphological surveys, and object-based image analysis combining Geomorphons classification. Our findings show that PPG occupied 15.7% of the study area, with a density of 628 polygons km². Polygon diameters range from 3.5 to 59.1 m (mean 10.5 m), and microrelief between PPG centers and troughs varies from −0.71 to +0.86 m (mean 0.2 m). Typical hexagonal, circular, random, and orthogonally oriented polygon nets are observed in WDL. Statistical analyses show that higher–relief PPG correlates with higher elevations, colder ground temperatures, higher soil moisture, fine–grained soils, and dense vegetation. In contrast, lower–relief PPG occurs on bottom WDL region with coarse, drier soils and sparse vegetation. The PPG morphology heterogeneity is closely linked to spatial variations in soil properties, thermal-hydrologic regimes, and active layer thickness. The transitions from low-centered to high-centered polygons recognize the microrelief between centers and troughs, thereby influencing soil, moisture, snow, vegetation, and ground thermal states at both both meter and regional scales. Furthermore, PPG areas experience greater active layer deepening under regional climate warming compared to non-PPG areas at similar elevations. These findings highlight PPG morphological heterogeneity is a valuable indicator of permafrost degradation and active-layer deepening on the QTP.

Keywords: Polygonal patterned ground, Qinghai-Tibet Plateau



YAMAL PENINSULA, PERMAFROST-RELATED TERRAIN PHENOMENA: TABULAR GROUND ICE, THERMOCIRQUES AND GAS EMISSION CRATERS

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Leading controls of terrain development in the permafrost zone are various types of ground ice. The paper deals with the formation of specific landforms in the continuous permafrost of Yamal Peninsula. Tabular ground ice (TGI) widespread there is represented by thick and extended ground-ice layers. Processes related to TGI are triggered by climate warming, deepening of the active layer and increase in ground temperature. Both processes analyzed notably activate in 2012-2013 after the extremely warm summer of 2012. An increase in the rate of thaw reaching the upper surface of TGI had started thermodenudation, the process covering all kinds of mass wasting on slopes related to permafrost thaw. An increase in ground temperature, probably, was the reason for gas-emission crater formation through decomposition of methane clathrates and formation of high pressure under the TGI layer until it breaks. Thus, TGI is a prerequisite for activation of both processes under discussion. In case of thermodenudation, TGI serves as a source of water for saturation of slope deposits and a shear surface for movement of these deposits down slope under the action of both heat and gravity. Being relatively impermeable to gas, TGI hinders gas released from decomposition of methane clathrates, to accumulate beneath the ice deforming this layer to form a gas-inflated mound, predecessor of the crater. When pressure exceeds the breaking strength of the TGI layer, an eruption occurs. Thermocirques, resulting from thermodenudation, and gas emission craters evolve with time depending on the ice extent, warming trend and local environmental specifics. Increase in the depth of thaw in 2012 and 2013 caused activation of thermodenudation associated with the start of TGI melt and formation of thermocirques. In 2016, some new thermocirques re-activated, at the same time the rate of growth reduced due to insulating of the ice wall by actively flowing down landslide bodies and exhausting of the ice layer. While in general, activity of thermodenudation depends on the extremes in climatic parameters, individual thermocirques develop depending on their cryolithological structure and may stabilize after different periods of activity. Warming trend results in increased ground temperature, release of enclosed in permafrost gas, and dissociation of gas hydrates. TGI serves as an impermeable membrane to possible gas emission to the surface, promoting temporary accumulation of gas to produce sufficient pressure for, at first, formation of mound-predecessor; then to trigger the ejection of frozen blocks mixed with water and gas to the surface. Evolution of GECs is growth in size, reduction in depth and formation of the lake-successor. The research was carried out within the framework of the state assignment of the Ministry of Science and Higher Education of the Russian Federation (theme No. FWRZ-2026-0016). A.Kizyakov was funded by the state assignment of MSU "Ground and underground glaciation in the context of modern climate change and anthropogenic impact". Yury Dvornikov was supported by the RUDN University Strategic Leadership programme and the state assignment FSSF-2024-0023.

Keywords: Ground ice, thermocirque, gas emission crater



REGULAR FIELD AND REMOTE-SENSING OBSERVATIONS OF CRYOGENIC LANDSLIDING AND MAPPING OF ITS HAZARD IN CENTRAL YAMAL, RUSSIA

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Regular field and remote-sensing observations of thermocirques (TC) (retrogressive thaw slumps, RTS) in the tundra zone of the West-Siberian Plain lay a basis for assessing the dynamics of cryogenic landsliding and mapping its hazard using landscape indication of the depth to the tabular ground ice top and the attribution of recent TCs (RTS) to specific landscape complexes. Such observations and mapping are relevant in the context of the increased activity of cryogenic relief-forming processes in the Arctic since the beginning of the 21st century, caused by climate changes, especially significant at high latitudes. In the tundra zone of West Siberia, the most common landforms, indicators of cryogenic landsliding, are landslide cirques (LC) formed by series of active-layer detachment slides, and TCs formed by a number of earth flows. A considerable increase in the number and growth of TCs after 2012 is associated with reaching the top of ground ice layers widespread here, followed by thawing out of the ice layers. Our field observations in key sites are accompanied by classical photogrammetric UAV-survey of TCs. This allows detailed monitoring of the process activity, updating the indicators of the landforms and, further on, inventory and classification of slope cryogenic processes based on satellite data for the entire area of the West-Siberian tundra. A method of cartographic assessment of the TC hazard is proposed. The basis for such an assessment is the landscape-geomorphological differentiation of the territory, used to map the depth of tabular ground ice occurrence and identify features of TCs' activity based on regular field and remote-sensing observations. Our earlier study of active-layer detachment slides and LCs compared to the study of TC dynamics allows to discover the fundamental difference between the assessment of TC and of LC hazards which are opposite to each other. Active-layer detachment slides re-appear in the same place after ages of recovery of the surface and LCs are relatively stable for hundreds of years. Earth flows (RTS) may grow or re-appear in a matter of months and years. As a result, the TC activation is possible even within overgrown or stable LCs and TCs resulting from an increase in the air temperature (especially thaw index) combined with high summer precipitation due to the seasonal thawing of the tabular ground ice top. Thus, it takes several years to re-activate a TC by new earth flows in the same place, compared to than hundreds of years, needed for LC re-activation. The work is carried out within the framework of the state assignment project of the Earth Cryosphere Institute Tyumen Scientific Centre SB RAS (themes NoNo. FWRZ-2021-0012 and FWRZ-2026-0016).

Keywords: Cryogenic landsliding, thermocirques, ground ice



AUFEIS ISSUES IN ULAANBAATAR, MONGOLIA

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Aufeis is a widespread cold-region phenomenon and occurs repeatedly in Ulaanbaatar, Mongolia the world's coldest capital and home to most of the country's population. Despite Mongolia's vast territory, extreme climate, and high population concentration make aufeis a recurring urban hazard that damages households and infrastructure each winter. Rapid urbanization has expanded settlements into areas affected by natural processes, often without sufficient consideration of environmental risks, worsening aufeis impacts. Aufeis forms through complex interactions among climate, geological conditions, permafrost, soil properties, hydrology, and surface topography, causing its spatial extent to vary annually. Although authorities and residents take mitigation measures, they have been largely ineffective due to a limited understanding of the processes governing aufeis formation. Thus, identifying the factors influencing its spatial and temporal dynamics is essential. This study investigates long-term changes in aufeis extent and examines the natural conditions controlling its development. Landsat satellite imagery from 2009-2024 was used to analyze multi-year spatial dynamics, while high-resolution monthly maps were produced through UAV surveys during the 2023-2024 winter. Results show that aufeis generally begins forming in November, reaches its maximum in March, and melts by May. The annual aufeis area between 2009 and 2023 ranged from 0.01 to 0.03 km². Electrical resistivity tomography identified a fault at the boundary between permafrost and bedrock, coinciding with a groundwater spring. Water chemistry results indicated high hardness, confirming groundwater discharge. Spring water temperature remained above freezing (minimum 1.51 °C), indicating a perennial spring. The temperature of the spring stream was strongly correlated with air temperature, and sections of the stream froze during mid-winter. As the spring water loses heat while flowing downstream, freezing blocks flow toward the pond, forcing water to emerge at the surface and refreeze as aufeis each winter. Chemistry results also showed that both spring and river water contribute to aufeis formation. Climatic analysis indicates that the air-temperature regime has a limited influence on interannual aufeis extent because groundwater-fed aufeis is relatively insensitive to seasonal climate variability. Instead, summer precipitation exerts a stronger effect on aufeis size. In 2023-2024, the aufeis expanded to 0.04 km² significantly larger than in previous years—and spread into residential areas, causing severe damage. Snowfall that winter was exceptionally high, and freezing n-factor values (0.05-0.11) demonstrated strong snow-insulation effects. Thick snow prevented ground freezing, enabling spring water to flow across unfrozen surfaces and accumulate in settled areas. In some households, soil water emerged beneath yurts and pit latrines, further enlarging the aufeis. Chemical analysis revealed elevated NH₄ concentrations in aufeis samples, indicating that wastewater from pit latrines had surfaced and contributed to aufeis expansion. Such contamination poses potential health risks to residents and the wider urban population. Overall, changing spatial patterns of aufeis negatively affect living conditions, damage infrastructure, and cause substantial economic losses. This study improves methodologies for investigating aufeis by combining remote sensing with field measurements and provides essential insights for mitigating aufeis impacts in urban environments.

Keywords: Aufeis, icing, spatial distribution, n-factor



SPATIAL VARIABILITY AND DECADEAL CHANGE IN FLOW DURATION OF INTERMITTENT PERMAFROST RIVERS IN CENTRAL YAKUTIA (EASTERN SIBERIA)

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Many small and medium-sized rivers in permafrost regions cease to flow during the cold season. Changes in flow duration and in the start and end dates of zero-flow periods directly affect water availability and provide an integrated signal of hydro-cryospheric change. Yet the spatial controls and recent trends in intermittency remain poorly quantified for the continuous permafrost zone in Eastern Siberia. We analyzed daily discharge observations for 23 gauged catchments with intermittent flow. For each river, we derived annual flow duration (days with recorded discharge), the average date of spring flow resumption, and the average date of flow cessation (start of the zero-flow period). We then evaluated relationships between these metrics and climatic, topographic, and landscape characteristics. For a subset of eight rivers with long-term discharge records, we quantified decadal changes in flow duration and in the timing of flow onset and cessation and related them to changes in air temperature and precipitation. Across the study set, mean flow duration ranged from 62 to 288 days. The average date of spring flow resumption varied from 24 April to 23 May, while the end of flow ranged from 29 July to 3 February of the following year. Rivers in northeastern Central Yakutia exhibit the shortest flow seasons, the highest interannual variability (coefficient of variation up to 0.57), and recurring summer drying. Catchment area and air temperature are key predictors of average flow duration, whereas the influence of precipitation on mean duration is weak. Seven of eight long-term records show a small, statistically insignificant increase in flow duration (+1.3 to +4.8 days per decade), driven by earlier spring flow resumption and later cessation in autumn/winter. Earlier onset is associated with warmer conditions in April-May. Shifts in flow cessation reflect contrasting controls: liquid precipitation is more influential where runoff ends early (sometimes before sustained sub-zero air temperatures), typically in smaller catchments, whereas air temperature in autumn and early winter are more important where flow ceases later. These results establish a regional baseline for intermittency timing in permafrost rivers and provide process-relevant constraints for water-resource planning and permafrost-hydrology model evaluation under continued warming.

Keywords: Intermittent rivers, zero-flow period



FACTORS CONTROLLING EXTRA-ZONAL PERMAFROST DISTRIBUTION IN BLOCK SLOPES AT LOW ELEVATIONS: A CASE STUDY IN HOKKAIDO, JAPAN

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Small and isolated permafrost exists at low altitudes where the Mean Annual Air Temperature (MAAT) is above 0°C in mid-latitude mountain areas. Intense cooling via air ventilation through voids in talus or block slopes, as well as ice formation from the refreezing of snowmelt water, are considered the primary drivers of this permafrost formation. This study aims to test the hypothesis that snowmelt water flow channels control the distribution patterns of extra-zonal permafrost bodies. The study sites are located on the slopes of lava domes within the Shikaribetsu volcano group in Hokkaido, Japan. Electrical Resistivity Tomography (ERT) was employed to detect the permafrost bodies. Tomography profiles across three transects revealed that high-resistivity areas are concentrated in the lower parts of block slopes and in valley bottoms filled with blocky materials. Drilling operations at two sites (Mt. Nishi-Nupukaushinupuri and Mt. Higashi-Nupukaushinupuri) confirmed that perennial ice is preserved where these high-resistivity zones were detected. Furthermore, ground ice formation was monitored at two locations where ERT soundings were conducted. The results showed that ice formed during the snowmelt season at both sites, indicating that water flow within the voids of blocky materials is fundamental to perennial ice formation. In conclusion, extra-zonal permafrost distribution is restricted to lower slopes and valley bottoms where snowmelt water infiltrates and flows through the block slopes.

Keywords: Block slope, perennial ice



MODELLING OF GROUND SURFACE THERMAL PROPERTIES BASED ON SNOWPACK CHARACTERISTICS IN NORTHERN ALASKA

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Modelling ground surface thermal properties (GSTP) beneath snow coverage is a key point for understanding the impact of climate change on permafrost and ecosystem dynamics. Although several studies in northern Alaska have investigated the spatial and temporal variability of snow depth and snow water equivalent, most models operate at coarse spatial resolutions, and fine-scale applications (≤ 30 m) remain limited. Furthermore, explicit modelling of surface offset (SO, °C) and ground surface temperature (GST, °C) driven by snow properties is lacking. In this study, we analyze the relationships between snow characteristics and GSTP and develop a fine-scale spatial modelling framework based on easily measurable snow parameters. The research was conducted near Toolik Field Station (Alaska) during the spring melt and fall seasons of 2023, 2024, and 2025. In situ data collection from snow pits were used to build multivariate regression models aimed at identifying the main controls on GST and SO. Results indicate that snow depth, number of snow layers, and snow temperature are the most influential predictors of SO and GST, with season emerging as the primary discriminant, as confirmed by t-tests. Additionally, season-specific models highlight the influence of ice layers and faceted snow. Among the analyzed parameters, snow depth consistently emerged as one of the most influential and robust predictors across seasons and models, also representing the most easily measurable snow parameter. For this reason, regressions between GST/SO and snow depth during late-spring 2025 and early fall 2025 were used to derive an empirical function for fine-scale GST and SO spatialization.

Keywords: Arctic Tundra, GST, offset, snow



INTERACTION BETWEEN SNOW, WIND AND VEGETATION IN A PYRENEAN SUBALPINE ENVIRONMENT: IMPLICATIONS ON SPATIAL VARIABILITY OF SOIL TEMPERATURE AND MOISTURE

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Twenty-five very high-resolution snow distribution and snow probability maps (20×20 cm) were produced using Unmanned Aerial Vehicle (UAV) LiDAR technology during the period 2022-2025 in a subalpine area of the Spanish Pyrenees. The study site is located at 1,700 m a.s.l., is exposed to strong winds, and is covered by a diverse assemblage of Mediterranean shrubs. Snow conditions are dominated by marginal snowpacks, with depths rarely exceeding 100 cm, exhibiting very high spatiotemporal variability and remaining in an isothermal state for most of the season. Gradient boosted tree models were used to analyse the influence of vegetation and topographic variables on snow dynamics and, in turn, on the spatial variability of soil temperature and moisture. These variables were measured using 30 TOMST sensors and two sets of thermistors monitoring vegetation and soil temperatures. Results show that the sheltering effect of shrubs, together with protection from solar radiation, explains the highest probabilities of snow presence. This effect generally dominates over longwave radiation emission, which at certain times of the year has a remarkable capacity to induce localized snowmelt in the immediate surroundings of vegetation. The combined effects of wind and vegetation generate highly patchy snowpacks, which account for the large variability observed in soil temperature. Snow-free areas exhibit a high number of frozen-soil days, frequent freeze-thaw cycles, and very low soil moisture. In contrast, longer-lasting snow patches on the leeward side of vegetation show very few days with frozen soils and substantially higher soil moisture. Overall, the results highlight the extremely high diversity of microclimates and microenvironments in Mediterranean mountain regions, as well as their vulnerability to climate warming, which may significantly shorten snow duration and induce major shifts in the thermal and moisture dynamics of these environments.

Keywords: Soil humidity, temperature, snow, shrubs



SEA ICE AREA VARIATIONS AND NORTHERN EURASIAN GROUND TEMPERATURES

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Large-scale atmospheric patterns were recently found to explain similarities in temporal variations of different terrestrial cryosphere variables across the Arctic. In addition, sea ice area patterns have been previously linked to changing vegetation greenness. Similarities in sea ice properties and permafrost features have been rarely investigated to date. Spatially and temporally consistent records are needed in order to identify and quantify such linkages. Gridded data sets of permafrost ground properties such as for example available from the European Space Agency Climate Change Initiative (ESA CCI+) Permafrost project allow regional comparisons of permafrost and sea ice dynamics. Previous studies focused on regional patterns across tundra regions. Here we extend the analyses south to 60°N (including both tundra and boreal permafrost regions) exploiting the Arctic Sea Ice and Land Parameter Correlations (ASILaC) database, which provides correlations between MAGT and monthly Sea Ice Area (SIA) for the entire Arctic and specific sea ice basins. Mean annual ground temperature (MAGT, 2m depth) records from CCI+ Permafrost were compared to monthly Sea Ice Area (SIA) for several basins across the Arctic (2000-2019). High correlations (partially larger than $R^2 > 0.8$) were found with sea ice basins located across the Arctic Ocean. The similarities with SIA dynamics, however, vary spatially and temporally across the Arctic. Here, we specifically focus on patterns for Northern Eurasia. For example, Western Siberian ground temperature variations show similarities with SIA in the East Siberian Sea (autumn) as well as Beaufort Sea (late winter), and Eastern Siberian MAGT with Chukchi Sea SIA variations (mid-winter and early summer). Central Siberian MAGT is linked with Fram Strait and Barents Sea SIA in late winter and increasingly with the Beaufort Sea SIA towards early summer. Findings underpin the role of Arctic temperature variations and large-scale atmospheric patterns for Northern Eurasian permafrost across the entire year. Eventually we discuss these findings in the context of recently observed permafrost landscape feature dynamics.

Keywords: Permafrost, sea ice, remote sensing



**4B: PERIGLACIAL DYNAMICS IN HIGH-LOW LATITUDES
POSTER**



SPATIOTEMPORAL DYNAMICS OF RIVER AUFEIS ALONG THE EG AND IDER RIVERS, MONGOLIA (2017-2025)

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Recent climate change has led to a decline in the frequency and spatial distribution of cold-related natural phenomena in Mongolia. However, studies examining temporal changes in aufeis extent remain limited. Quantifying these changes is essential for assessing ecosystem stability and providing baseline information for predicting future environmental impacts. This study investigates the temporal dynamics of aufeis along the major tributaries of the Selenge River basin, the Eg and Ider Rivers, between 2017 and 2025, and explores their relationship with climate variability. High-resolution (5 m) Planet satellite imagery was used to delineate ice cover established from late March to mid-April each year. Aufeis was calculated using ArcMap, allowing accurate assessment of spatial patterns and morphological characteristics. Precipitation and mean air temperature data from nearby meteorological stations were used to relate these variations to climate conditions. Results indicate that the maximum aufeis along the Ider River occurred in 2021 (1,404.7 ha), while the minimum was in 2017 (410.3 ha). Along the Eg River, maximum and minimum extents were recorded in 2020 (1,992.4 ha) and 2018 (1,202.2 ha), respectively. Principal Component Analysis (PCA) showed that the first two components explained 79-81% of the total variance. PC1 (45-46%) indicated that aufeis remained stable or slightly decreased during relatively warm and dry years, whereas PC2 (33-35%) suggested that cold years favored ice formation. PC3 (19-20%) reflected an inverse influence of precipitation. These findings demonstrate that aufeis along the Ider and Eg Rivers is influenced by climatic conditions, decreasing in warm, dry years and increasing in cold, wet years. The results provide critical baseline information for evaluating the effects of climate change and the resilience of riverine ecosystems in the region.

Keywords: Aufeis, area, Eg river, Ider river, PCA



THE RESULTS OF THE ACTIVE LAYER CHANGES OBSERVATIONS IN POLYGONAL PEATLANDS ALONG LAKESHORES IN THE NORTH OF THE PUR-TAZ INTERFLUVE IN 2025

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Recently, an increase in the sum of positive air temperatures and the average annual air temperature has led to several environmental changes in the Arctic. Permafrost temperature and seasonal thawing depth increase affects the state of soil-cryogenic complexes of polygonal peatlands. Since 2016, detailed complex study of frozen polygonal peatlands have been conducted in the Pur-Taz interfluve. The work includes traditional field methods: borehole drilling (for a lithological description of the active layer and the upper (transient and intermediate) layers of the permafrost) and measuring of seasonal thawing depth with a metal probe. In 2025 regular observations of changes in polygonal peatlands along lakeshores were continued. Observation sites are arranged in polygonal peatlands located in khasyreys with peat deposits from 0.3 m to 5.5 m thick, at different geomorphological levels. It is noted that from 2021 to 2025 the peatland with 0.3 m peat layer and peatlands with low excess over the lake water limit are characterized by an increase in the thawing depth up to 4 cm/year with an average thawing equal 80 cm. Compare, the increase in the thawing depth in massive peatlands with high coastal scarps varies from 0 to 1 cm/year. Study of polygonal peatlands in the area of interaction with lakes shows that, despite the different lithological structure and landscape-geomorphological conditions of observation sites, there is a gradual increase in the thawing depth and thawing of the upper layers of the permafrost, which leads to the development of thermokarst and the degradation of soil-cryogenic complexes of polygonal peatlands. This research was funded by the Russian Science Foundation (project No. 25-17-00010)

Keywords: Polygonal peatlands, soil-cryogenic complex, thawing



CONTRASTING GEOCHEMICAL TRACERS OF PERMAFROST THAW IN MARGINAL COLD REGIONS: METALS, ISOTOPES, AND PAHS FROM THE CAUCASUS AND MARITIME ANTARCTICA

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Permafrost degradation in marginal cold regions modifies hydrological pathways and promotes the mobilization of dissolved constituents from soils, sediments, and bedrock. However, the hydrochemical response of periglacial freshwaters strongly depends on local environmental conditions, catchment characteristics, and available geochemical tracers. This study presents a comparative analysis of permafrost-affected waters from two climatically and geographically contrasting regions: the alpine Caucasus (Abudelaury Glacier forefield, Georgia) and Maritime Antarctica (King George Island, Lions Rump Peninsula). In the Caucasus, surface waters from proglacial streams and lakes were analyzed for trace metals and polycyclic aromatic hydrocarbons (PAHs) to assess the mobilization of geogenic components and organic contaminants during active layer deepening in a region influenced by long-range atmospheric transport and local human presence. In contrast, Antarctic waters were investigated using trace metal concentrations combined with stable water isotopes ($\delta^{18}\text{O}$, $\delta^2\text{H}$), enabling the identification of meltwater sources, hydrological mixing processes, and metal mobilization under near-pristine conditions with minimal direct anthropogenic impact. Despite the use of different geochemical proxies, both datasets provide complementary insights into permafrost-controlled hydrochemical processes. Caucasian waters exhibit higher metal concentrations and detectable PAH signatures, reflecting enhanced chemical weathering, sediment-water interaction, and the release of atmospherically deposited organic compounds during seasonal thaw. Antarctic freshwaters are characterized by low mineralization and stable metal levels, while isotopic compositions reveal distinct contributions of snowmelt, glacier melt, and ground ice, highlighting the dominant role of hydrological routing rather than chemical enrichment. The results demonstrate that permafrost thaw does not produce uniform hydrochemical signals across regions but instead activates locally relevant geochemical pathways. Metals act as a common indicator of geogenic mobilization in both environments, while isotopes and PAHs serve as region-specific tracers capturing hydrological controls and organic matter release, respectively. This comparative framework emphasizes the importance of flexible, environment-adapted tracer selection when assessing permafrost-water interactions. By integrating alpine and polar periglacial systems, this study contributes to a broader understanding of how marginal permafrost regions respond to warming and how diverse geochemical indicators can be jointly interpreted to assess freshwater sensitivity to permafrost degradation.

Keywords: Hydrochemistry, periglacial waters, geochemical tracers, cold regions



4C: PERMAFROST AND ECOSYSTEM INTERACTIONS

Conveners: **Robin B. Zweigel**¹, **Anarmaa Sharkhuu**², **Ayumi Kotani**³, **Simone Stuenzi**⁴, **Sander Veraverbeke**⁵, **Hoatek Park**⁶ & **Temuujin Khurelbaatar**⁷

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Permafrost underpins coldregion ecosystems by regulating soil moisture, nutrient cycling, and vegetation patterns, yet thawinduced feedbacks can accelerate carbon fluxes and alter biodiversity. This session seeks studies integrating field measurements, remote sensing, and ecosystem modelling to reveal how permafrost dynamics drive shifts in plant communities, greenhousegas exchange, and biogeochemical pathways. We encourage contributions on ecohydrological coupling, microbial processes, and resilience assessments that inform both scientific understanding and landmanagement strategies in thawing landscapes.





BIOGEOCHEMICAL FEATURES OF PERMAFROST-AFFECTED SOILS: RESULTS FROM MULTI-YEAR MONITORING IN POLAR REGIONS

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Soils play a crucial role in the processes of accumulation, transformation, redistribution and migration of various chemical compounds and elements in polar ecosystems and serve as a linkage between the small and large geological cycles of matter and energy fluxes (Tarnocai et al. 2009; Zubrzycki et al. 2014). In this work we present the results of long-term research performed in both Arctic and Antarctic regions with the aim of comprehensive investigation of biogeochemical features of permafrost-affected soils. We will present data on detailed investigation of biogenic-abiogenic interactions, micromorphological features, physical-chemical and biological features, molecular composition of organic matter, microbiomequalitative and quantitative characteristics, pollution status of soils in remote areas of the Arctic (Yamal region, Svalbard archipelago, Yakutia) and Antarctic (Bunger Hills, Schirmacheroasis, Larsemann Hills, Maritime Antarctica) regions. We will present biogeochemical features of poorly studied soils developing under various conditions of soil formation in East Antarctica oases in a wide geographical area (from 11°49'26" E to 100°46' E). It has been shown that the main limiting factor for the development of organisms and soil formation on loose substrates of East Antarctica oases is insufficient moisture rather than low temperature. At the same time, local mitigation of the harsh soil formation conditions existing in Antarctica (especially in offshore oases) plays a crucial role in increasing the quantitative reserves of organic matter - this is especially typical for soils of wet valleys, wind shelters and rock baths, as well as soils under modern ornithogenic influence, characterized by increased carbon, nitrogen content and with their narrow ratio. It was shown that the rate of mineralization in the lower mineral horizons of the studied soils is usually lower than in the surface horizons. It is possibly that the composition of soil humic acids (the ratio of carboxyl groups and aliphatic components) changes under the influence of an ornithogenic factor, which can cause a change in the rate of mineralization of organic matter. Consequently, structural changes in the organic matter system under the influence of the ornithogenic factor play an essential role in the stabilization of soil organic matter. We will also present data on soils of the Arctic, where most of studied sites were characterized predominantly by acidic to strong acidic pH. Profile distribution of carbon, nitrogen and C:N ratio showed non-gradual changing with the depth due to manifestation of cryopedogenesis. Mean soil organic carbon stocks for the study area were $7.9 \pm 2.2 \text{ kg m}^{-2}$ (for 0-10 cm layer), $15.0 \pm 5.5 \text{ kg m}^{-2}$ (for 0-30 cm), $24.0 \pm 8.0 \text{ kg m}^{-2}$ (for 0-100 cm). Results of solid-state ^{13}C NMR spectroscopy showed low amounts of aromatic fragments in studied soils. All studied soils are characterized by predominance of aliphatic structures, and also carbohydrates, polysaccharides, ethers and amino acids. Our results provide further evidence of high vulnerability and sensitivity of permafrost-affected soils organic matter to Arctic warming. Consequently, these soils may play a crucial role in global carbon balance under effects of climate warming. This work has been performed within the framework of the Karelian Research Centre RAS research task № FMEN-2025-0002.

Keywords: Cryosols, soil organic matter, permafrost



FIRE MEDIATED FOREST DENSITY INFLUENCES ON ACTIVE LAYER PROCESSES IN SIBERIAN LARCH FORESTS

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A substantial portion of the continuous permafrost zone lies within the larch dominated boreal forest region of eastern Siberia. Forest cover exerts important influences on active layer thermal dynamics, and varies widely as a function of complex interactions between wildfire history and stand age. For example, mid-successional stands in northeastern Siberia have fractional canopy cover ranging from approximately 10% to upwards of 70%. Such large canopy cover variation, and accompanying shifts in understory vegetation composition, alters surface energy partitioning through impacts on processes such as ground shading, soil moisture utilization, and snow accumulation, among others. Several recent years with above average burned area in these Arctic larch forests may lead to substantial changes in forest cover across the region, with important implications for active layer dynamics and related climate feedbacks. These changes are especially important for understanding permafrost carbon climate feedbacks due to the presence of carbon- and ice-rich yedoma permafrost that is vulnerable to abrupt thaw that will mobilize pleistocene aged permafrost carbon. This study synthesizes results from a series of projects investigating variation in ecosystem and active layer properties across gradients in forest canopy cover and tree density. The work focuses largely on a series of forest stands within the perimeter of a single fire that burned ca. 1940, with tree density ranging from ~0.4 trees m⁻² to upwards of 4 trees m⁻². Results include a combination of new and previously published analyses that examine differences in surface energy exchange, evapotranspiration, and active layer dynamics between high- and low-density larch forests (71% and 13% canopy cover, respectively). Using observations of net radiation above and below the forest canopy, soil temperatures and heat flux, canopy dynamics, and transpiration, we examined how fire induced changes in forest density alter land surface energy dynamics. We observed the expected reductions in albedo in denser forests, particularly during periods of snow cover. However, we also found that differences in canopy cover had important effects on soil temperatures and permafrost thaw depths at scales ranging from diurnal to seasonal. In addition, we found that differences in transpiration between the two stands varied widely with key environmental drivers and were small when water was limiting. We consider these results in the context of intensifying fire regimes and accompanying ecosystem recovery under future climate scenarios.

Keywords: Siberia, larch, wildfire, active layer



ANTHROPOGENIC IMPACTS ON SOIL DISTRIBUTION AND PROPERTIES UNDERLAIN BY ISOLATED PERMAFROST IN NORTH-EASTERN MONGOLIA

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Isolated patches of permafrost, where ground thermal changes are affected by ecosystem factors such as vegetation cover rather than climate, may be vulnerable to environmental disturbances in semiarid regions. However, the impacts of ecosystem factors remain under-evaluated in Mongolia. Moreover, inland wetlands provide multiple ecosystem services, such as water filtration and storage, habitat for migratory birds, and support for diverse wildlife. They also function as important water sources and forage pastures for livestock and agricultural production. This study explores the impact of livestock grazing on soil properties of permafrost-affected wetlands and adjacent upland grassland soil groups in the Khurkh River Valley, north-eastern Mongolia. Composition and coverage of vegetation at 35 study sites were quantified from triplicate quadrat harvests (clipped at the soil surface). Pasture degradation level was categorized as non-degraded, slightly degraded, or moderately degraded based on the rate of occupation by deterioration indicator species. In order to characterize spatial variability in soils, soil physico-chemical properties from 45 cores (0-30 cm) were analysed. The impact of pasture degradation on surface soils varies according to soil groups. In grassland soils (Phaeozems, Kastanozems, Chernozems), livestock trampling and compaction reduce water infiltration and accelerate organic matter loss, leading to declining soil carbon and nitrogen pools with increasing degradation. Conversely, Cryosols and Histosols beneath permafrost were governed by strong freeze-thaw processes with high moisture availability and slow decomposition. These conditions promote organic matter accumulation even where the pasture plant community has degraded. The contrasting responses among soil groups highlight the need for soil-specific management to protect the valuable wetland ecosystems underlain by isolated permafrost in semi-arid Mongolia. Future research should aim to quantify the coupled influence of biological, chemical, and physical processes on the shaping of grazing impacts across different soils. Moreover, long-term monitoring and experimentation are necessary to identify degradation thresholds and effective resilience-focused interventions.

Keywords: Soil variables, degradation, permafrost wetland



DIFFERENTIATING ACTIVE AND INACTIVE ROCKGLACIERS BASED ON WOOD ANATOMICAL AND ISOTOPIC ANALYSES OF SHRUBS

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The presence of shrubs growing in permafrost areas, and here specifically on rockglaciers, is nowadays common in many alpine and arctic regions reflecting their ecological adaptability as response to warming climates. Vegetation patterns on rock glaciers frequently show a progression from unvegetated active fronts to increasingly vegetated, shrub-dominated relict lobes. This succession reflects declining movement rates, surface stabilization, and changing thermal conditions. Here, shrubs serve as bioindicators of permafrost stability, drivers of soil development, and agents of ecological succession. Understanding shrub-rockglacier interactions is therefore essential for assessing future landscape evolution and permafrost response to climate change. Combining tree-ring analyses and rockglacier dynamics is a topic rarely investigated in permafrost research. In our study we analyzed the anatomical structure of the xylem in roots and branches of shrubs growing on active and inactive rockglaciers. In addition, we investigate the isotopic composition of the plants and their surrounding (soil, water). To account for differences in alpine and arctic rockglacier dynamics, we sampled shrubs growing on rockglaciers in Greenland (Disko Island) and the Swiss Alps (Turtmanntal). The anatomical structure of shrub branches and roots show almost no differences in vessel sizes of the above ground parts while clear differences occur between the vessel sizes in roots of the same shrubs growing on active and inactive rockglaciers, respectively. It is known from former studies that mechanical stress results in a size reduction of the conducting tissue of broadleaved trees. Consequently, these vessel size differences in the roots of shrubs growing on active rockglaciers are likely caused by the differences in mechanical stresses exerted to the roots, and to a lower extend, by differences in the thermal regime causing differences in soil temperature close to the surface. These anatomical findings are supported by significant differences in $\delta^{18}\text{O}$ values of shrubs growing on active rockglaciers over the last three decades compared to shrubs growing on inactive rockglaciers. Isotope values indicate a stronger change in the hydrological setting caused by locally increasing soil and air temperatures that nearby sites without permafrost do not experience to the same extend. Understanding the effect of site differences, i.e., in the thermal regime of active and inactive rockglaciers, on the development of shrubs growing on rockglaciers can provide us with information about changes in surface movement and hydrological processes in both arctic and alpine permafrost regions.

Keywords: Vegetation, dendroecology, xylem, isotopes, rockglaciers



PROSPECTS FOR LAND-MANAGEMENT STRATEGIES AND TRANSDISCIPLINARY RESEARCH IN A PERMAFROST REGION OF NORTHERN MONGOLIA

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This contribution will assess the interaction of permafrost-based ecosystems and different types of land use: pastoralism, forestry, and land cultivation (tillage) for crop production. Based on explorative research in the northeastern area of Selenge Aimag, Mongolia, this presentation will also ask how to advance transdisciplinary research on permafrost and land use methodologically.

- Our short field study in March 2019 in Khuder comprised interviews with local experts and land users. In addition, we compiled one 2-km transect through the valley of Khudriin Gol, documenting vegetation and de-facto land use. We found that the dynamics of permafrost degradation are less influenced by the area's history of crop farming than by recent activities of logging. Thus, logging and subsequent permafrost degradation in this as well as other areas of northern Mongolia may lead to profound changes in regional hydrological conditions and degradation of pastures, hay meadows, and fields, all being important resources in the regional economy. Meanwhile, the rapid increase in livestock over past years is also contributing to ecosystem change, with manifold effects on permafrost which call for scientists' and land users' attention.

- Combining the findings of this explorative study with earlier results of the IPA Action Group on Permafrost and Culture (2014-2019) and insights from the IPA Action Group on Permafrost Agroecosystems Action Groups (2022-2023), this presentation seeks to achieve a more nuanced understanding of permafrost and ecosystem interactions mainly through the lens of land-management strategies. Simultaneously, it provides manifold linkages to the study of traditional livelihoods in permafrost regions.

Keywords: Agriculture, forestry, pastoralism, land use, Selenge



THE SULFUR ISOTOPIC SIGNATURE OF PERMAFROST DEGRADATION IN RETROGRESSIVE THAW SLUMPS AND IMPLICATIONS FOR PALAEOFAUNAL ISOTOPE ANALYSIS

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Permafrost thaw is key feedback in the Earth's climate system and a major source of carbon dioxide to the atmosphere. Thaw of permafrost perturbs the biogeochemical cycles of many critical nutrients, including the sulfur cycle. Recent palaeofaunal isotope analyses reveal a significant sulfur isotope ($\delta^{34}\text{S}$) excursion spanning the Last Glacial Maximum (LGM) and subsequent deglaciation, likely in part caused by widespread permafrost thaw. In this study we analyse the $\delta^{34}\text{S}$ changes associated with the thaw of modern permafrost via retrogressive thaw slumping on a 1000-km long transect through the permafrost zones of western Arctic Canada. Thaw slumping releases a previously sequestered reservoir of soil sulfide minerals such as pyrite, which are in turn oxidised, manifesting as a more negative $\delta^{34}\text{S}$ signal in soil water sulfate than surrounding pristine (control) permafrost sites. This distinctive signal is inherited by plants, and ultimately herbivores that feed on active slump lobes, though the magnitude of the offset relies on substrate type and may be damped by scale, locality, and age effects in small or old/stabilised slumps (Fig. 1). These results reveal how the release of formerly sequestered mineral sulfides impart a negative $\delta^{34}\text{S}$ signal in thawed material and crucially record $\delta^{34}\text{S}$ variation of equivalent magnitude to the excursion spanning the LGM. These modern analogue results evidence the major impact of permafrost thaw on plant and therefore herbivore $\delta^{34}\text{S}$ and complicate its use as a palaeodiet and palaeomobility tracer.

Keywords: Permafrost thaw, sulfur isotopes

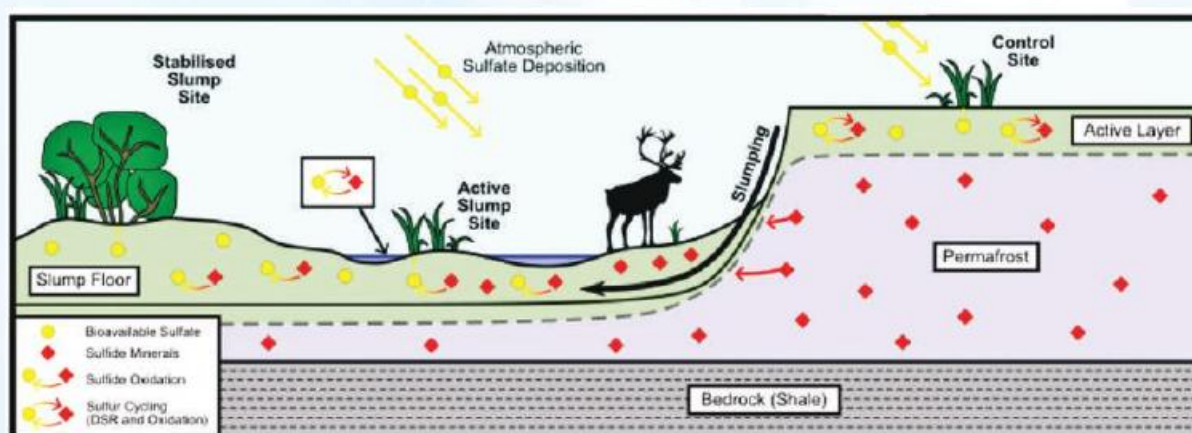


Fig 1. Schematic of the proposed mechanism of sulfur transport during retrogressive thaw slumping. DSR: dissimilatory sulfate reduction.



FOREST CANOPY REGULATION OF PERMAFROST THERMAL DYNAMICS: IMPLICATIONS FOR FROZEN CARBON VULNERABILITY

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Vegetation-snow-permafrost interactions control ground thermal regimes and soil organic carbon (SOC) vulnerability in high-latitude ecosystems, yet mechanistic understanding of canopy-mediated thermal regulation across vegetation gradients remains limited. Vegetation transitions, including shrub expansion, treeline advance, and forest densification, together with disturbance-driven shifts such as fires, thermokarst, and insect outbreaks, are altering permafrost stability through competing seasonal processes. Using the numerical land surface model CryoGrid, equipped with a multilayer canopy module, we quantify vegetation-snow-permafrost coupling across boreal forests, which cover approximately a quarter of the continuous permafrost zone. Simulations for deciduous needleleaf, evergreen needleleaf, and deciduous broadleaf forest types demonstrate that canopy thermal buffering, dominated by shortwave radiation attenuation in summer, with additional contributions from snow interception, sublimation, and suppressed turbulent heat exchange, maintains 59 Pg SOC in a perennially frozen state (32% of forested permafrost carbon), substantially exceeding aboveground and belowground biomass pools (7-19 Pg). Forest removal scenarios indicate potential mobilization of frozen SOC through active layer deepening (40 Pg) and thermokarst processes (19 Pg), revealing an order-of-magnitude asymmetry between biomass carbon storage and frozen SOC vulnerability. In contrast to forest cooling, shrub canopies are expected to promote net ground warming through enhanced winter snow accumulation and associated thermal insulation that exceeds sparse summer shading effects. Systematic analysis and quantification of these opposing thermal regimes across climate and vegetation gradients is needed to identify critical canopy structural thresholds governing transitions between net warming and cooling effects on permafrost. Additionally, forest conservation strategies in continuous permafrost zones must account for canopy-mediated thermal protection of frozen SOC, which far exceeds the size of biomass carbon pools.

Keywords: Ecosystem, permafrost, interactions, ecosystem services, carbon pools



CLIMATIC AND TOPOGRAPHIC LIMITS OF PERMAFROST-FOREST SYSTEMS IN CENTRAL MONGOLIA - INSIGHTS FROM NUMERICAL MODELLING WITH CRYOGRID

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Forest and permafrost are co-located on north-facing slopes across the forest-steppe ecotone in central Mongolia, a pattern also observed throughout the cold and semi-arid regions of Central Asia. Previous research suggests that forest and permafrost systems at least partially sustain another through mutually beneficial interactions: permafrost acts as an impermeable layer that elevates water tables keeping soil moisture available for plant growth, while deciduous forest cover provides shading and insulating litter layers that limit ground thaw in summer. These interactions may be especially critical during droughts, when gradual increases in thaw depth can release water from near-surface ground ice, sustaining forest survival. Yet, the coupled dynamics of permafrost and forest within local energy and water balances and their role in defining the spatial limits of these ecosystems are not fully understood. This knowledge gap has motivated the recent incorporation of a vegetation module capable of simulating forest cover into the permafrost-specific CryoGrid Community Model. In this study, we examine the climatic and topographic limits of forest-permafrost systems in central Mongolia. We first analyse forest cover and terrain data across a region that transitions from densely forested, high-elevation areas in the north to sparsely forested and open steppe in the south. Our results show that, outside the highest elevations, forest cover is confined to north-facing slopes steeper than approximately 7°, corresponding to areas with below-average potential incoming solar radiation (PISR). We then conduct numerical experiments using CryoGrid to simulate forest-permafrost interactions along an ~80 km transect spanning both a climatic gradient from warmer, drier conditions in the south to cooler, wetter conditions in the north and a PISR gradient. The simulations reveal that forests in the southern part of the transect exposed to near-average PISR experience water limitations under normal conditions, consistent with the absence of forest on such slopes in reality. During drought periods, the simulations show that forests in the southern transect under low PISR and those in the north under near-average PISR both experience reduced transpiration capacity. These responses may help explain the observed patterns of forest dieback and increased wildfire susceptibility during dry periods. Our next step is to disentangle the contribution of permafrost melt water to drought resilience by conducting targeted simulations in which permafrost is artificially removed. This will allow us to isolate and quantify the role of melt water released from permafrost on forest ecosystem survival in this climatically sensitive region.

Keywords: CryoGrid, forest-steppe ecotone, drought resilience



CHEMICAL IMPACTS ON SURFACE WATERS OF A DEGRADING PERMAFROST BANK OF THE KOLYMA RIVER (NE SIBERIA)

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Degrading permafrost may change chemistry of surface waters, e.g. by releasing legacy carbon or mercury. An increasing scientific interest focuses on chemical types and quantities remobilised from this source. Here, we investigate the short-term chemical impacts of a large yedoma outcrop thaw (Duvanny Yar,) on the concentrations of contaminants, such as heavy metals or polycyclic aromatic hydrocarbons (PAHs), in the waters of a Great Arctic River (Kolyma). We analysed concentrations of PAHs (with GC-MS) and other organic compounds, as well as metals and metalloids (using ICP-MS and ICP-OES), in 28 water samples from the lower Kolyma river (in north-eastern Siberia) and other water bodies in the area, including permafrost meltwater creeks. Total concentrations of 16 PAHs reached $30.2 \cdot 103$ ng/L, mainly in particulate phase (in suspended sediment), with highest concentrations in permafrost creeks and in Kolyma near the Duvanny Yar outcrop. These sampling locations experienced also elevated concentrations of heavy metals, such as As, Cu, Co, Mn and Ni (in the dissolved phase), sometimes also of dissolved phosphorus. Similarly, thermokarst lake waters were enriched in selected heavy metals, especially near lake bottom. Together, the collected chemical and hydrological information points to the permafrost thaw as likely source of a range of potentially harmful and neutral chemicals both. Their potential to impact downstream ecosystems encourages further studies on concentrations, sources, transport dynamics and environmental fate of such chemicals, with respect to toxic level thresholds. Acknowledgments. We thank N. Zimov and the North-East Science Station in Cherskii team for hospitality in 2021; V. Efimov and S. Chalov, for aid in fieldwork; F. Pawlak and B. Knoebelsdorf, for laboratory analysis support. Funds are acknowledged from: the National Science Centre of Poland (NCN) grant PER2Water (2021/41/B/ST10/02947, PI: D. Szumińska); INTERACT, H2020-EU.1.4.1.2. grant PollAct (730938; for fieldwork, PI: D. Szumińska); Research Potential Maintenance at Gdansk Tech and KWU.

Keywords: Yedoma thaw, organic chemicals, metals



PROJECTION OF THE STATUS AND FUTURE SHIFTS OF TOPSOIL ORGANIC CARBON STOCKS IN NORTHERN HEMISPHERE PERMAFROST REGIONS: PATTERNS AND DRIVERS

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The Northern Hemisphere (NH) permafrost areas harbor vast reservoirs of soil organic carbon (SOC), which are potentially at serious risk of release under ongoing climate change. However, projections of future changes in SOC stocks in these regions remain subject to large uncertainties, largely due to differences in model structures and limited representation of spatial heterogeneity. In this study, we constructed an integrated approach that combines space-for-time substitution with a machine learning model to estimate the current status of surface (0-30 cm) SOC stocks in NH permafrost regions and to project their future changes throughout the 21st century under various Shared Socioeconomic Pathways (SSPs). The results indicate that approximately 224.2 Pg C were stored in NH permafrost regions during the baseline period (1981-2000). Total surface SOC stocks are projected to remain relatively stable by the end of the 21st century under the low-emission scenario SSP1-2.6 ($-0.5 \pm 0.9\%$), whereas a substantial loss of about $-8.5 \pm 3.5\%$ is projected under the high-emission scenario SSP5-8.5. Spatially, future SOC increases are mainly concentrated in the continuous permafrost zone, while widespread SOC declines are identified across most discontinuous, sporadic, and isolated permafrost regions, particularly near the southern permafrost boundary. Ecosystem-specific responses further reveal contrasting patterns, with grasslands and deserts projected to function as net carbon sinks, while forests and wetlands exhibit the largest SOC losses and dominate the total regional decline. Strong regional contrasts in driving mechanisms are also identified: temperature exerts the strongest control on SOC dynamics in the northern circumpolar permafrost region through a pronounced nonlinear threshold effect, whereas precipitation and vegetation productivity play a dominant role in governing SOC changes on the Third Pole. These findings demonstrate that permafrost SOC responses to climate change are highly heterogeneous and threshold-dependent rather than spatially uniform, highlighting the importance of accounting for permafrost type, ecosystem composition, and regional climate sensitivity when assessing future carbon-climate feedbacks and developing region-specific mitigation and adaptation strategies.

Keywords: Soil organic carbon, Permafrost



REVEALING THE IMPACTS OF ENVIRONMENTAL AND ANTHROPOGENIC FACTORS ON PERMAFROST DEFORMATION IN THE CENTRAL QINGHAI-TIBET PLATEAU USING INSAR AND INTERPRETABLE MACHINE LEARNING

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Permafrost stability on the Qinghai-Tibet Plateau (QTP) is vital amid environmental changes and human activities. Interferometric Synthetic Aperture Radar (InSAR) effectively monitors permafrost deformation, capturing seasonal and long-term trends via active layer hydrothermal shifts. While prior studies emphasized large-scale deformation, finer-scale regulatory effects of environmental factors and human activities remain underexplored. We used Small Baseline Subset (SBAS)-InSAR to derive ground deformation time series and developed an XGBoost-based model to assess impacts of soil hydrothermal conditions, vegetation, terrain, and human activities. Our results show that soil moisture plays a dominant role in permafrost deformation, with its interaction with soil temperature exhibiting nonlinear effects on permafrost deformation. Long-term changes in Normalized Difference Vegetation Index (NDVI) were significantly positively correlated with the seasonal deformation amplitude ($R^2 = 0.3546$, $p < 0.001$). Geomorphons exerted significant control, with valleys and lowlands exhibiting reduced permafrost deformation due to distinct hydrothermal conditions, whereas highlands demonstrated greater stability. Human infrastructure further influenced ground deformation. The Wudaoliang (WDL) Train Station (median subsidence rate: -11.55 mm/yr) and Qinghai-Tibet Railway (median subsidence rate: -8.75 mm/yr) exhibited strong regulatory effects, whereas WDL Town (median subsidence rate: -12.45 mm/yr) and the Qinghai-Tibet Highway (median subsidence rate: -10.32 mm/yr) experienced more pronounced deformation, which highlights the importance of engineering design in mitigating permafrost degradation. The results provide new insights into the regulatory mechanisms of environmental factors and human activities on permafrost deformation across the QTP using interpretable machine learning (ML), which is important for environmental conservation and engineering disaster prevention in permafrost regions.

Keywords: Permafrost deformation, environmental impact mechanism



DIFFERENCES IN ISOTOPE COMPOSITION AND ANATOMICAL STRUCTURE OF SWISS WILLOW SHRUBS GROWING ON ACTIVE AND INACTIVE ROCKGLACIERS

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Stable isotopes in tree-rings are a well-established tool to reconstruct climatic and ecological conditions of the past. Especially $\delta^{18}\text{O}$ variations in wood indicate differences in the source water and are therefore an ideal recorder of spatio-temporal variations in the water cycle. The $\delta^{18}\text{O}$ value of precipitation is highly dependent on air temperature and this signal is in turn imprinted into wood/cellulose. However, when woody plants have access to other water sources the climate signal gets overprinted. It is known that the $\delta^{18}\text{O}$ signal also gets influenced by permafrost presence and can be highly biased by isotopically differing water sources of the solum. However, vegetation in alpine permafrost is often sparse and limited to shrubs and lower plants. Studies on shrubs growing on permafrost in alpine regions are still limited. In an earlier study we showed that vessel sizes in roots of shrubs are smaller on active rockglaciers compared to inactive rockglaciers. However, it is still unknown if these differences are caused by lower soil temperatures or mechanical stress due to the movement of the active rockglacier. The aim of this study is to gain further insights on how shrubs are influenced by growing on the dynamic surfaces of rockglaciers. For this project a total of 48 shrubs (*Salix helvetica*) were sampled in the Turtmanntal, Switzerland. Samples were taken on the surface of an active rockglacier as well as on an inactive rockglacier directly below it. As a reference, additional samples were taken on adjacent locations without permafrost presence and on stable ground. All samples were analysed for $\delta^{18}\text{O}$, $\delta^{13}\text{C}$ and mean vessel lumen area (VLA) signals. First results show significant differences in $\delta^{18}\text{O}$ values on the active and the inactive rockglacier. In addition, temporal changes are observed at different sites: The $\delta^{13}\text{C}$ values show a trend to higher values in the last decades on the active rockglacier, while $\delta^{13}\text{C}$ values remain constant at the other locations. In contrast to former studies on root VLA, the vessel sizes of branches are not showing any significant differences. The results indicate that shrubs growing on active rockglaciers not only face different site conditions as a changing hydrological setting compared to permafrost free sites but also face rapidly changing soil temperature conditions that other nearby sites do not experience. Understanding the relationship between shrubs and different activity stages of rockglaciers can provide us with information about changes in surface movement and hydrological processes in alpine environments. Using vegetation for the analysis of recent and former ground conditions, such as hydrology and ground movement, allows for an environmental monitoring without further instrumentation.

Keywords: Isotopes, temperature, vegetation, xylem, hydrology



LAND COVER TYPES AND DEPTH REGULATE CARBON AND NITROGEN CYCLE FUNCTIONAL GENES IN PERMAFROST REGIONS

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Microorganisms are essential for carbon and nitrogen cycling in the active layer of permafrost regions, but the distribution and controlling factors of microbial functional genes across different land cover types and soil depths remain poorly understood. This gap hinders accurate predictions of carbon and nitrogen cycling dynamics under climate change. This study aims to explore how land cover type and soil depth influence microbial functional gene distribution in the Qinghai-Tibet Plateau's permafrost regions. We collected soil samples (0-50 cm) from alpine wet meadows, alpine meadows, and alpine steppes. We analyzed the samples for physicochemical properties, microbial amplicon sequencing, and metagenomic sequencing. Correlation analyses were conducted between microbial community structure, functional genes, and environmental factors to identify the drivers of microbial carbon and nitrogen cycling. Our results showed that bacterial richness was 6.03% lower in steppe soils compared to wet meadow soils. Steppe soils exhibited the highest aerobic respiration potential, while deeper wet meadow soils had enhanced anaerobic carbon fixation potential and a higher abundance of carbon decomposition-related genes. Nitrogen assimilation was highest in steppe surface soils, whereas denitrification and ammonification were greatest in wet meadow soils. Carbon cycling potential was influenced by total soil carbon, nitrogen, phosphorus, and belowground biomass, while nitrogen cycling was driven by belowground biomass, soil moisture, and pH. These findings underscore the role of environmental factors in microbial functional gene distribution, providing new insights for modeling carbon and nitrogen cycling in alpine permafrost ecosystems under climate change.

Keywords: Permafrost, carbon cycling, microbes, soil



COMPREHENSIVE STUDIES OF ORGANOGENIC DEPOSITS ON THE QINGHAI-TIBET PLATEAU (CHINA) AND PUTORANA PLATEAU (RUSSIA)

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This research presents a comprehensive study of organogenic deposits in two distinct regions: the Qinghai-Tibet Plateau in China and the Putorana Plateau in Russia. The project integrates multidisciplinary approaches to investigate paleoclimate dynamics, environmental changes, and landscape evolution in these high-latitude regions. The study employs a wide range of research methods, including AMS ^{14}C dating, carbon dynamics analysis, ground temperature monitoring, microspatial distribution of soil protists, and testate amoeba-based water table reconstruction. Special attention is paid to proxy methods such as pollen analysis, spore research, and peat accumulation studies. The primary objectives of the research are: To reconstruct paleogeographic conditions of the Holocene period in the Russian Arctic and Chinese highlands; To analyze environmental dynamics using various proxies; To establish connections between climate changes in Arctic regions and their impact on highland ecosystems. The research encompasses several key areas: Field studies in Norilsk area, Norilskaya River terraces, Lama and Melkoe lakes and Qinghai-Tibet Plateau sites; Laboratory analysis conducted at Shenzhen MSU-BIT University, Lomonosov Moscow State University, and Guangzhou Institute of Geochemistry; Climate monitoring systems installed at multiple test sites; Geophysical surveys including electrical resistivity tomography and ground penetrating radar. The findings contribute to understanding: - Historical climate patterns in high-latitude regions; - Vegetation dynamics and fire history; - Permafrost evolution and thermokarst processes; - Environmental changes over Holocene. The study represents a significant step in understanding the complex interactions between climate, environment, and ecosystems in these critical regions, providing valuable data for future climate change predictions and environmental management strategies.

Keywords: Permafrost, organogenic deposits, paleoclimate, AMS ^{14}C



**4C: PERMAFROST AND ECOSYSTEM INTERACTIONS
POSTER**



LAND-USE DISTURBANCES AMPLIFY THERMAL STRESS AND ACCELERATE PERMAFROST REGIME SHIFTS IN MONGOLIA

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Permafrost ecosystems are increasingly exposed to combined pressures from climate warming and human land-use activities, yet the relative magnitude and mechanisms of land-use-induced thermal stress remain poorly quantified, particularly in climatically transitional permafrost regions. Here, we present experimental evidence of the thermal impacts of grazing and logging on permafrost ecosystems in Mongolia, based on paired disturbance-control observations conducted between 2021 and 2024 within the framework of the Cryo-Stress project. Study sites span continuous, discontinuous, island, and patchy permafrost zones across the Hovsgol and Khentii mountain regions, encompassing forest, open forest, shrubland, and grassland ecosystems. At each site, grazing exclusion plots (4×4 m) and adjacent disturbed plots were established to isolate the thermal effects of grazing, while logged and unlogged forest sites provided long-term post-disturbance contrasts. Soil temperatures at 2 cm and 50 cm depths were continuously recorded using automated data loggers, enabling direct comparison of seasonal and annual thermal regimes under contrasting land-use conditions. Across all ecosystems, grazing and logging consistently increased summer and mean annual soil temperatures, reduced winter cooling, and prolonged the thaw season. Disturbance-induced warming was strongest at shallow depths but remained detectable at 50 cm, indicating enhanced downward heat transfer and reduced thermal insulation following vegetation and surface disturbance. The magnitude of land-use-driven thermal stress was comparable to, and in some cases exceeded, recent climate-driven warming trends, resulting in earlier thaw onset, delayed refreezing, and lengthening of the active season by several weeks. These effects were most pronounced in open forest and grassland systems under heavy grazing, where surface energy balance alteration and soil compaction jointly enhanced heat penetration into the ground. Our results demonstrate that land-use disturbances act as effective amplifiers of permafrost warming, accelerating transitions toward thermally unstable states that are not predictable from climate forcing alone. We conclude that grazing and logging represent critical, yet underrepresented, drivers of permafrost degradation in Central Asian Mountain regions. Incorporating land-use-induced thermal perturbations into permafrost risk assessments is essential for accurately evaluating ecosystem vulnerability, thermokarst hazard potential, and infrastructure stability in regions undergoing rapid socio-environmental change

Keywords: Grazing, logging, surface temperature



MAPPING OF SOIL ORGANIC CARBON CONTENT IN PERMAFROST REGIONS: CASE STUDY AREA BAYANZURKH SOUM IN KHUVSGUL

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Soil organic carbon (SOC) is the largest carbon reservoir in the terrestrial ecosystem and plays an important role in the global carbon cycle. Consequently, even a slight change in SOC content due to land use, soil management, or rates of soil erosion can considerably increase atmospheric CO₂ concentrations. In particular, permafrost soils distributed in northern Mongolia store large amounts of organic carbon. Therefore, investigating changes in SOC has become an important research issue. The main purpose of this study is to predict and map SOC content at a small-scale using machine learning (ML) algorithms based on field measurements and remote sensing data, and to compare the predicted SOC contents among different soil types within the study area. We used three different algorithms such as Random Forest (RF), Extreme Gradient Boosting (eXGB), and Gradient Boosted Regression (GBR) of ML. According to field work, 123 soil samples (0-30 cm) were collected from Bayanzurkh soum in Khuvsgul, and 26 variables were used to predict SOC content. According to the prediction results, the GBR algorithm demonstrated the highest performance, explaining 78% of the variation in soil SOC content, with an RMSE of 42.9 g kg⁻¹. and an MAE of 33.1 g kg⁻¹. The ranking of model performance in terms of prediction accuracy was GBR > eXGB > RF. We found a strong relationship ($R^2 = 0.94$) between the predicted and measured values based on linear regression analysis. An analysis of the distribution of predicted SOC content by soil type showed that the mean SOC content was highest in Mollic Cryosols 225.5 g kg⁻¹, followed by Umbrisols (Gelic) 178.8 g kg⁻¹. These results demonstrate that SOC content can be effectively predicted using machine learning algorithms. However, it is advisable to compare the performance of multiple algorithms and select the most suitable approach for the small area.

Keywords: Soil organic carbon, Machine learning



PERMAFROST DEGRADATION SERVICES FOR ARCTIC GREENING

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As an important component of the climate system, permafrost responds significantly to climate change, and its impact on the ecosystem cannot be ignored. In this study, we analyzed the temporal and spatial variation trends of the normalized difference vegetation index (NDVI) in Arctic permafrost regions and revealed the correlation between the active-layer thickness (ALT), soil temperature, and NDVI change. Using the partial correlation method, we assessed the ecological regulation service of permafrost to the ecosystem. The results showed that both the average annual maximum and summer NDVI values in the Arctic region followed a significant increasing trend from 1982 to 2015. The average correlation coefficient (ACC) between Arctic NDVI and ALT was 0.35, followed by the ACC (0.33) between NDVI and soil temperature at 7-28 cm depth, and had a lower ACC (0.31) at 0-7 cm ALT. When the precipitation and snow water equivalent (SWE) remained unchanged, the partial correlation between NDVI and ALT was 0.711, which was a significant positive correlation. It also showed that permafrost degradation was the dominant factor controlling Arctic NDVI increase, whereas precipitation and SWE had little effect. The study revealed the impact of permafrost on NDVI change, deepened our understanding of the importance of permafrost degradation for ecosystem services, and effectively filled the gap that tundra ecosystem services value has been ignored in the global ecological service value assessment.

Keywords: Permafrost degradation; NDVI change



ACTIVE LAYER REGIME SHIFTS IN A LARCH FOREST FOLLOWING EXTREME WETTING IN EAST SIBERIA

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The active layer thickness (ALT) is a key parameter of land-atmosphere interaction in permafrost ecosystems. While the Stefan equation is a widely-used model for estimating ALT, its accuracy is often limited by the contrasting influence of soil moisture: increased moisture can either promote thawing by enhancing thermal transport or suppress it by increasing latent heat requirements. This study applies the Stefan equation as diagnostic framework to detect temporal variation in its proportionality coefficient, (apparent thawing efficiency). We examined the internal hydrothermal sensitivity of the seasonal thawing, based on, which was back-calculated as the ratio of ALT to the square root of the integrated surface temperature. We evaluated the interannual variability of, using a 20-year observation (1998-2020) at two larch forest sites, Spasskaya Pad (SP) and Elgeei (EG), in eastern Siberia. Observations revealed no significant positive correlation between ALT and at either site, suggesting that internal hydrothermal factors primarily controlled ALT dynamics. At the EG site, an unexpected negative correlation between and ALT was observed. This suggests the dominance of latent heat effects, where wet active layer acts as a latent heat buffer that stabilizes thaw depth despite surface warming. In contrast, at the SP site, an extreme wet event (2005-2008) triggered a regime shift toward heat transport dominance. While α increased with soil moisture during the wet year, it remained significantly higher than pre-wet years levels and less sensitive to soil moisture throughout the subsequent decade of drying periods. This reveals a thermal memory effect, where persistent moisture in the deep layer maintains enhanced thawing efficiency. These findings indicate that α can be used diagnostically to effectively reveal the active-layer thermal regime shifts and interpret the soil moisture functions.

Keywords: Active layer, soil water, seasonal thaw, boreal forest, Stefan equation



MODEL ASSESSMENT FOR SNOW IMPACTS ON PERMAFROST AND GREENHOUSE GAS FLUXES

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Snow critically affects permafrost and hydrothermal processes, then feeds back to climate and ecohydrology. In recent decades, observational records captured the amplified warming magnitude of permafrost, likely due to the combined impacts of warming temperature and more snow insulation. Depth hoar refers to large, faceted snow grains crystals that form near the bottom of the snowpack due to a strong temperature gradient that induces a vapour gradient. The thin and sparse connection between depth hoar grains results in low thermal conductivity. The formation of depth hoar in a snowpack likely enhances permafrost warming during the winter season, and the impact could be sequentially feedback to CO₂ fluxes from the permafrost soil during the next growing season. Observations and models have provided little quantitative assessments on the impact of depth hoar on permafrost temperature and the associated feedback to CO₂ fluxes. To decrease this deficiency, we coupled the depth hoar process to the land surface model CHANGE. The model was used to assess the impact of the depth hoar on permafrost and the associated greenhouse gases, based on two experiments that included or excluded the depth hoar process, over the pan-Arctic scale for 1979-2019. The differences between the two experiments indicated that the depth hoar-caused thicker snow depth and the resultant warmer permafrost temperature were linked to larger both vegetation photosynthesis and decomposition of soil organic carbon. These results suggest further improvements for snow processes in land surface models for better simulations and future projections on the Arctic environmental changes.

Keywords: Depth hoar, permafrost, CO₂ flux



FIREALT: A DATA SET OF ACTIVE LAYER THICKNESS ESTIMATES FOR PAIRED BURNED AND UNBURNED SITES ACROSS THE NORTHERN HIGH LATITUDES

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As the northern high-latitude permafrost zone experiences accelerated warming, permafrost has become vulnerable to widespread thaw. Simultaneously, wildfire activity across northern boreal forest and Arctic/subarctic tundra regions impacts permafrost stability through the combustion of insulating organic matter, vegetation, and post-fire changes in albedo. Efforts to synthesize the impacts of wildfire on permafrost are limited and are typically reliant on antecedent pre-fire conditions. To address this, we created the FireALT dataset by soliciting data contributions that included thaw depth measurements, site conditions, and fire event details with paired measurements at environmentally comparable burned and unburned sites. The solicitation resulted in 52 466 thaw depth measurements from 18 contributors across North America and Russia. Because thaw depths were taken at various times throughout the thawing season, we also estimated end-of-season active layer thickness (ALT) for each measurement using a modified version of the Stefan equation. Here, we describe our methods for collecting and quality-checking the data, estimating ALT, the data structure, strengths and limitations, and future research opportunities. The final dataset includes 48 669 ALT estimates with 32 attributes across 9446 plots and 157 burned-unburned pairs spanning Canada, Russia, and the United States. The data span fire events from 1900 to 2022 with measurements collected from 2001 to 2023. The time since fire ranges from 0 to 114 years. The FireALT dataset addresses a key challenge: the ability to assess impacts of wildfire on ALT when measurements are taken at various times throughout the thaw season depending on the time of field campaigns (typically June through August) by estimating ALT at the end-of-season maximum. This dataset can be used to address understudied research areas, particularly algorithm development, calibration, and validation for evolving process-based models as well as extrapolating across space and time, which could elucidate permafrost-wildfire interactions under accelerated warming across the high-northern-latitude permafrost zone. The FireALT dataset is available through the Arctic Data Center (<https://doi.org/10.18739/A2RN3092P>).

Keywords: Wildfire, active layer thickness, circumpolar



METHANE CONCENTRATION OF MASSIVE ICE BEDS AND HOST SEDIMENTS OF EASTERN CHUKOTKA AS AN INDICATOR OF THEIR ORIGIN

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Eastern Chukotka is the territory east of Kresta Bay to the Bering Strait. This region is characterized by the widespread occurrence of massive ice beds large underground ice bodies reaching tens of meters in thickness and hundreds of meters in length. The distribution of massive ice beds makes Chukotka similar to Western Siberia or northern Canada. The origin of massive ice beds is a subject of scientific discussion. There are two main hypotheses: massive ice beds are the buried remnants of a sheet glacier, or massive ice beds are subsurface ice formed by the freezing of water-saturated sediments. Establishing the origin of massive ice beds will allow us to associate it with a specific type of sediment and subsequently identify areas with potential massive ice. This will help prevent hazardous cryogenic processes associated with massive ice (thermodenudation and thermokarst) during engineering development of the area. From 2016 to 2025, we studied six massive ice beds in Eastern Chukotka near the villages of Lavrentiya. Two of these bodies were discovered on the shore of Lavrentiya Bay, and four on the shore of Mechigmsky Bay. All massive ice bodies were found in thermocirques adjacent to the seashore. We did a cryolithological description of all the massive ice bodies, establishing the shape of the ice bodies, their structure, and their contact with sediments. We sampled gas from bubbles within the massive ice bodies, as well as from the surrounding sediments. We used the headspace equilibrium degassing method. The gas composition was determined using a Shimadzu GC 2014 gas chromatograph. We believe methane to be the most significant component. We believe that high methane concentrations in massive ice indicate its buried origin. Atmospheric ice contains atmospheric air trapped in bubbles, which has low methane concentrations (1.7 ppmV). Therefore, if massive ice has a low methane content, it may be a buried glacier or snowfield. However, massive ice may not contain a significant number of bubbles, in which case its low methane content will not reliably indicate its buried origin. In general, all ice on the coast of Mechigmen Bay has very low methane concentrations in bubbles, close to atmospheric values (up to 20 ppmV). We believe that these are buried ice of atmospheric origin. On the coast of the Gulf of Laurentia, methane content in massive ice is higher (up to 450 ppmV), indicating its intrasedimental origin. We compared reconstructions of the origin of massive ice based on isotopic analysis and on the determination of methane content in bubbles and concluded that these two methods are compatible and yield consistent results. Only in one case out of six did we obtain contradictory conclusions: based on the isotopic composition, the ice was identified as subsurface ice, but based on the methane content, it was similar to buried atmospheric ice. The laboratory research was supported by the RSF project No. 23-27-00123.

Keywords: Permafrost, methane, headspace, Chukotka, cryolithology



ORGANIC CHEMISTRY IN RIVER-LAKE SYSTEM'S IN THE CONTEXT OF PERMAFROST OCCURRENCE (MONGOLIA, VALLEY OF THE LAKES)

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The main aim of the study is to summarize patterns in fresh water organic chemistry in Valley of the Lakes (Mongolia) in relation to permafrost occurrence, as well as other natural and anthropogenic impacts. The basins of the analyzed river-lake systems cover an area of 45,020 km² and 14,929 km² for the Baydrag-Böön Tsagaan system and the Tuyn-Orog system, respectively. Both rivers have their source zones in the Khangai mountains, and they flow to the south, across the uplands to the Valley of the Lakes, where they feed two large lakes -Böön Tsagaan Lake and Orog Lake. The analyses involved water samples taken in 2013 from the rivers, lakes and supply springs. In the water samples, total organic carbon (using TOC-VCSH/CSN analyzer, Shimadzu) and polycyclic aromatic hydrocarbons (using GC-MS -QP 2010 Ultra, Shimadzu) were detected and quantified. Additionally, other organic compounds, such as organic halogen compounds, phthalates, and higher alkanes were also noted (using GC×GC system based on 6890A gas chromatograph (Agilent Technologies) and Pegasus IV time-of-flight mass spectrometer (LECO Corp.)). The organic matter content (TOC) in the studied waters ranged from 15.41 mg·L⁻¹ to 30.8 mg·L⁻¹ in the river and springs, and amounted to 45.7 mg·L⁻¹ and 119.3 mg·L⁻¹ for the Böön Tsagaan Lake and Orog Lake, respectively. TDS (total dissolved solids) were from 0.15 to 6.38 g·L⁻¹ for the Bajdrag River - Böön Tsagaan Lake system and from 0.07 to 1.71 g·L⁻¹ for the Shargaljuut /Tuyn Rivers-Orog Lake system. The highest TDS and amounts of ions were observed in the lakes, with distinctively higher concentrations in BöönTsagaan compare to Orog Lake. Total PAHs concentrations ranged 36-365 ng·L⁻¹ and 43-363 ng L⁻¹, for Baydrag-Böön Tsagaan system and Shargalyuut/Tuyn-Orog System, respectively. The concentration of PAHs > 300 ng·L⁻¹ was found in the Shargalyuut river, Böön Tsagaan Lake and a spring located near that lake. Naphthalene, fluorene and phenanthrene were the compounds with a significant input in the total sum of PAHs in both systems. Organic halogen compounds (organochlorides, organobromine and organoiodine compounds) were identified in each sampling point. Among the identified compounds we can highlight single compounds, such as: dibutyl phthalate, bis-(2-methylpropyl)-1,2- benzenedicarboxylic acid ester (diisobutyl phthalate), tetrachloroethene, and higher alkanes, e.g. nonane, tridecane, pentadecane, heptadecane. The obtained results showed that organic compounds found in the studied waters may be of natural (volcanic sedimentary rocks) and human activity origin (local sources and the long-range transport of chemicals). Furthermore, indicated the retention of organic matter in the area of continuous and discontinuous permafrost occurrence and its release into the water due to permafrost degradation. Furthermore, the differences between the chemistry of the both studied lakes were found, which are resulted by seasonal drying out of Lake Orog and deflation of evaporites from the exposed lake beds.

Keywords: Water chemistry, organic compounds, permafrost



LONG-TERM DYNAMICS OF SEASONAL THAWING AND PHYTOMASS IN TYPICAL TUNDRA OF WESTERN YAMAL AS A BASE TO PREDICT ACTIVATION OF HAZARDOUS CRYOGENIC PROCESSES

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This study is devoted to the investigation of phytomass measurements in typical tundra in the western Yamal (West Siberia, Russia). With changes in the thermal state of dominant landscapes in the Western Yamal region, due to an increase in the air temperature of the warm period and its duration, there is a growth in the depth of seasonal thawing. Against this background, there is also an increase in phytomass in the tracts of typical tundra, as determined using the NDVI index. An increase in NDVI index values has been observed for all dominant landscapes of typical tundra in the Western Yamal region, in the area of the Marre-Sale research station, over the period 2000-2023. The maximum values are characteristic of moist, waterlogged shrub-herb-moss tundra (ranging from 0.22 to 0.32), while the minimum values are observed in sandy blowouts with fragments of vegetation (ranging from 0.1 to 0.18). The identified patterns allow the use of NDVI values to determine the trend of increasing thaw depth, enabling the application of remote sensing methods for assessing thaw depth. The rise in NDVI in the tundra reflects the integrated interactions between the changing Arctic climate, vegetation cover, and the state of permafrost. The NDVI index cannot reflect the following processes: a decrease in thaw depth due to an increase in the thickness of the organic layer (peat, moss), which has low thermal conductivity and slows down the penetration of heat into deeper layers. However, this effect will persist as long as the conditions (primarily climatic) for the existence of typical tundra remain in place. At the same time, as the boundaries of shrub tundra shift northward, there will be an increase in phytomass (primarily due to shrub vegetation) and the NDVI index. In this case, an increase in thaw depth is expected due to changes in surface albedo and transpiration. Shrubs contribute to snow accumulation, which acts as a thermal insulator in winter, preventing deep soil freezing. Additionally, dark shrub vegetation absorbs more solar radiation compared to light lichens or snow cover, which can enhance soil warming. Variations in the depth of seasonal thawing largely influence and determine the possibility of the onset of the development of dangerous cryogenic processes. This study was supported by RSF grant 25-27-00480.

Keywords: Climate change, phytomass change, NDVI



INFLUENCE OF VEGETATION AND SNOW COVER STRUCTURE ON HEAT FLOW AND ACTIVE LAYER REGIMES IN ARCTIC PERMAFROST

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The relevance of the study is driven by persistent warming trends in the Arctic, leading to the degradation of permafrost, which threatens the stability of infrastructure and ecosystems. The natural cover, comprising vegetation and snow, acts as a key natural regulator of heat exchange between the atmosphere and the ground. However, its transformative role has been insufficiently quantified, creating a need to develop models for predicting changes in the seasonally thawed layer (STL) and assessing geocryological risks during the economic development of the Yenisei North territories. The aim of the work is a quantitative assessment of the influence of the spatial heterogeneity of natural tundra covers on heat flow and the thermal regime of the STL. To achieve this, the following tasks were addressed: conducting an analysis of literature data and a review of existing methodologies for studying heat exchange in the “vegetation-snow-ground” system; investigating the spatial structure of vegetation and snow cover at key sites in the Norilsk and Igarka regions; assessing the thermal regime of the STL and heat flow parameters under main phytocoenosis types; and establishing quantitative relationships between cover type, heat flow magnitude, and STL thickness. The research methodology included field and desk-based methods. At the key sites, geobotanical descriptions, instrumental observations of the thermal regime and STL thickness, and studies of snow cover thickness and density were conducted. Subsequent laboratory processing involved the analysis of vegetation samples, mathematical processing of data and statistical analysis, as well as heat flow modeling. The main results of the study showed that the spatial heterogeneity of natural tundra covers is a leading factor shaping the mosaic pattern of the thermal regime and STL thickness within a single landscape. It was established that seasonal changes in heat flow intensity by 1-2 orders of magnitude are a direct consequence of the transformative role of the cover. In the summer period, vegetation type regulates the flow magnitude through albedo and thermal conductivity, while in winter the main filter becomes the spatial heterogeneity of the snow cover, previously shaped by vegetation. Using the example of the Yenisei North, it was proven that differences in heat flow under the main phytocoenosis types can cause variations in STL thickness of 30-50%, which is critical for assessing the stability of geotechnical structures and local activation of cryogenic processes. The maximum transformative effect was identified in moss-shrub communities with a powerful organogenic layer. The conclusions of the work are that the natural tundra cover serves as a key diagnostic feature and regulator of heat and mass transfer in the cryolithozone. The obtained quantitative relationships emphasize the necessity of accounting for the local heterogeneity of vegetation and snow cover when forecasting changes in permafrost conditions. The results have practical significance for assessing geocryological risks, designing sustainable infrastructure, and developing adaptation measures in the context of the changing Arctic climate.

Keywords: Active layer, vegetation cover, permafrost



FROM THAW PROCESSES TO SURFACE WATER CHEMISTRY: ICE-RICH PERMAFROST DEGRADATION IN NORTHWESTERN ALASKA

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The degradation of ice-rich permafrost is a spatially heterogeneous process that reflects variations in ground-ice content, geomorphological setting, hydrological connectivity, and disturbance history. In northwestern Alaska, permafrost thaw manifests across a wide spectrum of landscape expressions, including localized surface subsidence and thermokarst, lake expansion and drainage, extensive thaw slumping at the coast as well as thermo-erosional gullies. Differences in thaw dynamics lead to contrasting impacts on freshwater systems and associated biogeochemical fluxes. Beyond their environmental significance, these changes have direct implications for local communities by influencing surface water quality, aquatic habitat conditions, and the availability and reliability of freshwater resources used for subsistence and daily activities. Understanding how spatial variability in permafrost degradation translates into contrasting hydrochemical responses is therefore critical for both process-based permafrost research and the assessment of societal impacts under continued Arctic warming. This study is based on interdisciplinary fieldwork focused on permafrost-ecosystem interactions in northwestern Alaska from 2022 through 2025. We combine hydrochemical analyses of surface waters with geomorphological assessments and remote sensing-based change detection to capture both the spatial variability and temporal evolution of permafrost-related disturbances as well as their impact on aquatic systems. Investigated sites include locations visibly impacted by recent, rapid permafrost thaw, such as thermokarst features, thaw slumps, and thermo-erosional gullies as well as sites that appear undisturbed based on their current surface expression or that have no ice-rich permafrost. This enables comparisons across different disturbance types, intensities, and catchment characteristics. Surface water samples were analyzed for pH, electrical conductivity (EC), dissolved organic carbon (DOC), total dissolved nitrogen (TDN), the absorption of colored dissolved organic matter (CDOM), stable water isotopes ($\delta^{18}\text{O}$, δD), and major ions, providing a valuable baseline dataset to characterize hydrochemical variability. Change detection based on multi-temporal remote sensing data, together with spatial and geomorphological analyses, is used to quantify the extent and progression of thaw-related landscape change. The observed hydrochemical differences are then linked to permafrost disturbance modes and catchment-scale variability in order to identify characteristic hydrochemical signatures associated with different pathways of ice-rich permafrost degradation. This landscape-oriented perspective contributes to a more comprehensive understanding of permafrost-hydrology-biogeochemistry interactions in regions experiencing rapid warming.

Keywords: Ice-rich permafrost, rapid thaw, hydrogeochemistry



GEOCHEMICAL SIGNATURES OF ENCLOSED GAS AS INDICATORS OF GROUND ICE GENESIS

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The geochemistry of ground ice has been extensively studied for multiple purposes. Ice-matrix geochemical analyses include major ion compositions and stable water isotopes, the latter of which are widely used as proxies for winter paleotemperature, particularly in ice wedges. Radiocarbon dating of organic matter provides constraints on the timing of ground ice formation. In contrast, the geochemistry of gases enclosed in ground ice remains poorly studied due to analytical and methodological challenges. In this study, we extracted enclosed gases from ground ice using a melt-refreezing technique and subsequently analysed a single aliquot with gas chromatographic systems. We report 73 simultaneous concentration measurements of greenhouse gases (CO_2 , CH_4 , and N_2O) and major atmospheric constituents (N_2 , O_2 , and Ar) from individual ground-ice gas samples. The ages of ground-ice formation were constrained using radiocarbon dating of plant remains and dissolved organic carbon, spanning from the Last Glacial Maximum (~20 ka BP) to modern ice (post-1950 AD). Eight ground-ice bodies representing different genetic types were analysed, including ice wedges, segregated ice, intrusive ice, and open-cavity ice. The $\delta(\text{N}_2/\text{Ar})$ ratio provides a robust indicator of ground ice formation mechanisms. Ice formed by freezing of gravitational water yields $\delta(\text{N}_2/\text{Ar})$ values between -30 and -60%, whereas ice formed by hoarfrost accumulation exhibits values close to 0%. These interpretations are consistent with previously published data and are independently supported by polarized-light observations of ice crystal structure. In contrast to $\delta(\text{N}_2/\text{Ar})$, concentrations of CO_2 , CH_4 , and N_2O do not show systematic differences among ground ice genetic types. This indicates that greenhouse gas composition in enclosed gases is not primarily controlled by ice-formation processes but rather by local environmental conditions in the overlying active layer at the time of air entrapment.

Keywords: Ground Ice, enclosed gas, geochemistry



VEGETATION RECOVERY FOLLOWING RETROGRESSIVE THAW SLUMPS ACROSS NORTHERN TUNDRA REGIONS

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Warming permafrost is driving widespread terrain destabilization and collapse through retrogressive thaw slumps, stripping vegetation and releasing soil carbon. Despite increasing thaw slump disturbances in permafrost regions, the time and patterns of vegetation recovery remain uncertain. Here, we estimate surface greenness recovery times and compositional changes following disturbances across northern tundra regions, using data from remote sensing imagery. Our findings reveal that greenness recovery following RTS initiation was rapid in low-Arctic sites but considerably slower in high-Arctic and high-elevation sites, where stable RTS often remained partly barren for decades. In the low-Arctic regions of TL, NT, MD, and YP, the NDVI values in undisturbed areas are 0.62 ± 0.03 , 0.80 ± 0.03 , 0.77 ± 0.04 , and 0.68 ± 0.03 , respectively. Following disturbance, NDVI recovered rapidly to undisturbed levels (0.65, 0.80, 0.75, and 0.69, respectively) within five to ten years (7.6 ± 1.3 , 6.1 ± 1.7 , 5.4 ± 1.7 , 9.3 ± 1.1 years, respectively), after which vegetation greenness remained stable with only slight increases. In contrast, recovery in the CQ, WQ, WB, and EB regions of the high-Arctic was markedly slower, exhibiting a gradual increasing trend over several decades. These trends indicate it requires approximately 49.4 ± 4.4 , 103.9 ± 90 , 34.6 ± 5.0 , and 105.0 ± 35.8 years for NDVI to recover, respectively. Greenness recovery time (τ , yr) varies widely but can be accurately predicted by a power-law function ($1.18 * (\text{GPP})^{-1.78}$, $p < 0.05$) based on annual ecosystem gross primary productivity (GPP, $\text{kg C m}^{-2} \text{ yr}^{-1}$). This study provides a regionally-scalable framework for estimating the surface greenness recovery time and revealing various patterns of vegetation succession following permafrost disturbances across tundra regions.

Keywords: Retrogressive thaw slump, vegetation recovery



GROUNDWATER DISCHARGE FROM A SANDY MASSIF IN CONTINUOUS PERMAFROST: HYDROCHEMICAL AND ISOTOPIC EVIDENCE FROM THE PESKI SITE (TRANSBAIKALIA)

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In continuous permafrost zones, sandy massifs (deserts) are associated with aquifer taliks. These hydrogeological anomalies, which contrast with the surrounding frozen landscapes, represent potential water supply sources in permafrost regions. The lack of an up-to-date assessment of groundwater flow conditions in these sandy massifs under changing climate hampers the practical use of their resources. This study aims to assess the current groundwater flow conditions in the Peski sandy massif (Chara Basin) using a comprehensive hydrochemical and isotopic analysis of discharging springs. Summer fieldwork (2022-2025) focused on collecting water samples from springs, wells, surface waters (rivers, streams, lakes), and precipitation. More than 200 water samples were collected. Chemical analysis involved titration, capillary electrophoresis, inductively coupled plasma mass spectroscopy (ICP-MS), and inductively coupled plasma atomic emission spectrometry (ICP-AES). Stable water isotopes ($\delta^{18}\text{O}$, $\delta^2\text{H}$) were determined using laser absorption spectrometry. The analysis also incorporated archival data (1983). The discharge of groundwater from the Peski sandy massif is spatially variable and occurs in two main forms: (1) springs at the foot of sandy slopes (often associated with suffosion sinkholes), and (2) subaqueous discharge directly into spring-fed streams (sometimes through spring vents). This pattern is attributed to mixing between two contrasting aquifer complexes in the discharge area. Waters from the first aquifer complex (aeolian and lacustrine-alluvial sands) are fresh ($\text{TDS} < 0.1 \text{ g/L}$) and range from bicarbonate calcium-magnesium to mixed-cation types. They exhibit elevated iron (up to 2-3 mg/L) and low fluoride ($< 2.0 \text{ mg/L}$). Their isotopic composition is relatively heavy ($\delta^{18}\text{O}$: -14.5 to -16.0‰; $\delta^2\text{H}$: -110 to -125‰; d-exc: 3-6). The hydrochemistry of small, peripheral springs from this complex is altered by cryogenic processes, resulting in elevated concentrations of Na^+ and Mg^{2+} . This aquifer complex is primarily recharged by precipitation infiltration. Sampled via a well, the second complex (within fluvioglacial gravels) contains confined, intrapermafrost waters (head ~40 m, $T \leq 2^\circ\text{C}$). These bicarbonate calcium waters are fresh ($\text{TDS} 80 \text{ mg/L}$) but are characterized by elevated concentrations of fluoride (3.5-4.5 mg/L), manganese (110-180 $\mu\text{g/L}$), and arsenic (14-23 $\mu\text{g/L}$). Their stable isotope signature is markedly lighter ($\delta^{18}\text{O} = -19.9\text{‰}$, $\delta^2\text{H} = -148\text{‰}$, d-exc = 11.6). These waters originate in part from glacial melt, as shown by their light isotope values (similar to glacier-fed Sredny Sakukan River). They are recharged via taliks (including taliks associated with tectonic faults), and their chemistry is controlled by water-rock interaction with ore-bearing rocks of the Kodar-Udokan zone (copper sandstones, gold-quartz veins, etc.). Mixing of waters from these two complexes in the discharge zone is evidenced by intermediate values of hydrochemical and isotopic tracers. The concurrent freshening of spring waters suggests an increasing contribution of glacial meltwater into the intrapermafrost waters. The study was supported by the R&D project No. 122012400106-7 (MPI SB RAS, Yakutsk, Russia).

Keywords: Dunes, taliks, springs, hydrochemistry, Transbaikalia



THERMAL AND MOISTURE REGIME OF THE UPPER VADOSE ZONE IN THE PESKI SANDY MASSIF (TRANSBAIKALIA)

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Significant groundwater reserves within sandy massifs (deserts) are a focus of intensive research, including those located in permafrost regions. A key aspect in studying the genesis of desert groundwater is the analysis of heat and mass transfer processes in the vadose zone. This study examines temperature and moisture regime formation in the vadose zone of the Peski sandy aeolian massif (Chara Basin). The thermal regime of dune sands was studied from 2007 to 2025 using hourly-automated and one-time temperature measurements. Observations were conducted in pits (1.0 and 4.5 m deep) and in the 15 m deep borehole located on the dune top in the massif's northeastern part, employing HOBO U-12 loggers. Moisture dynamics in the upper vadose zone were assessed during 2013-2015 in a 1.0 m deep pit with a 4Ch Soil Water Content HOBO sensor. The thermal regime of the sandy deposits is characterized by distinct depth differentiation. Three zones are identified: (1) an active layer (down to 4 m) with high amplitude of seasonal temperature fluctuations (from 35-45°C at the surface to 6°C at 4 m depth), (2) a transitional zone (5-13 m depth) with a decreasing amplitude and a mean summer temperature of 2.5-2.8°C, and (3) a zone of relatively stable temperatures at depths of 13 m and more, with a temperature of about 3°C and an amplitude not exceeding 0.3°C. The increasing of the mean annual ground temperature is observed at 13 m depth. It's probably related to a groundwater level's rising. Four distinct seasons are identified in the annual moisture cycle of the upper layer (deeper than 1 m) of the Peski area: a summer period (June - September) with moisture content up to 12-14%, autumn freezing accompanied by a decrease in soil moisture (October - November), a winter phase with an absence of liquid moisture (November - April), and spring moistening (April - May) due to thawing of the frozen layer, meltwater infiltration, and likely condensation. The consistent excess of summer moisture over winter moisture is a critical factor in the formation of taliks within sandy massifs of the permafrost zone. Summer moisture dynamics are determined by precipitation patterns. Soil moistening at the 0.2 m depth is beginning even with a short-term precipitation of 10-15 mm. It's causing a 1-4% increasing of moisture content. At the 0.5-1.0 m depths the moisture content is increasing only during prolonged infiltration recharge caused by sustained rainfall (e.g., >50 mm over 1-2 days). Short-term heavy downpours exceeding 20-30 mm leads to an increase in moisture content in the upper meter of vadose zone by no more than 1-3%. It is noted that the spring moisture reserve, formed by meltwater infiltration through frozen sands, influences the summer moisture regime characteristics. A sand moisture content of 6-10% at the start of summer, which is probably near field capacity, facilitates more efficient moisture redistribution. The study was supported by the Grant No. FMWM-2025-0003, IEG RAS.

Keywords: Dunes, vadose, taliks, thermohydrology, Transbaikalia



SPATIAL VARIATIONS OF THAW DEPTH, SURFACE DISPLACEMENT AND VEGETATION IN THE POKER FLAT RESEARCH RANGE, INTERIOR ALASKA

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Recent climate changes have stimulated permafrost thawing, impacting several aspects, such as ecohydrological changes and infrastructure destruction. It is crucial to assess the impact of recent environmental disturbances on permafrost thawing in the context of global warming, particularly in the southern limit of permafrost regions where the consequences are likely to be significant. To address this issue, we have started carrying out fieldwork, satellite observations, and numerical simulations at the Poker Flat Research Range in interior Alaska. Thaw depths under different surface conditions were measured and compared with the results of the Advanced Land Observing Satellite-2/4 (ALOS-2/4) L-band interferometric synthetic aperture radar (InSAR), which is operated by the Japan Aerospace Exploration Agency. We also compared them with the results of pseudo-3D numerical simulations, which we used to calculate the depth of the top of the permafrost table. Spatial variations in surface vegetation were confirmed using satellite optical images and a field survey. Our preliminary results show that the thaw depth in the fire scar burned in 2004 and in anthropogenically disturbed areas is much larger than that in non-disturbed areas. This tendency is also consistent with InSAR-based surface displacement data. However, the thaw depth records suggest that spatial heterogeneity on the order of several meters, and that micro-topography is likely to be important. We plan to conduct denser field observations of thaw depth during our next fieldwork to compare with the satellite and simulation results in two horizontal dimensions.

Keywords: Permafrost, thaw depth, surface displacement, vegetation, topography



THE ORIGIN OF THE MASSIVE ICE OF WESTERN YAMAL BASED ON THEIR GEOCHEMICAL AND ISOTOPIC COMPOSITION

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Massive ice beds (or tabular ground ice) are underground ice sheets ranging in thickness from 0.5 to several tens of meters and up to several hundred meters in length. The genesis of massive ice beds is controversial. Some researchers believe they are remnants of ancient Pleistocene glaciations, while others believe they formed during the freezing of marine sediments. Determining the genesis of massive ice beds is one of the main modern tasks of paleogeography. Understanding the mechanism and conditions of formation of massive ice is necessary for accurately reconstructing the formation history of permafrost deposits and predicting their deposits during engineering surveys. We studied massive ice beds in August 2025 on the coast of Western Yamal, near Sharapov Bay and Cape Kharasavey. We conducted a cryolithological description of the massive ice beds in the field, establishing their contacts with overlying sediments, and describing their structures. In this study, we used three methods to determine the origin of massive ice beds in Western Yamal: we determined the methane content of the beds, established their isotopic composition, and conducted a cryolithological characterization. These methods complement each other well, addressing each other's limitations. This allows for more confident interpretation of analytical results and more accurate hypotheses about the ice's genesis. Five massive ice beds were investigated during the fieldwork, which was supported by the Faculty of Geography of Lomonosov Moscow State University, JSC "IEPI," and the State Public Institution of the Yamal-Nenets Autonomous Okrug "NCIA." Two beds (CB1 and CB2) were discovered on coastal escarpments in the Black Coast area near Cape Kharasavey. Three more beds (KZ1, KZ2, and KZ3) were uncovered on coastal escarpments on the coast of Sharapov Bay. The analysis yielded average methane content and $\delta^{18}\text{O}$ and δD isotope ratios. Methane content ranged from 0.07 mL/kg (80 ppmV) to 7.84 mL/kg (8713 ppmV). Based on the data obtained, all studied deposits were divided into three groups: - Intraground deposits with high methane content (1.66-11.06 mL/kg or 2076-12289 ppmV) and an isotopic ratio characteristic of intraground massive ice. - Deposits with low methane content (0.25-0.33 mL/kg or 321-371 ppmV) and low $\delta^{18}\text{O}$ and δD values. These analytical values allow us to confidently assume that the ice is of glacial (i.e., atmospheric) origin. - Deposits with low methane content (less than 0.12 mL/kg or 135 ppmV) and the absence of air bubbles in the ice structure. The genesis of such ice can only be definitively determined through isotopic analysis of the ice melt.

Keywords: Massive ice beds, methane, isotope



DIVERGENT RESPONSES OF BACTERIAL COMMUNITIES TO PERMAFROST DEGRADATION AND THEIR ASSOCIATIONS WITH CARBON ACROSS VERTICAL PROFILE

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Permafrost degradation poses a significant threat to the organic carbon (C) pool primarily through regulating microorganisms. However, microbial responses and their associations with C loss across vertical profile remain unclear. Here, we used metagenomic sequencing to investigate bacterial communities in 125 samples from five 15 m-depth permafrost cores, spanning from the active layer to the permafrost layer along a degraded gradient on the Qinghai-Tibet Plateau. We find that α -diversity decreases, while stochastic processes and community stability increase from the active layer to the permafrost layer. Along permafrost degradation, these community attributes follow similar variations within the active layer but remain constant within the permafrost layer. The relative abundance and interaction of core taxa play important roles in maintaining community stability in the active and permafrost layers, respectively. Interestingly, degradation strengthens the negative associations of community stability with C storage, with this link being stronger in the active layer than the permafrost layer, further exacerbating C loss. Our findings provide novel insights into the potential capacity of microbial-mediated permafrost C sequestration and contribute to modeling C dynamic under future warming.

Keywords: Degradation, vertical profile, microorganisms, carbon



MEASUREMENTS OF SPATIAL VARIABILITY IN PERMAFROST THAW DEPTH IN A LARCH FOREST IN NORTHEASTERN MONGOLIA

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Permafrost thaw depths were measured at 25 points within a 20 m by 20 m plot in a larch forest at Udleg Research Forest in northeastern Mongolia from August 11 to 13, 2025, to evaluate its spatial variability. The handheld dynamic cone penetrometer was unable to accurately identify the thaw depth because the soil at the site remained soft even when frozen. To address this issue, a vertical soil temperature profile was used in conjunction with the penetrometer to determine the thaw depths. Two out of 25 points showed exceptionally deep thaw depths, 190.5 cm and 210 cm, while others were 121.0 ± 11.3 cm with a mean and standard deviation. Considering that the 2-m soil thaw date in 2011, based on borehole soil temperature data, was August 18, the mean thaw depth in this study was much shallower than in 2011. The spatial distribution of thaw depths was adequately modeled by a gamma distribution when the two deepest points were excluded. The shape parameter k and the rate parameter λ were 117.54 and 1.03, respectively, which are high for a mean thaw depth of approximately 120 cm, indicating small spatial variability and a close approximation to a normal distribution. The shallow thaw depth, with minor spatial variability, at this site in August 2025 is likely due to higher soil moisture levels resulting from increased snowfall in the region over recent years.

Keywords: Permafrost thaw depth, gamma distribution, spatial variability, Mongolia, boreal forest



5A: COMMUNICATING PERMAFROST SCIENCE: KNOWLEDGE TRANSFER THROUGH EDUCATION, OUTREACH, AND PARTICIPATORY RESEARCH

Conveners: Josefine Lenz¹, Julie Malenfant-Lepage², Ylva Sjöberg³, Frédéric Bouchard⁴, Saruulzaya Adiya⁵

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Effective permafrost science communication bridges research, policy, and public engagement, fostering climate literacy and community resilience. This session explores innovative outreach formats-arts, infographics, story maps, podcasts, citizen science, and participatory sampling to engage audiences from schoolchildren to policymakers. We welcome case studies on inclusive education programs, stakeholder co-creation models, best practices in digital and traditional media, and evaluations of how multidirectional learning builds trust and drives evidence-based decision-making in permafrost regions.





NEW WAYS TO PRACTICE SCIENTIFIC OUTREACH - ENGAGING THE WIDER PUBLIC WITH PERMAFROST AND COLD ENVIRONMENT RESEARCH THROUGH DATA-BASED SOUNDSCAPES AND IMMERSIVE SENSORY EVENTS

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This contribution presents new ways of science communication and for creating scientific outreach products for permafrost and cold region geomorphology research. The traditional way of communicating science through papers, conference contributions and websites proved not specifically effective to reach non-scientific audiences and audiences not generally interested in research results. Providing a time and place constrained opportunity (i.e. immersive events) for the public to 'experience' research results with more senses, for example listening to how data sound like, so far proved as a successful concept to communicate research results and generated interest and engagement from formerly non-science interested groups. We first present two ongoing projects for sonification of measurement data, such as temperature data, into electronic soundscapes, also called 'datascares'. In addition, light and video arrangements were adjusted to the sounds, creating immersive events in gallery and event spaces with high-quality sound systems. The data used for the sonification come from a project on estimating frost weathering in plateau blockfields in Norway and Svalbard, a research project on land surface change in a glacier foreland and permafrost and lake level change in an endorheic catchment in Tibet. As visuals and as a base to create visual art from, distributed model output, raw measurement data, as well as mapped change scenarios, field pictures and field videos were used. Information on the origin of the data were always given before the immersive session started and supporting information were accessible as handout sheets at all times during the events. The artistic interpretation of the data adds an emotional component to the perception of research. This emotional perception might cause a different memory establishment in the audience where data are not only dryly memorized, but also connected to a long-term emotional memory. The awareness and possible action that results from this way of perceiving and understanding science are crucial for a society moving forward in a changing world and vulnerable environment. Looking forward, we also explore further opportunities on how to transform research results from the permafrost research arena into more accessible and more experienceable information for the wider public, specifically focusing on easy, low-threshold and low-cost solutions, so that their integration into research projects becomes manageable.

Keywords: Science communication, outreach, data sonification



BUILDING A NETWORK FOR INTERNATIONAL PERMAFROST INTERNSHIPS: THE PERMAINTERN AND SEDNA UARCTIC INITIATIVES

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To address the limited availability of education and training opportunities in permafrost science and engineering across the Nordic countries, the PermaIntern initiative was developed with the aim to strengthen permafrost education through structured internships. Funded by the Danish Agency for Higher Education and Science as a UArctic Nordic network project (2022-2025), the PermaIntern platform www.permaintern.org was launched in summer 2024 to connect students, hosts, and supervisors and provide flexible, high-quality internship experiences in permafrost research. Students from all academic levels and disciplines can participate, and hosts include research institutes, universities, companies, and government agencies. To expand the initiative at the international level, the SEDNA project (2024-2026), supported by Memorial University and UArctic through the Global Arctic Leadership Initiative in Canada, develops the platform even further (<https://www.permaintern.org/sedna>). SEDNA also organizes online seminars for students to present their permafrost internship experiences. To date, sixteen students have completed (or are completing) internships, and more are expected to join in the near future, gaining practical experience, professional networking and permafrost-related skills. However, there have also been significant challenges, including adapting the model to diverse university administrative systems, managing international funding logistics, supporting student mobility across national borders, and the lack of salary support which limited participation from local Indigenous students and those in government agencies or industry. The most effective approach was found to be a voluntary (unpaid) internship model supported by mobility stipends for students covering transport and accommodation. Establishing internships within universities and research centers has proven much easier than within companies or government agencies, who often face significant administrative barriers such as restrictions on unpaid internships, the need to define projects far in advance, data security limitations, and prioritization of local over international students, with extensive time demanding rules and regulations to follow to allow foreign students to do internships. These experiences have helped the refinement of the permafrost internship program and highlight the value of international collaboration in Arctic education, especially about permafrost, a topic with unfortunately very little dedicated university training. The presentation will outline the development, challenges, and future vision for this emerging service, which - we hope - may serve as a model for similar initiatives across UArctic programs and thematic networks.

Keywords: Permafrost, internships, higher education, Arctic



PERMAFROST EDUCATION IN THE NORILSK INDUSTRIAL DISTRICT: A MODEL FOR EXPERIENTIAL LEARNING AND KNOWLEDGE TRANSFER

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Permafrost is a defining component of the Arctic environment, critically influencing the stability of natural landscapes, infrastructure, and socio-economic systems. In Russia, where continuous and discontinuous permafrost underlies approximately two-thirds of the territory, effective management of permafrost-related risks is paramount for sustainable northern development. Accelerated permafrost degradation driven by climate warming increasingly compromises industrial infrastructure, transportation networks, and settlements. Consequently, demand is growing for specialists who possess integrated theoretical knowledge and practical expertise in permafrost science, geology and civil engineering. The higher-education landscape remains dominated by programs in central academic hubs (Moscow, Saint Petersburg, Tyumen), which frequently offer limited opportunities for intensive field training in Arctic environments. Consequently, graduates often lack the integrated competencies required to assess complex permafrost conditions or to design infrastructure resilient to its degradation. To address this capacity gap, Fedorovsky Polar State University initiated a series of seasonal field courses in the Norilsk Industrial District in 2023. This region, characterized by complex permafrost conditions and intensive industrial development, serves as an exceptional natural laboratory for experiential learning. The program synthesizes permafrost science, applied geology research, and civil engineering principles. Between 2023 and 2025, five field courses engaged 95 students and early-career researchers from Russian universities. The pedagogical framework is grounded in experiential and inquiry-based learning. Participants develop practical skills through direct observation, measurement, and interpretation. Core training modules include ground-temperature monitoring, active-layer thickness measurement, shallow drilling and coring, and geophysical survey techniques, geotechnical observation. The program also emphasizes documentation and preliminary analysis of field data using Geographic Information Systems (GIS). These activities foster essential interdisciplinary competencies bridging natural science, engineering, and environmental management. Furthermore, the field courses function as a platform for knowledge transfer across institutional, disciplinary, and cultural boundaries. Participants collaborate with faculty, industry professionals, and local community representatives, engaging in a process of mutual learning and knowledge co-production. Program outcomes demonstrate its efficacy in strengthening professional competencies and research motivation. Numerous participants have utilized collected data in graduation theses and conference presentations, thereby contributing to the broader Arctic knowledge base. The initiative also supports regional workforce development by encouraging young professionals to pursue careers in Arctic engineering, environmental monitoring, and climate adaptation. In conclusion, these field courses exemplify how localized, field-intensive training can bridge the critical gap between academic theory and practical expertise. They contribute to the long-term goal of sustainable Arctic development by cultivating a cohort of specialists equipped to anticipate and manage permafrost-related risks. As climate change continues to transform the cryosphere, replicating such educational models across circumpolar regions will be pivotal for enhancing socio-ecological resilience and ensuring evidence-based decision-making throughout the global permafrost.

Keywords: Permafrost education, field courses, Norilsk



COMMUNICATING PAN ARCTIC PERMAFROST LANDSCAPE CHANGE TO NON SPECIALIST AUDIENCES USING THE ARCTIC LANDSCAPE EXPLORER (ALEX)

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Permafrost thaw is transforming Arctic landscapes through accelerated coastal erosion, increased thaw slumping in ice rich regions, changing lake dynamics, and an intensification of other disturbances such as forest and tundra fires and droughts. These changes threaten infrastructure and livelihoods and, in some regions, are making the relocation of settlements a necessary adaptation strategy. While remote sensing enables systematic detection and mapping of such disturbances across the pan Arctic, the resulting products are often difficult to access and interpret for non specialist audiences, including local communities, planners, stakeholders, and rights holders in permafrost regions. Building on pan Arctic land surface disturbance trend datasets from the ERC PETA CARB, ESA CCI Permafrost, and NSF Permafrost Discovery Gateway projects, the web based Arctic Landscape EXplorer (ALEX, <https://alex.awi.de>) was developed to improve communication of remotely sensed permafrost landscape change. ALEX provides interactive maps showing recent land surface changes, hot spots of disturbances, and potential sites of active permafrost thaw and erosion, allowing users to move seamlessly from local to pan Arctic scales. To address the issue of sometimes limited internet bandwidth in Arctic communities, the portal is optimized for lightweight data transfer while still offering intuitive tools, such as swipe and fade functionality to compare map layers and satellite imagery, and an “At a Glance” section on the homepage that highlights locations with extraordinary landscape change. ALEX integrates updated disturbance trends (currently covering 2005-2024, including Landsat 9 OLI 2 imagery) with narrative elements, such as a story map on shore erosion that explains the geomorphic and permafrost processes underlying observed changes. This combination supports both exploration and contextual understanding for users with diverse backgrounds. Stakeholder interactions with local representatives, governmental and tribal entities, and research partners indicate strong interest in using ALEX for planning, research, and outreach, reflected in requests to reuse the tool and underlying web services. Together, these elements illustrate how an interactive, lightweight web portal can help translate complex Earth Observation products into actionable knowledge for communities and decision makers in permafrost regions.

Keywords: Landscape change, disturbance trends, earth observation, communication, web-based tool



CO-CREATING PERMAFROST KNOWLEDGE: YOUTH ENGAGEMENT AND CLIMATE LITERACY WITH THE UNDERCOVEREISAGENTEN

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Participatory research offers a promising pathway to enhance both environmental literacy and scientific data quality in permafrost research. The UndercoverEisAgenten citizen science project, funded 2021-2024 by the German Federal Ministry of Education and Research (BMBF, now BMFTR), explored this potential through an innovative framework combining participatory mapping, cross-cultural collaboration and digital tools. The initiative engages secondary school students in Germany and Indigenous students in Aklavik, Northwest Territories, Canada, in collection and classification of drone imagery capturing ice-wedge polygon networks in the Mackenzie Delta region. By translating permafrost geomorphology into accessible visual tasks - such as identifying polygon centers through micro-mapping - kids and youth contributed Volunteered Geographic Information (VGI) that closely approximates expert reference data. Validation analyses demonstrate that morphological characteristics can be reliably extracted from citizen-generated mapping data, highlighting the accuracy and scalability of participatory remote-sensing approaches. UndercoverEisAgenten facilitated multidirectional knowledge transfer through school workshops, digital tutorials and teaching materials, co-developed with educators. An integrative framework like this, strengthens climate competence among youth while promoting co-production of knowledge between scientists and non-specialists. UndercoverEisAgenten demonstrates that citizen science, when embedded in intercultural and educational contexts, can enhance both permafrost research capacity and science communication impact. It showcases a replicable model for combining participatory observation, data quality assurance and educational outreach in the rapidly evolving field of permafrost science communication.

Keywords: Participation, citizen science, knowledge transfer



ARCTIC PERMAFROST ATLAS

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The Arctic Permafrost Atlas is a key outcome of Nunataryuk, (<https://nunataryuk.org/>) an European Union Horizon 2020 funded permafrost research project. Edited by GRID-Arendal together with all Nunataryuk project partners, it presents state-of-the-art knowledge about permafrost and the impacts of permafrost thaw on human communities in the Arctic. This atlas is an attempt to translate and consolidate the available scientific knowledge on permafrost in a format accessible to both scientific and non-scientific audiences alike. It is a timely book suffused with the compelling enthusiasm of its authors and contributors. Close to a hundred individuals participated in its making, and it does a great job at describing permafrost related issues with different types of narratives. Far from being an academic product in the traditional sense, it gathers the knowledge from the voices of scientists, Indigenous Peoples, northern residents, and local practitioners to provide a holistic and inclusive view of today's challenges in the "country of permafrost". The print and digital publication is a highly visual product. Covering over 150 pages, it includes original maps and illustrations, drone imagery, and photographs, as well as engaging text based on the latest permafrost science. As an interdisciplinary publication, it focuses on the natural sciences of permafrost, but also the Arctic communities and people whose lives revolve around permafrost exploring strategies they can use to adapt to permafrost thaw. Fig. 1 Arctic Permafrost Atlas print publication.

Keywords: Communication, knowledge transfer, atlas, interdisciplinary





6A: GLOBAL ACTIVITIES ON PERMAFROST IN THE NEXT DECADE

Conveners: Isabelle Gärtner-Roer¹ & Gonçalo Vieira¹

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We invite contributions on global collaborations, monitoring networks, strategies to integrate Indigenous knowledge, and innovative technologies to address permafrost thaw's climate, ecosystem, and hazard impacts, aligned with the UN's sustainable development priorities as well as cryospheric priorities within the International Decade on Cryospheric Sciences (2025-2034) and International Polar Year framework.





CONSEQUENCES OF CHANGING PERMAFROST CONDITIONS FOR THE RUSSIAN ARCTIC ZONE

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The aim of our research is the analysis of the consequences of natural and ecological risks and the complex assessment of the territory of the Arctic zone of the RF (Fig. 1) for information support of the stable development and formation of the social-economic policy in the region. The methodological basis is theoretical works of domestic and foreign researchers on problems of interaction between nature and society, geocryology, rational utilization and protection of natural resources. Economic mechanisms of mitigating the danger of social losses, destruction of buildings and edifices, pollution of the environment during the development of a complex of dangerous processes, should be oriented, on the one hand, to the risk reduction, and, on the other hand, to searching new efficient sources for financing corresponding activities in Arctic Regions. The highest damage to the social-economic area may be caused, where the changes in climate may bring about a sharp deterioration of the permafrost conditions. It should be mentioned that the social-economic damage could not always be valued and usually show decreased quantitative and qualitative indicators. In the absence of the cost-based results, the rank semi quantitative estimation can be applied. The interaction of nature and society, contribution to stable development of the Arctic Regions is a multisided problem. Studying natural and natural-technogenic processes, we consider that at present, one of the main problems for the people of many countries is security and safety of the attained level of life, calm and substantial development. To achieve the stable development and elaborate new ethics for global management in the Arctic Regions it is necessary to identify the main priorities, among which: 1) Education of the population. The people should understand the essence of phenomena they face today; 2) Problems of stable development should be part of the government policy. They should be necessarily related to the main tendencies of the economic and social politics; 3) Development of new branches of industry with ecological norms; 4) Scientific information aimed at achieving stable development, involvement of the university and academic science into the Arctic exploration. Therefore, it is very important to note that Russia is included in the Decade of Action for Cryospheric Sciences (2025-2034), declared by the UN General Assembly on 13 August 2024.

Keywords: Arctic zone, permafrost, dangerous processes



Fig 1. Arctic zone of the Russian Federation (A, Pryadilina, I. Chesnokova, 2025)



SCIENCE DIPLOMACY AND PERMAFROST THAW IN TIMES OF GEOPOLITICAL FRAGMENTATION

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Permafrost thaw is one of the most critical and understudied consequences of climate change, with far-reaching environmental, economic, and security implications for Arctic but also high-altitude regions. Historically, permafrost research represented a rare area of scientific cooperation across geopolitical divides. During the Cold War, collaboration among Canada, the United States, and the USSR enabled significant advances in permafrost monitoring and modelling. Today, such cooperation is urgently needed again, as much of the world's permafrost lies within Russian territory, making access to shared data and expertise essential for understanding global thaw dynamics. Since the heightened geopolitical tensions in 2022, however, international scientific cooperation on permafrost has been severely disrupted. Sanctions and institutional disengagement have resulted in major data gaps, particularly in ground-based monitoring, at a time when only a limited number of climate models adequately account for permafrost thaw. These gaps hinder accurate risk assessment and policy planning. The consequences of permafrost degradation are profound. Thawing soils threaten to release vast amounts of stored carbon, potentially accelerating global warming. Infrastructure built on permanently frozen ground—roads, railways, and buildings—is already experiencing widespread damage, leading to significant economic and safety risks. In addition, concerns persist regarding pathogens and viruses preserved in permafrost, raising questions about emerging biological risks that require coordinated scientific evaluation. This contribution highlights the need for renewed, depoliticised dialogue and collaboration on permafrost science. This session will bring together scientific experts from countries with key stakes in the Arctic to examine both opportunities and challenges in international collaboration on permafrost research, share insights, and discuss pathways to strengthen cross-border data exchange and joint scientific efforts.

Keywords: International cooperation, dialogue, climate change



PERMACOST: NEW INTERNATIONAL RESEARCH NETWORK FOR COORDINATED AND STANDARDISED MONITORING OF PERMAFROST RESPONSE TO CLIMATE CHANGE

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PermaCOST is a new international research network funded by the COST Action programme of the European Union (CA24157). This four-years project (2025-2029) brings together European permafrost researchers, stakeholders, and practitioners with expertise in different measurement techniques and permafrost conditions to work towards a coordinated and standardised monitoring of permafrost response to climate change. Permafrost has been dramatically warming and degrading in most mountain and polar regions, with far-reaching and long-term implications for natural and anthropogenic environments. In this context of rapid changes and large socio-economic impacts, the increased scrutiny from the society and the growing demand for sound data from stakeholders make permafrost monitoring a timely and highly relevant field of research. Documenting, analysing, and assessing the response of permafrost to climate change requires fundamental cross-disciplinary and cross-geographic knowledge that can only be achieved through coordinated and standardized monitoring activities. For years, European research groups have been at the forefront of operational and innovative permafrost monitoring activities, but they have not been able to further coordinate their activities or to establish widely accepted standards for data acquisition and processing. Through an unprecedented network of experts and early career investigators, PermaCOST aims to promote and foster operational networking of permafrost researchers, stakeholders and practitioners to facilitate an overall comparability of data sets and time series of various permafrost variables for a better characterisation of the long-term permafrost evolution on the global scale. PermaCOST is organised in five Working Groups (WGs) with the specific objectives to identify key novel permafrost monitoring methods (WG1), to homogenise permafrost data acquisition standards (WG2) and permafrost data processing standards (WG3), to assess the state and evolution of permafrost in Europe (WG4) and to promote the development of operational permafrost monitoring networks at national, regional, and European scales (WG5). In this contribution, we will present the objectives and structure of the project, as well as the concrete tasks and ongoing activities in the WGs. We will also inform the permafrost community on how to join the network, and take advantage of the upcoming opportunities for networking, training, and research collaboration, through short-term scientific missions, travel grants, training schools and workshops.

Keywords: Permafrost monitoring, research network, cooperation



TRACKING A THAWING WORLD: THE NEW GTN-P (GLOBAL TERRESTRIAL NETWORK FOR PERMAFROST) DATA PLATFORM

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Permafrost covers nearly one quarter of the Northern Hemisphere's land surface. As the climate warms, permafrost temperatures are rising globally, destabilizing landscapes and infrastructure and releasing greenhouse gases such as methane and carbon dioxide. Long-term observations are essential to understand permafrost responses to warming and to estimate its future role in global carbon emissions. The Global Terrestrial Network for Permafrost (GTN-P) is the main international program for sustained permafrost monitoring. Researchers from over 30 countries collect permafrost temperature (PT) and active layer thickness (ALT) data, shared through the GTN-P platform. The original system, launched in 2015, has become outdated, prompting the development of a modernized database. The new system was developed within the Arctic PASSION project in the Alfred Wegener Institute's Permafrost Research Section in collaboration with the GTN-P Steering Committee and was launched in the beginning of 2026. It serves as the central platform for sharing and accessing permafrost data. It currently supports the Permafrost ECV products Permafrost Temperature and Active Layer Thickness, and is planned to include Rock Glacier Velocity (RGV). The updated platform features an intuitive interface, flexible data downloads, and time-series visualization tools. An annual global data compilation will include co-authorship for contributors, and additional synthesized products will be provided. Collaboration with the WMO ensures adherence to international data standards, enhancing interoperability and compliance with FAIR Data Principles. For data providers, the streamlined upload process includes automated quality checks with real-time feedback. Supported by AWI's IT infrastructure, the new GTN-P platform strengthens accessibility, reliability, and sustainability for the global permafrost research community.

Keywords: Permafrost warming, FAIR data



6B: PERMAFROST AND CLIMATE CHANGE FEEDBACK AND POLICY IMPLICATIONS

Conveners: Dashtseren Avirmed¹ & Battogtokh Dorjgotov¹

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Permafrost thaw releases carbon and methane, amplifying climate change feedbacks, while posing challenges for infrastructure and communities. This session examines this feedback alongside governance frameworks, regulatory tools, and financing mechanisms, such as NDCs and Arctic Council agreements, to address permafrost-driven risks. We invite studies on carbon cycling, policy gap analyses, and multi-stakeholder proposals to integrate permafrost science into climate mitigation and sustainable development strategies.





GEOCHEMICAL CONSTRAINTS ON GREENHOUSE GAS FORMATION IN ARCTIC ICE WEDGES

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We examined the geochemistry of ice wedges from Chokurdakh near the Northeast Siberian Sea, the Fox Tunnel and North Slope ice wedges from inland Alaska. The primary objective was to compare the chemical compositions of ice wedges from different regions and investigate the factors contributing to greenhouse gas formation in the ice wedges. The Chokurdakh and Fox Tunnel ice wedges date back to the Last Glacial Maximum (LGM). In contrast, the North Slope ice wedge from Alaska has age of the Late Holocene. In terms of $\delta(\text{N}_2/\text{Ar})$ ratios, the Chokurdakh and Fox Tunnel ice wedges dominantly shows near zero values, indicating that it primarily formed through dry snow compaction. In contrast, the North Slope ice wedge displays relatively depleted $\delta(\text{N}_2/\text{Ar})$ values, with a mean of -6.23%, suggesting that meltwater played a role in its formation. For the greenhouse gas (GHG) compositions, the average mixing ratios of gas trapped in bubbles in the ice wedges are 5-20% CO_2 , 846-34,700 ppm CH_4 , and 6-84 ppm N_2O . All the GHG concentrations clearly exceed the atmospheric levels, suggesting the presence of additional GHG production mechanisms. These elevated GHG concentrations likely indicate production through microbial activity. CH_4 - SO_4^{2-} biplot revealed an L-shaped distribution across all ice wedges, with enrichment in CH_4 and depletion in SO_4^{2-} , or vice versa, possibly suggesting sulfate reduction as a contributing mechanism. Future research will focus on further elucidating the mechanisms governing GHG dynamics in ice wedges.

Keywords: Ice wedge, greenhouse gas, geochemistry



A COMPREHENSIVE METEOROLOGICAL DATASET FOR THE CONTINUOUS PERMAFROST ZONE OF NORTHEASTERN EURASIA

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Although meteorological and climate data are crucial for permafrost studies, they are collected from a very sparse weather-station network in Northeastern Siberia including the Republic of Sakha (Yakutia), Magadan Oblast and Chukotka, with roughly one station covering an area equivalent to Israel or Armenia. In this study, we compiled a raw dataset from 169 weather stations distributed across approximately 4.1 million km², derived from three open-source data repositories, and processed the data using standard statistical methods and machine-learning techniques focusing on air temperature, precipitation and snow cover thickness as the primary indices for permafrost modelling. Over the period 1966-2025, only one third of the meteorological stations have nearly complete data records. Many stations exhibit observational gaps of 5-10 years, and about 10% of the stations provide less than 50% of the available data. The main outcome is the revealing of a statistically significant air temperature trend across the study area with amplifying in cities and more moderate tendency in the mountainous areas, offshore zones and seasonal road acceptable weather stations. Across the observation period from 1966 to 2025, mean annual air temperature (MAAT) increased by 0.8-1.5 °C at 18 stations, by 1.5-2.5 °C at 95 stations, and by more than 2.5 °C at the remaining 56 stations. Liquid precipitation exhibits no clear pattern, while snow cover thickness generally thinning at the station with longest snow cover observations. Air-temperature time series were reconstructed for each weather station using various techniques, and snow cover thickness was averaged on an annual basis. The results will be made available through an online dashboard, including MAAT, positive and negative degree-days, the duration of cold and warm seasons, and snow cover evolution. Several climatic records were identified across northeastern Eurasia, including an absolute daily minimum air temperature of -63.5 °C (WMO ID 24136, Sukhana, 8 January 1979) and an absolute daily maximum of 30.2 °C (WMO ID 24263, Batagay, 6 July 2020). The highest recorded daily air temperature amplitude reached 47.2 °C (WMO ID 25526, Kegali, 2 February 2017). MAAT ranged from a minimum of -18.5 °C (WMO ID 24691, Delyankir, 1987) to a maximum of -2.3 °C (WMO ID 24944, Olekminsk, 2020). The greatest recorded snow cover thickness was 278 cm (WMO ID 25677, Beringovskaya, 16 April 2012). The shortest warm season, defined as the number of days with daily mean air temperature below 0 °C, lasted only 38 days (WMO ID 21432, Kotelný, 1996). The high-quality and continuous meteorological dataset is essential for robust spatial modelling, as well as for hindcasting and forecasting permafrost conditions, since climate is the primary controlling factor governing the ground thermal regime.

Keywords: Northeast Eurasia, climate change, meteorological data, continuous permafrost zone



BEYOND CARBON: MULTI-SCALE THERMAL AND HYDROLOGICAL FEEDBACK OF PERMAFROST ON THE TIBETAN PLATEAU

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Thawing permafrost alters climate not only through carbon emissions but also via energy-water feedback and atmospheric teleconnections. This review focuses on the Tibetan Plateau, where strong freeze-thaw cycles, intense radiation, and complex snow-vegetation interactions constitute non-carbon climate responses. We synthesize recent evidence that links freeze-thaw cycles, ground heat flux dynamics, and soil moisture hysteresis to latent heat feedback, monsoon modulation, and planetary wave anomalies. Across these pathways, both observational and simulation studies reveal consistent signals of feedback amplification and nonlinear threshold behavior. However, most Earth system models underrepresent these processes due to simplifications in freezethaw processes, snow-soil-vegetation coupling, and cross-seasonal memory effects. We conclude by identifying priority processes to better simulate multi-scale cryosphere-climate feedback, especially under continued climate warming in high-altitude regions.

Keywords: Permafrost, feedbacks, climate change, modeling



DYNAMICS OF OPEN SANDS IN THE WEST SIBERIAN ARCTIC - RISKS AND CLIMATE ADAPTATION POTENTIAL

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The Arctic is a region where climate change and intensifying human activity are driving rapid landscape transformation. The activation of exogenous geomorphic processes, reindeers overgrazing, and various forms of technogenic disturbance to soil and vegetation cover expose mineral substrates, providing further habitat degradation. Wind deflation promotes the formation of sand blowouts and dunes that are nearly devoid of vegetation and often occupy extensive areas in Yamal-Gydan Arctic. The expansion of open, wind-eroded sand surfaces indicates an emerging process of Arctic desertification. Sand blowouts also alter local heat, water, and carbon balances, causing permafrost thaw and subsequent intensification of cryogenic geomorphic processes. The aim of this study is to assess the dynamics of open sand areas in the West Siberian Arctic, specifically within the Yamal-Nenets Autonomous Okrug north of 60° N. The assessment of aeolian sand extent was conducted using a combination of geospatial datasets and machine-learning methods. Cloud-free Landsat ARD mosaics developed by the Global Land Analysis and Discovery group at the University of Maryland served as the primary dataset. We also employed the ArcticDEM digital elevation model. Based on expert visual interpretation, we constructed a training dataset containing two classes: sands and other landscape types. We use compaction-efficient machine learning methods of supervised classification based on decision decision trees models. Map accuracy was evaluated using an independent sample of validation points. The resulting raster maps exhibit high classification accuracy (Overall Accuracy > 0.95). We analyzed the dynamics of open sands across four major categories: channel and floodplain alluvial sands, interfluvial sands, coastal-marine sands, and anthropogenic embankment sands. The results indicate a sharp increase in sand areas associated with human activity. Information on the genesis and temporal dynamics of aeolian sands provides an essential basis for nature-based climate solutions aimed at ecosystem adaptation to climate change, mitigation of its impacts, and support for biodiversity. Potential directions for such solutions, which must consider the spatial distribution and genesis of wind-eroded sands, include:

- ecological restoration aimed at reactivating natural ecosystem mechanisms by restoring key components that can lead to the recovery of biodiversity and ecosystem functioning
- regulation of reindeer population numbers and grazing pressure, including support measures for local communities to promote pasture recovery

The dynamics of aeolian sand extent serve not only as an indicator of permafrost landscape degradation but also as a critical tool for advancing toward managed climate adaptation. This approach enables a shift from reactive responses to proactive planning, minimizing ecological risks such as carbon emissions and biodiversity loss, as well as socio-economic costs for Indigenous peoples and industrial stakeholders in the Arctic.

Keywords: Open sands, remote sensing, climate



**6B: PERMAFROST AND CLIMATE CHANGE FEEDBACK AND
POLICY IMPLICATIONS
POSTER**



SPATIOTEMPORAL CLIMATE VARIABILITY AND PERMAFROST SENSITIVITY IN MONGOLIA (1981-2024)

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Mongolia is located in the cold, semi-arid interior of Central Asia and is characterized by a highly continental climate with pronounced seasonal contrasts, large annual and diurnal temperature variability, and strong latitudinal and altitudinal climatic gradients. These conditions support extensive discontinuous and isolated permafrost, while simultaneously rendering the cryosphere highly sensitive to recent climate variability. Despite increasing evidence of rapid warming across Mongolia, national-scale assessments that explicitly quantify the influence of key climatic drivers on permafrost sensitivity remain limited. Climate variability was examined using bias-corrected WorldClim (CRU-TS 4.09) monthly weather data at 2.5 arc-minute spatial resolution to characterize national-scale temperature and precipitation variability across Mongolia before detailed spatial and raster-based analysis. Long-term trends were evaluated for the period 1980-2024, and an annual anomaly series relative to the 1981-2010 baseline was constructed to characterize interannual variability and recent climatic extremes. Trend analysis based on Sen's slope estimator and the Mann-Kendall test reveals a statistically significant warming signal in both minimum and maximum temperature over 1980-2024. Annual minimum temperature increased by approximately 0.45°C per decade, while maximum temperature increased by 0.42°C per decade ($p < 0.001$), indicating a dominant role of minimum temperature in recent climate warming. In contrast, annual precipitation exhibits strong interannual variability and a weak, statistically insignificant long-term trend. The anomaly series indicates a transition from predominantly negative temperature anomalies during the 1980s to persistently positive anomalies after the late 1990s, with the largest positive anomalies occurring recently. In 2024, minimum and maximum temperature anomalies reached approximately +1.9°C relative to the 1981-2010 baseline, highlighting an exceptional warming signal. Overall, the results demonstrate that sustained temperature anomalies particularly those associated with minimum temperature play a critical role in increasing permafrost vulnerability in Mongolia. By quantifying long-term warming trends and persistent temperature anomalies, this study directly contributes to understanding permafrost-climate feedback mechanisms and provides climate-relevant evidence to support permafrost risk assessment and policy-oriented adaptation planning in cold, semi-arid regions.

Keywords: Permafrost, climate variability, temperature anomalies



PERMAFROST AS A FROZEN COMMONS: LESSONS FROM THE ARCTIC

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Thawing permafrost is one of the elements of the cryosphere that is rapidly transforming due to climate change. In the Arctic, these changes contribute to “Arctic amplification” causing the region to warm four times faster than the rest of the world. Rockstrom et al. (2024) recently identified the Arctic Cryosphere as a planetary commons, spanning national and supranational boundaries. Taking permafrost conditions into account in decision-making has already been introduced in infrastructure planning across Russia and North America. In particular, creating national permafrost monitoring systems and adapting construction in cities, using specialized techniques for stable construction, understanding permafrost’s role in engineering, and facing high costs to maintain vulnerable highways. Hazards related to permafrost degradation are an increasing concern for Arctic and Sub-Arctic communities and regions. Permafrost is sinking at an alarming rate across high-latitude and high-altitude cold regions of the Arctic. Infrastructure are at risk: roads, pipelines, buildings, and airports are vulnerable, leading to structural damage and huge costs. The extent of observed infrastructure damage is substantial (up to 60-80% of infrastructure elements) and is likely to increase with climate warming. Nearly 70% of current infrastructure in the permafrost domain is in areas with high potential for thaw of near-surface permafrost by 2050. (Hjort et al, 2022) Sustaining these frozen commons requires engagement from diverse actors and diverse ways of knowing at local, regional, national, and global levels, extending beyond nation-to-nation decision making. Building on experience from Interior Alaska and northern Mongolia, this presentation highlights the importance of the concept of frozen commons for current discussions about permafrost and climate change feedback. Bringing perspectives, amplifying voices, and elevating the ethics of care for human and non-human relations developed by Indigenous Peoples and nomadic herders in decision-making and planning efforts is necessary to address climate change in a just and equitable way.

Keywords: Permafrost, frozen commons, Indigenous Peoples



7A: HIGH-RESOLUTION REMOTE SENSING AND IN-SITU INTEGRATION FOR PERMAFROST MODELLING

Conveners: Jurjen van der Sluijs¹ & Stefano Ponti²

¹*Government of Northwest Territories*

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Bridging the gap between plotlevel observations and regional permafrost forecasts requires closerange sensing drones, GPR, ERT, multispectral/hyperspectral imaging and rigorous insitu validation. We particularly encourage studies that advance scaling workflows through multi-sensor integration, drone-based data acquisition, multispectral/hyperspectral imaging, custom sensors, and reproducibility techniques. Submissions combining diverse data sources such as spectral imaging, ground penetrating radar, and electrical resistivity tomography to enhance model calibration, validation, and interpretation across scales are especially welcome.





ASSESSING THE POTENTIAL OF SEPARABLE DUAL-COIL FREQUENCY-DOMAIN ELECTROMAGNETIC (FDEM) SYSTEMS FOR DETECTING FROZEN LAYERS IN ALPINE PERMAFROST

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Geophysical investigations play a key role in characterizing mountain permafrost, where direct information from boreholes or excavations is often limited by logistical constraints and harsh environmental conditions. Among the available techniques, Electrical Resistivity Tomography (ERT) is the most widely applied method for imaging frozen ground in alpine environments such as rock glaciers due to the strong resistivity contrast between frozen and unfrozen layers. In contrast, Frequency Domain Electromagnetic (FDEM) methods have been rarely applied in these settings, despite their potential advantages, including rapid data acquisition, light and portable equipment, operational simplicity, and efficient coverage of large areas. This study evaluates the capability of a separable dual-coil FDEM system to detect frozen layers and characterize subsurface structures in alpine permafrost. Field measurements were conducted at four mountain permafrost sites, three rock glaciers and one protalus rampart, characterized by heterogeneous permafrost conditions. FDEM surveys were performed using a separable dual-coil instrument capable of probing electrical resistivity from a few meters down to several tens of meters of depth. The FDEM results were systematically compared with ERT profiles acquired along the same transects, allowing a direct assessment of the correspondence between the two datasets and the reliability of FDEM in permafrost terrains. Despite lower spatial resolution and less accurate resistivity values compared to ERT, FDEM consistently captures the main structural patterns of the investigated permafrost areas, reproducing key contrasts between frozen and unfrozen layers. Overall, the study highlights the potential of separable dual-coil Frequency Domain Electromagnetic (FDEM) systems as a complementary tool for permafrost investigations, enabling straightforward, preliminary, first-order assessments of subsurface structures, supporting the planning of detailed geophysical surveys as ERT does, and allowing extended characterization even in remote or difficult-to-access areas.

Keywords: Alpine permafrost, rock glaciers, geophysical



INTEGRATED GEOPHYSICAL INVESTIGATION OF MOUNTAIN PERMAFROST IN A PSEUDO-RELICT ROCK GLACIER: INSIGHTS FROM ELECTRICAL, ACTIVE SEISMIC, AND GRAVITY METHODS

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Rock glaciers are mountain permafrost landforms composed of a mixture of ice, rock debris, air, and liquid water (Wagner et al., 2020). They typically occur in high-altitude periglacial environments and, in some cases, in Antarctic environments (Guglielmin et al. 2018), where permafrost conditions enable the long-term preservation of ground ice (Barsch, 1996). The internal composition of rock glaciers can vary significantly over space and time, influenced by local climatic, hydrological, and geological factors (Matsuoka, 2011). In the context of global warming, the study of mountain permafrost has gained increasing relevance (Mollaret et al., 2019). Understanding the internal structure and thermal regime of rock glaciers is crucial for assessing their stability, estimating ice content, and evaluating their role in local hydrological systems. However, their heterogeneous composition and difficult accessibility make their investigation particularly challenging. In this regard, non-invasive geophysical methods have proven effective tools for imaging subsurface conditions in periglacial environments (Hauck and Kneisel, 2008). The Sadole rock glacier, in the south-eastern Alps (Trentino-Alto Adige, Northern Italy) has traditionally been classified as relict due to its low elevation (1820-2093 m a.s.l.) and vegetation cover, which typically lead to the assessment of permafrost absence. However, recent Electrical Resistivity Tomography (ERT) investigations by Pavoni et al. (2023) revealed the presence of discontinuous permafrost within its subsurface. Rock glaciers like Sadole, which appear relict but still contain permafrost, are referred to as pseudo-relict and recent studies suggest they are widespread yet understudied in this region (Carturan et al., 2024). These findings are further corroborated by ground surface temperature (GST) monitoring and spring water temperature measurements, which consistently remain below 2 °C throughout the year, confirming the presence of permafrost and questioning its previous classification. This highlights the importance of detailed subsurface investigations to better constrain permafrost conditions in marginal and transitional environments. In this study, we aimed to characterize the internal structure and estimate the ice content of the Sadole rock glacier through an integrated geophysical approach. We employed Electrical Resistivity Tomography (ERT) and active seismic methods, including Seismic Refraction Tomography (SRT) and Multichannel Analysis of Surface Waves (MASW), to detect and map the extent of frozen ground. In addition, gravity measurements were carried out to constrain the density distribution within the subsurface, providing an independent estimate of the ice fraction. The collected results pave the way for combining these geophysical methods to obtain a more plausible and consistent interpretation of the rock glacier's structure, composition, and permafrost conditions.

Keywords: Rock glacier, geophysics, ERT, seismic, gravimetry



PERMAFROST-HYDROGEOLOGICAL STRUCTURE OF THE GIANT ANMANGYNDA AUFEIS ACCORDING TO THE DATA OF GEOPHYSICAL RESEARCH (NORTHEASTERN EURASIA)

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Icing processes indicates the interaction between geocryological conditions and the hydrological cycle. From 2021 to 2025, comprehensive geophysical studies were conducted at the Anmangynda aufeis complex research station to study the permafrost-hydrogeological structure of the Anmangynda River aufeis glade. The main objectives were to determine ice thickness, seasonal freezing depth, and identify talik and permafrost boundaries. The soundings using ground-penetrating radar (GPR), capacitively coupled electrical resistivity tomography and transient electromagnetic (TEM) method were used to address these issues during the period of maximum ground freeze (March-April). Electrical resistivity tomography was used during the period of maximum ground thaw (September). Currently (2000-2025), the maximum size of the Anmangynda aufeis is 5.4 km² in area and 8.2 million m³ in volume, with ice thickness in some areas reaching 5-6 m. According to the TEM data, it was established that groundwater outlets above the aufeis glade spatially coincide with the outcrops of steeply dipping zones of low resistivity, which are interpreted as faults. Electrical resistivity tomography performed in the autumn identified the boundaries of shallow supraperafrost taliks and deep (up to 30 m) subchannel taliks with filtration channels in the channel alluvium and the zone of exogenous fracturing of the bedrock. Ice mounds form above these taliks in winter at the outlets of pressurized groundwater. Unique data were obtained through the combined use of ground-penetrating radar and capacitively coupled electrical resistivity tomography. For the first time, a three-dimensional geoelectric model of ice was obtained using electrical sounding data, identifying a lens of unfrozen water. Such results were previously unknown. GPR data established the relationship between ice thickness and seasonal freezing depth: a direct relationship is observed for ice thicknesses up to 2 m, and an inverse relationship beyond that. Such research is essential for the timely detection of dangerous trends and the development of methods to prevent the negative consequences of ice formation.

Keywords: GPR, aufeis, electrical resistivity, TEM

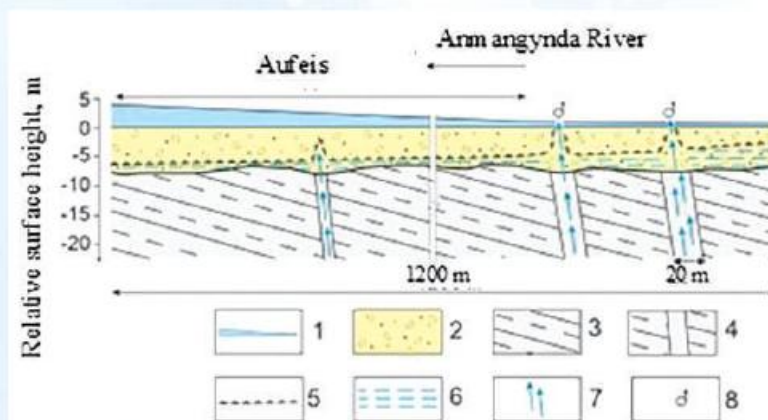


Fig 1. Formation of the aufeis according to the data of geophysical research. 1 - ice, 2 - alluvium, 3 - clay silt, 4 - fault, 5 - the boundary of annual frost zone, 6 - thaw zone, 7 - groundwater outlet, 8 - spring.



IMPROVING GROUND ICE REPRESENTATION AND THAW TRAJECTORIES BY DATA ASSIMILATION OF INTER-ANNUAL GROUND SUBSIDENCE

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Increases in permafrost temperatures are observed globally and models predict this increase to continue with climate change, imposing economic, societal and environmental consequences. For well-informed future projections of permafrost evolution, accurate representations of current ground states are needed, but models typically suffer from the spatial and temporal sparsity of in-situ measurements. In ground ice-rich landscapes, permafrost degradation is often associated with subsidence of the surface due to melting of ice-rich layers at the top of the permafrost, making the permafrost ground ice content one of the most important variables determining ground subsidence and landscape development upon permafrost thaw. Quantifying and monitoring surface subsidence has long been a challenge, but novel remote sensing techniques using the InSAR method can now quantify the surface subsidence signal over several years. We combine the CryoGrid community model with observations of inter-annual ground subsidence in a data assimilation framework to constrain the ground ice content of the uppermost permafrost layers. Data assimilation frameworks offer a promising method to reduce uncertainty in local permafrost state estimates and to improve projections of permafrost evolution and landscape response to global warming. In a previous study, the assimilation of small-scale snow cover observations into the CryoGrid model has been found to significantly improve the representation of the local ground thermal regime. In this study, we investigate the suitability of the data assimilation scheme to infer subsurface parameters such as soil properties and ground ice content. We apply the scheme to a set of well-studied and monitored permafrost sites close to Ny-Ålesund, Svalbard, Norway, for which the InSAR Svalbard project has recently compiled the first prototype maps of multi-annual surface subsidence. The maps show a clear subsidence signal of several centimeters in the last years in some areas, while other areas have remained stable. We present a dedicated validation data set comprising permafrost properties from promising field sites with largely varying permafrost conditions.

Keywords: Data assimilation, modelling, remote sensing



FREEZE-THAW-DRIVEN SURFACE DEFORMATION AND ACTIVE LAYER THICKNESS ESTIMATION IN HIMALAYAN PERMAFROST: INSIGHTS FROM TSO KAR VALLEY

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Permafrost constitutes a fundamental component of the mountainous cryosphere, exerting a strong influence on land surface stability, hydrological processes, ecosystem functioning, and the integrity of both natural and built infrastructures. While permafrost dynamics and degradation have been extensively investigated across Arctic and alpine regions such as the European Alps, comparable observations remain sparse in the Himalayan region. Under continued climatic warming, understanding this critical landform is essential due to its implications for permafrost-related hazards, including landslides, ground instability, landscape changes. To monitor these rapidly changing landscapes, we employed a large-scale remote sensing approach based on Small Baseline Subset Interferometric Synthetic Aperture Radar (SBAS-InSAR) over the Tso Kar valley, Ladakh, Western Himalayas. Seasonal Sentinel-1A/B SAR data acquired between March 2021 to November 2024 were utilized to observe seasonal and annual ground deformation associated with permafrost active layer (AL). The analysis reveals distinct seasonal signals along with annual trends, reflecting cyclic freeze-thaw of AL and potential indicators of permafrost degradation. Our findings indicate the seasonal line-of-sight (LOS) deformation amplitude ranging from approximately 10 to 25mm, with mean annual LOS deformation rates between -10 to -30mm/yr. To further characterize ground deformation, we combined data from both ascending and descending passes to derive the vertical and horizontal component of the deformation. Since line-of-sight (LOS) displacement alone cannot be directly attributed to permafrost thawing or ALT changes, computing vertical deformation component is essential. The results showed significant vertical deformation ranging from -10 to -40mm and the East-West movement between -15 to 18mm over study region, indicating freeze-thaw induced ground movement associated with cyclic active layer thaw settlement and long-term permafrost degradation. These findings highlight the critical need for comprehensive studies in the Indian Himalayas to better understand permafrost dynamics. In response, InSAR-based temperature inversion modelling was carried out to provide the first estimates of ALT and permafrost status for the region. Due to the lack of in-situ observations in the Indian Himalaya, the inversion approach was evaluated over the Qinghai-Tibetan Plateau (QTP), where point-scale validation data are available. Mean ALT in the Tso Kar region is estimated to be approximately 3.2 m, with values ranging from 2.5 to 4.5 m. These estimates are broadly consistent with the ALT ranges reported for cold-arid, high-elevation permafrost environments in the Hindu Kush Himalaya, indicating that the values are physically reasonable within the regional geomorphic and climatic context. At the same time, the lack of in-situ observations indicate there is an urgent need for extensive ground temperature and active layer monitoring across Himalayas to support modelling and long-term assessment of permafrost degradation in the regions.

Keywords: InSAR, Permafrost, Active layer thickness, Himalayas



METHANE FLUXES SPATIALIZATION FROM CHAMBER MEASUREMENT TO PLANETSCOPE AND UAV IN THE ALASKAN ARCTIC TUNDRA ENVIRONMENT

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The significant impact of methane (CH_4) emissions from the Arctic tundra on climate change highlights the need for future modeling efforts to account for the high spatial variability of these fluxes. Here, we present the spatial distribution of CH_4 emissions through the 2024 thawing season in an area near the Toolik Field Station (Alaska) by comparing PlanetScope and UAV reflectance imagery. We spatialized CH_4 fluxes measured across various tundra types (dry, wet, and tussock) using data collected from closed-system chambers, combined with PlanetScope and UAV imagery. Multiple linear regression models with residuals interpolation were developed between in situ CH_4 fluxes and PlanetScope near infra-red (NIR) band for all the available (and cloud-free) dates in 2024. The models were validated using a leave-one-out cross-validation (LOOCV) and subsequently applied to PlanetScope NIR at 3 m of resolution. Results show that CH_4 fluxes response to NIR is robust at the beginning of the summer season (June and July 2024) with a good model performance (i.e., lower RMSE than standard deviation of observed fluxes) for spatial mapping. For one date in June, despite its higher resolution, UAV NIR did not perform well as satellite imagery, with a RMSE close to the standard deviation of fluxes. Such a discrepancy between UAV and Sentinel-2 spatialization is likely due to the different spatial resolutions of the two systems leading to an interaction between vegetation-ground activities that is better resumed by a coarser satellite pixel. The modelled CH_4 fluxes at our site were compared with other authors at nearby locations, resulting in comparable emissions for wet and tussock tundra, while a slightly higher uptake for dry tundra. This was explained by a possible mismatch between chamber and eddy covariance measurements, our more recent fluxes observations and the climatic diversity of the study site.

Keywords: Methane fluxes; Arctic tundra; PlanetScope; Spatial mapping



CHARACTERING THE SPATIAL AND TEMPORAL VARIABILITY OF PERMAFROST ACTIVE LAYER THICKNESS IN THE PAN-ARCTIC REGION AND ITS NON-LINEAR RELATIONSHIP WITH SEASONAL DEFORMATION

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Permafrost degradation driven by ongoing climate warming has profound implications for Arctic and alpine ecosystems, infrastructure stability, and carbon-climate feedbacks. Active layer thickness (ALT), defined as the maximum seasonal thaw depth, is a key indicator of permafrost thermal stability, and accurate characterization of its spatio-temporal variability is essential for understanding permafrost dynamics. InSAR-derived surface deformation is closely linked to active-layer freeze-thaw processes and offers strong potential for high-resolution ALT mapping. However, its applicability at regional scales remains uncertain because surface deformation is also influenced by local surface and subsurface conditions. Here, we investigate the link between permafrost active-layer dynamics and seasonal surface deformation, supported by a physically improved ALT baseline. We develop a snow-corrected Stefan framework by incorporating the snow insulation module of the Kudryavtsev model into the effective thermal forcing of the Stefan formulation, enabling explicit representation of winter insulation effects in snow-rich permafrost regions. Using multi-source remote sensing and reanalysis datasets, we generate a pan-Arctic ALT dataset at 1-km spatial resolution for regions north of 50°N spanning 2001-2025. Validation against CALM in situ observations shows that the improved Stefan model substantially outperforms the original formulation, achieving $R^2 = 0.78$, a bias of 0.23 m, and an RMSE of 0.35 m. The model also reproduces long-term ALT trends more accurately than existing 1-km ALT products, with a trend agreement of $R^2 = 0.46$ relative to observed ALT trends. Spatially averaged ALT across the study region is 0.72 ± 0.48 m, with an overall increasing trend of 0.64 ± 0.81 cm yr⁻¹ during 2001-2025. Building on this improved ALT baseline, we examine its relationship with seasonal surface deformation derived from Sentinel-1 C-band InSAR and L-band PolSAR data. Deformation time series were generated using a small-baseline approach, and seasonal deformation was quantified as the displacement difference between pre-thaw and post-thaw periods. To isolate soil effects from thermal forcing, we introduce an empirical Edaphic factor defined as ALT normalized by thawing degree days derived from MODIS land surface temperature. We identify a strong inverse relationship between the Edaphic factor and seasonal deformation ($R^2 = 0.89$, $p < 0.01$), indicating reduced deformation sensitivity in drier or coarse-grained soils. These results demonstrate that soil properties play a critical role in modulating deformation responses to thawing, beyond thermal forcing alone, and provide a physically grounded basis for interpreting InSAR-derived deformation in support of large-scale, high-resolution permafrost mapping.

Keywords: Active layer thickness, Seasonal deformation



**7A: HIGH-RESOLUTION REMOTE SENSING AND IN-SITU
INTEGRATION FOR PERMAFROST MODELLING
POSTER**



FEASIBILITY OF SATELLITE-DERIVED DEMS FOR SHALLOW LANDSLIDE VOLUME ESTIMATION IN PERMAFROST TERRAIN (WEST GREENLAND)

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Between 2019 and 2024, three landslides in mid-western Greenland were reported by local inhabitants. Subsequent analysis of multi-temporal remote sensing revealed more than 700 additional landslides occurring over the same period, primarily in remote, sparsely populated permafrost terrain. The Landslides are located by using a Normalized Difference Vegetation Index (NDVI) from the respective years and identifying changes in landscape color. These failures are hypothesized to be linked to permafrost degradation driven by recent climate warming. The three landslides reported are situated relatively close to civilization and have been investigated thoroughly by field campaigns and spatial models have been done with Unmanned Aerial Vehicle (UAV) to generate high resolution Digital Elevation Model (DEM). These DEMs give a precise volume of the landslides, but because of the remoteness of the other 700 landslides, they are not easily reached for in-situ surveys. Because the vast majority of landslides are inaccessible for UAV surveys, we evaluate whether high-resolution satellite-derived DEMs can be used to estimate landslide volumes at regional scale. Stereo imagery from Pléiades (CNES) and WorldView 2-3 (Maxar) have been used to generate 2m DEMs and 0.5m orthophotos over the landslide areas and compared against UAV surveys for the three reference sites. This comparison quantifies the accuracy, uncertainty, and scaling potential of satellite-based volume estimates. Our results demonstrate the feasibility of using optical satellite stereo imagery to approximate landslide volumes in remote permafrost environments. The end goal is to generate a framework for applying these techniques to landslide and climate modelling to enhance model prediction of released nutrients, CO₂ and possible dangers to users of the back country.

Keywords: Remote Sensing, permafrost landslides, UAV



MULTI-FREQUENCY INSAR OBSERVATIONS OF PERMAFROST THAW SUBSIDENCE

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Seasonal thaw subsidence of permafrost terrain indicates the thickness and ice content of the active layer and produces measurable movement that can be monitored using interferometric synthetic aperture radar (InSAR). InSAR provides high-resolution subsidence estimates over vast areas that are used to map ground ice distribution and help predict how the landscape will respond to permafrost thaw under a warming climate. Typically, InSAR measurements of permafrost subsidence are reported as surface deformation signals. However, SAR is highly sensitive to ground surface roughness and water content, making the physical interpretation and direct comparison with in-situ subsidence measurements challenging. The radar wavelength is an important parameter that governs the interaction of the electromagnetic wave with the surface, controlling signal penetration depth and, thereby, the physical volume of the soil contributing to the observed measurement, with longer wavelengths penetrating deeper into the ground. In this work, we compare InSAR observations from spaceborne Sentinel-1 C-band SAR (5 cm) to long-wavelength P-band (69 cm) and L-band (23 cm) airborne SAR measurements acquired on the North Slope of Alaska during the NASA ABoVE campaign in 2017. Using all available C-band data from June to October, this dense time series provides detailed temporal evolution of seasonal subsidence, while the sparse time series of long-wavelength airborne data captures cumulative deformation with increased subsurface sensitivity. A consistent InSAR processing chain is applied to enable direct comparison across wavelengths. The results are then compared to in-situ measurements of subsurface temperature and volumetric water content. Although the large-scale seasonal subsidence signal is consistently observed across all bands, we find pronounced differences at different wavelengths in both displacement magnitude and spatial variability. In particular, P-band generally exhibits larger displacement (mean of -9 cm over the area of interest) and greater spatial variability (standard deviation 4 cm) compared to C-band (mean -2 cm, STD 1 cm), while L-band exhibits intermediate behavior (mean -2.5 cm, STD 2.5 cm). We interpret these differences primarily as a consequence of wavelength-dependent penetration depth and varying phase-center location. Thaw onset and variations in soil water content alter the dielectric properties of the active layer, affecting the sensing depth of the radar system. This causes the effective SAR phase center to move vertically within the active layer, which appears as apparent displacement in InSAR measurements in addition to the true subsidence signal. This wavelength-dependent response implies that P-, L- and C-band InSAR are not simply measuring the same physical surface at different frequencies but are sampling different parts of the active layer. From this perspective, a larger penetration depth becomes a measurement advantage: long-wavelength InSAR provides indirect information about seasonal changes in subsurface electromagnetic properties linked to seasonal active layer dynamics. Preliminary land-cover analysis suggests that the magnitude of this effect varies across vegetation types, motivating future integration with polarimetric SAR indicators of scattering mechanism. Our work is timely, as systematic satellite observations at long wavelengths will soon be available nearly globally with the launches of NISAR (L-band) and BIOMASS (P-band) in 2025.

Keywords: InSAR, thaw subsidence, penetration depth



ALLOMETRIC SCALING OF RETROGRESSIVE THAW SLUMPS ON THE QINGHAI-TIBET PLATEAU

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The warming climate on the Qinghai-Tibet Plateau leads to the accelerated degradation of permafrost. As one kind of abrupt permafrost degradation, retrogressive thaw slumps (RTSs) have become increasingly widespread across the Plateau, with both their number and affected area increasing several-fold since 2016. Once initiated, RTSs can keep active and retreat for several years to decades, stripping vegetation, transporting sediment toward downslope streams, and exposing soil organic carbon. Despite growing knowledge of the temporal trends in RTS numbers and areal expansion, the volume changes of RTSs remain poorly quantified, which can be used to estimate the magnitude of sediment and organic carbon mobilized during slump growth. This knowledge gap is primarily due to the limited availability of high spatial- and temporal-resolution digital elevation models. To quantify RTS volume changes across the Plateau at high temporal resolution, we developed empirical area-volume scaling relationships using unmanned aerial vehicle (UAV)-derived elevation data. Since 2021, we have conducted repeated UAV surveys for 15 RTSs located in the central and eastern Qinghai-Tibet Plateau. UAV imagery was processed using DJI software to generate orthorectified optical images and the corresponding elevation dataset. Multi-temporal optical images and their associated elevation datasets were co-registered to the most recent acquisition. RTS boundaries were delineated based on the orthorectified optical images. Volume changes were then calculated using the elevation differences between two consecutive years within the delineated RTS boundaries. Then, we applied power-law models to characterize the relationship between area expansion and volumetric change for RTSs in both regions. The scaling exponent for RTSs in the central Qinghai-Tibet Plateau is 0.97, which is higher than that observed in the eastern Plateau (0.44). A larger scaling exponent indicates greater vertical disturbance relative to lateral expansion, suggesting deeper thaw depths in the central Plateau. This regional contrast may be explained by differences in ground-ice conditions, with shallower ground ice in the eastern Plateau compared to the central region. In summary, we established area-volume power-law models for RTSs in two main permafrost ecosystems. These models enable direct estimation of RTS volume changes from annual areal measurements and provide a critical basis for quantifying sediment and carbon mobilization associated with abrupt permafrost thaw.

Keywords: Retrogressive thaw slump, volume changes



PERMAFROST SIGNALS IN SENTINEL-1 VELOCITIES OVER THE TIBETAN PLATEAU, QILIAN SHAN AND TIAN SHAN

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Using Sentinel-1 radar images acquired during 2016-2024, the Centre of Observation and Modelling of Earthquakes, Volcanoes and Tectonics (COMET) produced trans-national average surface velocities and time series at 1 km spatial resolution across the Alpine Himalayan Belt. The thawing of permafrost under a warming climate is a process that induces land surface subsidence on a large scale. Comparing the spatial patterns of our vertical velocities and the permafrost zonation index (PZI) reveals a spatial correlation between subsidence and regions with PZI between 0.5 and 1. In particular, the correlation is best observed in the Qilian Shan and the interior of the Tibetan Plateau, across almost the entire Qiangtang region. At least 5 mm/yr of subsidence is measured across most of the permafrost zone. Up to 10mm/yr of subsidence rates are measured on the low-relief valley slopes of the Qilian Shan. Up to 20 mm/yr of subsidence is captured within the Kokoxili region in the central Tibetan Plateau. This is also where the permafrost zonation index indicates a transition from PZI=1 in northern Qiangtang, where permafrost presence occurs under all conditions, to PZI<0.5 in the southern Tibetan Plateau, where permafrost is only expected under very favourable conditions. We observe this characteristic across the whole region, where permafrost at the border of stability is the most susceptible to thawing and inducing the fastest subsidence. We further correlated the vertical velocities in the Qilian Shan with published permafrost zonation index, permafrost active layer thickness, mean annual ground temperature, elevation, and ground ice contents in the 2-3 m, 3-5 m and 5-10 m depths. We found negative correlations between vertical velocities and ground ice contents, permafrost zonation index, and elevation, and positive correlations between vertical velocities and active layer thickness and mean annual ground temperature. These observations suggest that high elevation and cold temperature are conditions for permafrost existence, thin active layer thickness facilitates thermal diffusion and that surface subsidence rate due to permafrost thawing is limited by ground ice content. In Tian Shan, permafrost subsidence might be mostly offset by the tectonic uplift rates. Hence, the dominate feature we observe in permafrost zones is the horizontal component of what might be downslope solifluction on the east- and west-facing slopes. Despite uncertainties in the absolute subsidence rates measured by InSAR, we reveal a big picture of subsidence patterns over the most extensive high-altitude permafrost zone on Earth, highlighting the value of InSAR in improving our understanding of high-mountain permafrost dynamics.

Keywords: Sentinel-1, subsidence, High Mountain Asia



FILLING WHITE, BLUE AND BLIND SPOTS IN HIGH MOUNTAIN ASIA - THE BHUTANESE-SWISS CRYO-SPIRIT PROJECT

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In the Himalaya's, thawing permafrost is widely recognised as posing a major risk of triggering mass movements, influencing hydrological runoff and impacting biodiversity. However, information and knowledge on the occurrence of mountain permafrost, and even more so on changes to it, are still very scarce or absent in most areas. This is particularly the case for Bhutan. In the recently launched CRYO-SPIRIT project, Bhutan and Switzerland are collaborating to establish permafrost research in Bhutan. The project is funded by the Swiss National Science Foundation (<https://data.snf.ch/grants/grant/216522>). The CRYO-SPIRIT project is based on four pillars: Firstly, we take the first ever in-situ measurements of permafrost indicators in Bhutan and combine them with geomorphological mapping. Thereby, we follow well-established methods developed and used by PERMOS (Permafrost Monitoring Switzerland) and international standards. In the vicinity of the Thana Glacier (5,200 m above sea level), we deployed a cosmic ray neutron sensor and re-placed the broken sensors at the automatic weather station (AWS) already in place to measure temporally continuous high-elevation snow water equivalent (SWE), solid precipitation (snowfall) and the related meteorological variables. These data will be extrapolated in time and space using satellite and climate reanalysis datasets in order to derive a comprehensive pattern of cryospheric relevant variables across Bhutan. This research is undertaken in the Chamkhar Chhu Basin in Bumthang. The site was selected because of (i) its proximity to one of the three benchmark glaciers visited annually by researchers from Bhutan's National Centre for Hydrology and Meteorology, and thus to ensure the long-term continuation of the measurements, (ii) the presence of an automatic weather station and (iii) identified periglacial landforms. Secondly, we assess potential (future) risks from thawing permafrost and co-develop adaptation strategies with the local population and stakeholders. Thirdly, we introduce and establish education programmes at the university level (CNR, Royal University of Bhutan), and finally, we raise awareness among governmental institutions, NGOs, and the public through workshops, public events, and collaboration with various stakeholders. In our contribution, we will present and discuss the concepts as well as first results of the CRYO-SPIRIT project and we aim to foster collaborations with other interested parties in the region and internationally.

Keywords: Permafrost, CRS, Bhutan, risks, adaptation



STUDYING THE PROBABILITY DISTRIBUTIONS OF POLYGONAL ICE WEDGES MORPHOLOGICAL STRUCTURES BASED REMOTE SENSING DATA

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The relevance of this study is determined by the wide occurrence of polygonal-wedge structures within the permafrost zone, which is currently undergoing significant transformations due to climate change. The mechanisms and formation of ice-wedge polygons have been studied by many authors, with considerable attention paid to the morphometric analysis of polygon networks (Lousada M.F., Kessler M.A., Panchenko E.G., Stanilovskaya Yu.V., et al.). However, the probabilistic regularities of the spatial organization of these networks remain insufficiently explored. The aim of this research was to identify the probabilistic patterns of the morphological structures in areas characterized by the development of polygonal-wedge ice. Spatially, polygonal-wedge ice networks display various geometric configurations formed under the influence of multiple factors. This study focuses on the regularities of non-orthogonal networks, in which no dominant orientations are observed. Ten morphologically homogeneous key sites located in different physico-geographical conditions were selected for analysis. These sites are mainly situated in waterlogged alases depressions and river valleys. Using high-resolution satellite imagery (WV-2, WV-3, 1.2 m/pixel), the main network elements segments, junction nodes, and polygons were digitized. Segment lengths and orientation angles were measured. The resulting datasets were compared with various theoretical probability distributions to assess the agreement between empirical and theoretical data using Pearson's chi-square test. The samples were compared with uniform, normal, lognormal, exponential, and gamma distributions, while the number of polygon centers and network nodes was compared with the Poisson distribution. The analysis revealed the following statistical regularities, observed consistently across all sites with sufficiently large sample sizes (207-1478):

- The polygon area distributions follow a lognormal distribution, which can be explained by a model of repeated sequential subdivision of polygons into smaller ones in an independent manner;
- The segment length distributions predominantly follow a gamma distribution; the causes of this pattern require further investigation;
- The distributions of segment orientation angles mostly correspond to uniform distributions, which is preliminarily interpreted as evidence of isotropic network development conditions in these areas.

Although the general types of distributions remained consistent, the distribution parameters varied among the study sites due to differences in sediment composition and geocryological conditions. Analysis of the number of network nodes and polygon centers within randomly selected areas showed statistically significant deviations from the Poisson distribution, indicating that node formation cannot be regarded as purely random and independent.

Keywords: Polygonal wedge ice



7B: MODELING PERMAFROST DYNAMICS ACROSS SCALES

Conveners: Juditha Aga¹, Jan Nitzbon², Simone Stuenzi³, Rachele Lodi⁴, Clarissa Willmes¹

¹*University of Oslo*

²*Alfred-Wegener-Institute*

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⁴*Institute of Polar Sciences - National Research Council*

This session focuses on advancing mathematical and physics-based models to better capture permafrost dynamics across local to global scales. We invite contributions on thermal, hydrological, ecological, biogeochemical, and carbon-cycle processes, as well as approaches that integrate field observations, remote sensing, and data assimilation into modeling frameworks. By fostering dialogue among diverse modeling approaches, the session aims to bridge scales and improve projections of permafrost change and its impacts under a warming climate.





A HYBRID MODELING APPROACH FOR IMPROVED SIMULATION OF THERMAL-HYDROLOGICAL DYNAMICS IN ACTIVE LAYER ON THE QINGHAI-TIBET PLATEAU

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Co-authors: Dongfeng Li, Zhuotong Nan

Accurately modeling active layer dynamics on the warming and wetting Qinghai-Tibet Plateau (QTP) is crucial for understanding local hydrological processes, ecosystem dynamics, and infrastructure integrity. However, land surface models (LSMs) are often limited by simplified representation of physical processes in frozen ground and by uncertain forcing data. We present a novel hybrid modeling approach that enables the use of the Simultaneous Heat and Water (SHAW) model, with its advanced representation of physical processes in frozen ground, in data-sparse regions by generating robust lower boundary conditions from random forest-corrected Noah LSM simulations. When evaluated at seven permafrost sites on the QTP, the hybrid approach significantly outperformed both the standalone Noah LSM and traditional SHAW configurations in simulating active layer temperature and moisture. For testing data, the hybrid approach achieved higher average Nash-Sutcliffe efficiency values for soil temperature (ST) (0.81 vs. 0.69) and soil moisture (0.35 vs. 0.17) compared to the Noah LSM. Notably, the hybrid approach corrects key biases of the Noah LSM, which tends to overestimate ST and unfrozen water content during freezing periods. This study provides a robust framework for large-scale simulation of permafrost dynamics in data-sparse regions, with direct implications for assessing environment change, infrastructure risks, and carbon emissions linked to permafrost degradation.

Keywords: Permafrost, model simulation, Qinghai-Tibet Plateau



MODELING CIRCUMPOLAR PERMAFROST CARBON FLUXES

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Rapid Arctic warming over the past four decades has accelerated permafrost degradation, with significant implications for high-latitude carbon-climate feedbacks. Increasing permafrost temperatures promote deepening of the active layer and thaw, enhancing microbial decomposition of previously frozen organic carbon and increasing emissions of carbon dioxide (CO₂) and methane (CH₄). These processes are further amplified by interacting disturbances, including more frequent and severe wildfires, thermokarst development, and changes in surface hydrology and wetland extent, all of which strongly influence carbon fluxes across Arctic and boreal ecosystems. In this study, we present recent advances in modeling permafrost carbon dynamics across the circumpolar Arctic-Boreal (CAB) region using the Terrestrial Ecosystem Model (TEM). The model explicitly represents soil thermal and hydrological processes, vegetation dynamics, wildfire disturbance, and wetland CH₄ production, enabling an integrated assessment of multiple carbon-cycle pathways. Simulations are conducted at high spatial resolution using historical climate forcing as well as future projections from the MRI-ESM2.0 CMIP6 Earth system model under low-emissions (SSP1-2.6) and high-emissions (SSP5-8.5) scenarios. We compare carbon flux trajectories across scenarios, with particular emphasis on the relative contributions of wetland methane emissions and wildfire-related carbon losses to net ecosystem carbon balance. Results highlight strong sensitivities of permafrost carbon release to the magnitude of warming, disturbance regime, and hydrological change. Our findings underscore the importance of representing interacting permafrost, fire, and wetland processes in Earth system models and provide new insights into the magnitude, timing, and spatial variability of permafrost carbon feedbacks under future climate change.

Keywords: Permafrost, carbon fluxes, methane, wildfire



PERMAFROST FORECASTING AT REGIONAL SCALE: SOUTH OF TAYMYR PENINSULA

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Permafrost temperature projections remain a critical uncertainty in Arctic climate impact assessments, particularly for regions where observational networks are sparse and landscape variability is high. This study addresses this gap by presenting a physically based, landscape stratified modelling framework for mean annual ground temperature (MAGT) at 10 m depth across the region south of the Taymyr Peninsula (8 000 km²), with validation against a 11 test sites ground temperature monitoring network and projections extending to 2050. To develop this framework, a hierarchical landscape typology was established across the study region using geomorphology, surficial deposits, vegetation associations, and climate zoning as classification criteria, yielding 76 unique landscape units. For each unit, one dimensional transient heat conduction models were constructed using subsurface thermal and physical properties derived from archived borehole logs (80 boreholes, 1975-2000) and parameterized with site specific vegetation and snow cover characteristics. The model framework incorporates realistic upper boundary conditions including air temperature, vegetation insulation effects, and snow cover dynamics, while a geothermal heat flux defines the lower boundary. This approach was validated against direct observations from 11 permafrost monitoring test sites, with measured MAGT values at 10 m depth in 2024 ranging from -3.64°C to -0.13°C . Modelled temperatures for 2024 show good agreement with in situ observations, demonstrating that the landscape stratified approach successfully captures the spatial heterogeneity of permafrost thermal regimes. All 76 landscape models were forced forward to 2050 using regionalized climate projections from the Russian Federal Service for Hydrometeorology and Environmental Monitoring (SSP 5.8.5 scenario). By 2050, average MAGT will increase. Areas with low temperatures (from -3 to -4°C), which occupy 18% of the territory in 2024, will disappear completely. Areas with discontinuous permafrost distribution (temperatures from $+1$ to -0.5°C) will increase from 20% to 33% of the total area by 2050. According to the calculation results, perennial thawing will begin on 20% of the territory (temperatures from $+1$ to -0.5°C) in 2050, the permafrost table for different landscapes will be from 2.2 to 8 meters. This work demonstrates that integrating legacy observational data, ground temperature monitoring, and landscape classification enables robust, observation constrained permafrost projections at regional scales. The framework and resulting maps serve as a foundation for climate adaptive infrastructure planning and ecosystem vulnerability assessments across Arctic permafrost regions, while the methodology is readily transferable to other polar areas where comparable data exist.

Keywords: Permafrost forecasting, landscape modelling, Taymyr



REPRESENTATION OF CANOPY EFFECTS IN GLOBAL-SCALE MONITORING OF PERMAFROST

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Permafrost ground temperature and thaw depth are monitored as Essential Climate Variables (ECVs) but cannot be directly observed from space-borne sensors. The ESA Permafrost_CCI project estimates these ECVs globally using a computationally efficient transient heat-conduction scheme in the CryoGrid model, driven by remotely sensed land surface temperature and land-cover, as well as ERA5 reanalysis data. Sub-grid variability is represented through multiple model ensembles per 1 km grid cell based on landcover-associated parameterizations of a simplified snow scheme and ground stratigraphies. Approximately one quarter of the continuous permafrost zone is forested, and forest canopies strongly modify permafrost thermal and hydrological regimes. Canopies intercept up to 90% of incoming summer radiation and exert major controls on winter snow accumulation. Forest types differ regionally: deciduous needleleaf forests dominate Siberia, whereas evergreen needleleaf and deciduous broadleaf forests are more common in North America, leading to distinct effects on snow redistribution and melt. These canopy-driven processes strongly influence ground temperature amplitudes and active-layer thickness, yet they are only implicitly represented in Permafrost_CCI through parameterizations of snow melt, soil organic layers, and hydrology. This study evaluates how well the ensemble method captures vegetation effects by comparing Permafrost_CCI ensemble results to detailed point-scale simulations from a coupled multilayer vegetation-permafrost model. Initial site-level comparisons show good agreement in summer ground temperatures but substantial winter biases, indicating limitations primarily associated with snow parameterization. Discrepancies are largest at North American forest sites, where canopy structure differs markedly from Eastern Siberian larch stands. We conduct systematic parameter-sensitivity analyses across forested Circumpolar Active Layer Monitoring Network (CALM) sites with active-layer thickness observations, assessing the roles of canopy properties, wind compaction, water table dynamics, field capacity, and soil stratigraphy. By integrating observations with ensemble and point-scale simulations, we identify key parameters and regional patterns needed to better represent canopy effects in large-scale permafrost mapping. This work advances understanding of forest controls on active-layer dynamics and outlines pathways for incorporating explicit canopy effects into global permafrost monitoring frameworks.

Keywords: Permafrost, modeling, boreal forest, active layer thickness



LONG-TERM THERMAL REMOTE SENSING ARCHIVES AS A RESOURCE FOR PERMAFROST CHANGE DETECTION

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The Arctic cryosphere has experienced pronounced warming since 1980, leading to a shortening of the freeze season and a reduction in the duration of snow cover extent. Permafrost is particularly sensitive to increasing air temperatures and changes in the snow regime and has warmed across the Arctic. Current in situ measurements of permafrost temperature indicate that further warming will continue to impact permafrost; however, the magnitude and timing of the response remain uncertain. Permafrost monitoring is primarily conducted by measuring ground temperatures in boreholes, which are unevenly distributed, resulting in significant spatial gaps in the monitoring. Satellite-derived land surface temperature (LST), snow cover, and land cover data can serve as input variables for permafrost models, thereby enhancing permafrost monitoring over large areas. The CryoGrid community model, a ground thermal model, has successfully utilised these datasets to model circumpolar ground temperatures at various depths and active layer thickness. Within the frame of the ESA Climate Change Initiative (CCI) Permafrost project, Moderate Resolution Imaging Spectroradiometer (MODIS) LST data, land cover data, and ERA5 reanalysis data were used to produce permafrost maps of the Northern Hemisphere. A drawback is that MODIS LST products have only been available since 2001, which prevents differentiating multi-decadal climate trends from decadal-scale climate oscillations. The historic Advanced Very High-Resolution Radiometer (AVHRR) sensor series now covers more than 40 years of data, with at least twice-daily overpasses. A new pan-Arctic LST dataset has been developed using EUMETSAT's AVHRR Fundamental Data Record (FDR). The pan-Arctic AVHRR LST product covers the period from 1981 to 2023 and has a spatial resolution of approximately 1 km. It has been super-resolved from native coarse global area coverage (GAC) AVHRR data by applying a deep learning framework that relies on anisotropic diffusion, a methodology commonly used in robotics navigation and has been proven to be efficient for downscaling LST data over large scales. The newly developed pan-Arctic AVHRR LST dataset has been integrated into the CryoGrid community model, enabling the modelling of the thermal state of the ground across various Arctic regions for the past four decades. This dataset facilitates a detailed investigation into land surface temperature dynamics and the response of the permafrost over the past four decades, providing valuable insights into long-term permafrost extent and changes in areas where in situ measurements are sparse.

Keywords: Remote sensing, LST, modelling



ASSESSING THE IMPLICATIONS OF ARCTIC PERMAFROST THERMODYNAMICS AND HYDROLOGY ON INDUSTRIAL CLIMATE WITH THE MPI-ESM

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Permafrost processes shape long-term pan-Arctic climate variability. Changes in the representation of underground heat propagation, freeze-thaw, snow cover, or freshwater partition into drainage and runoff in permafrost areas control soil moisture and modify temperature and precipitation responses to external forcing. Even though the latest Land Surface Models (LSMs) include many processes relevant for a realistic representation of permafrost, they exhibit large discrepancies in the hydrological response to global warming in the permafrost and pan-Arctic regions. To assess climate sensitivity to changes in the representation of permafrost hydrology and thermodynamics, we conducted an ensemble of simulations of the historical and SSP scenario periods up to 2300 CE with the Max Planck Institute for Meteorology Earth System Model (MPI-ESM) in which we modified its LSM, JSBACH. In particular, we introduced two vertical schemes additional to the standard five-layer discretization (5L) with an enhanced vertical resolution (11L) and subsurface depth (18L), and a more realistic representation of freeze-thaw processes under two hydrological configurations that generate relatively WET or DRY states of the Arctic land compared to the reference JSBACH state (REF). Combining the three hydrological configurations and vertical discretizations yields an ensemble of 9 simulations, the MPI-ESM Permafrost Physics Ensemble (MPIESM-PePE). In this work, we illustrate how divergent states of Arctic soil hydrology (WET vs. DRY) can produce large differences in permafrost mean temperature (3 °C), active layer thickness (1-2 m), and area (5 million km²). These differences are not limited to permafrost responses, but have wider implications for Arctic temperatures and Arctic amplification, and for large-scale general circulation in the Northern Hemisphere.

Keywords: Permafrost Modeling, Arctic climate change

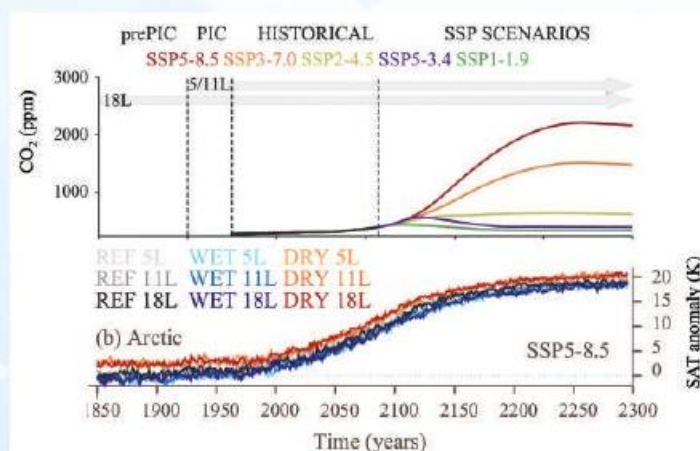


Fig. 1 General description of the MPIESM-PePE. (Above) CO₂ forcing (concentration) used as boundary condition for the various SSP scenarios in the ensemble (see legend). (below) Arctic (north of 66° N) surface air temperature response (as anomalies with respect to 1850-1900) in the different hydrological configurations (REF, WET, and DRY) and vertical discretizations (5L, 11L, and 18L) of the MPIESM-PePE for the SSP5-8.5 scenario until 2300.



**7B: MODELING PERMAFROST DYNAMICS ACROSS SCALES
POSTER**



IMPROVING PERMAFROST SOIL REPRESENTATION IN A DYNAMIC GLOBAL VEGETATION MODEL ENHANCES PREDICTIONS OF BOREAL FOREST CARBON DYNAMICS

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Co-authors: Simone Maria Stuenzi, Yanqiu Xing, Moritz Langer

Boreal forests constitute a major component of the global terrestrial carbon sink, yet their ecosystem functioning is increasingly threatened by climate-driven permafrost degradation. Despite their importance, the persistence of this carbon sink remains highly uncertain, partly due to limitations in Earth system model projections of future carbon dynamics in permafrost-affected regions. Here, we improve the soil module of the LPJ-GUESS model by implementing a deep soil profile (3 m), refined vertical discretization (30 layers), and explicit ice-impedance effects, and apply the enhanced model (LPJ-GUESS-Cryo) to the climate-sensitive boreal forests of Northeast China. Model evaluation shows that LPJ-GUESS-Cryo substantially improves the simulation of soil hydrothermal dynamics relative to the default configuration. The correlation coefficient for deep soil temperature (1.0 m) increases from 0.818 to 0.894, while the pronounced overestimation of soil water content is effectively removed, with the bias at 1.0 m reduced from 0.321 to -0.006 . These process-level improvements lead to a more realistic simulation of vegetation composition. The dominance of needleleaf forests is corrected from near-complete saturation to 24.1%, consistent with observed vegetation patterns. Consequently, biases in carbon estimates are reduced, with simulated net primary productivity decreasing from 583.5 to 560.1 $\text{g C m}^{-2} \text{yr}^{-1}$ and aboveground biomass from 112.9 to 99.0 t ha^{-1} , approaching satellite-based observations. Sensitivity analysis further indicates that vegetation composition responds strongly to soil hydrothermal conditions, with pronounced shifts occurring when soil temperature increases exceed 0.6°C and soil water deficits exceed $0.6 \text{ m}^3 \text{ m}^{-3}$ relative to the default model. Overall, this study highlights that accurately representing permafrost processes in dynamic global vegetation models is critical for reducing uncertainties in high-latitude climate-carbon feedbacks.

Keywords: Carbon, LPJ-GUESS, permafrost, DGVM, boreal forest



ACTION PLAN FOR RISKS OF GLACIAL AND PERIGLACIAL ORIGIN IN THE FRENCH ALPS: ONGOING DEVELOPMENTS TO BETTER ASSESS PERMAFROST-RELATED HAZARDS

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Since about 15 years, the French Ministry for Ecological Transition funds research to better assess hazards caused by permafrost and glacial dynamics in the Global Warming context. In this presentation, we outline the developments in permafrost sciences to support stakeholders in their hazard mitigation strategy. Those are three-folds: (i) improving assessments of permafrost distribution and conditions (warm vs cold permafrost) from regional to local (outcrop) scale, (ii) improving understanding of permafrost degradation rates at decadal timescale, and (iii) assessing infrastructures exposed to potential rockfall runouts. To assess permafrost distribution, two modelling approaches are deployed. First, a rockwall permafrost map has been made for the French Alps, using a multiple regression linear model fitted with 72 measured mean annual rock surface temperature collected in various massifs of the French Alps, air temperature data and computed potential incoming solar radiation. The model is fitted for steep rock slopes with limited or inexistent snow cover. In parallel, energy balance simulations with the CryoGRID community model are used to assess permafrost conditions at ~50 snow-covered measurement points, and to test the robustness of the statistical model for steep slopes. An automatic calibration tool to retrieve the best combination of energy balance parameters for each measurement points has been developed. In the coming years, the energy balance model will be applied using a 10-m resolution DEM to map permafrost in any type of alpine ground and to provide permafrost maps that account for the complexity and variability of heat exchanges at the ground-atmosphere interface. In parallel, permafrost degradation processes are investigated through energy balance simulations to address the role of variable snow cover in space and time. Coupled heat and water flows are also simulated using 2D numerical models taking into account typical steep rockwall geometries. Sensitivity to properties of fractures (dipping, aperture, etc.), that are the preferential water flows, are tested to determine rates of permafrost degradation under non-linear heat transports. Furthermore, monitoring of the electrical resistivity along 2 profiles at a high mountain rockwall site (Aiguille du Midi, 3842 m) over the period 2020-2023 has evidenced heterogeneities in seasonal active layer thawing and permafrost warming, and the capabilities of the method to represent ground temperature when coupled with petrophysical analyses. This investigation has highlighted strengths and limitations of this method for supporting operational hazard assessments. Finally, the rockwall permafrost map and the analyses of rockfalls inventoried in the Mont Blanc massif (1087 events between 2007 and 2021) allowed to define the most active rockwalls according to their permafrost conditions. Using the RockavELA tool (EcorisQ) designed recently to map potential rockfall trajectories based on the Energy Line Angle and Area Under the Profile parameters at minimal computation costs, 2 maps of potential rockfall impact susceptibilities (either representing channelled or laterally spreading runouts) have been produced for the entire French Alps to support stakeholders in their risk assessments. In the coming years, this work will also integrate developments to better interpret permafrost maps against potential ice contents, writings of recommendations to stakeholders and workflows development.

Keywords: Permafrost degradation, permafrost mapping, energy balance modeling, heat transfer modeling, risk assessment



DETAILED SCHEDULE OF THE FIELD TRIPS

LOCAL FIELD TRIP

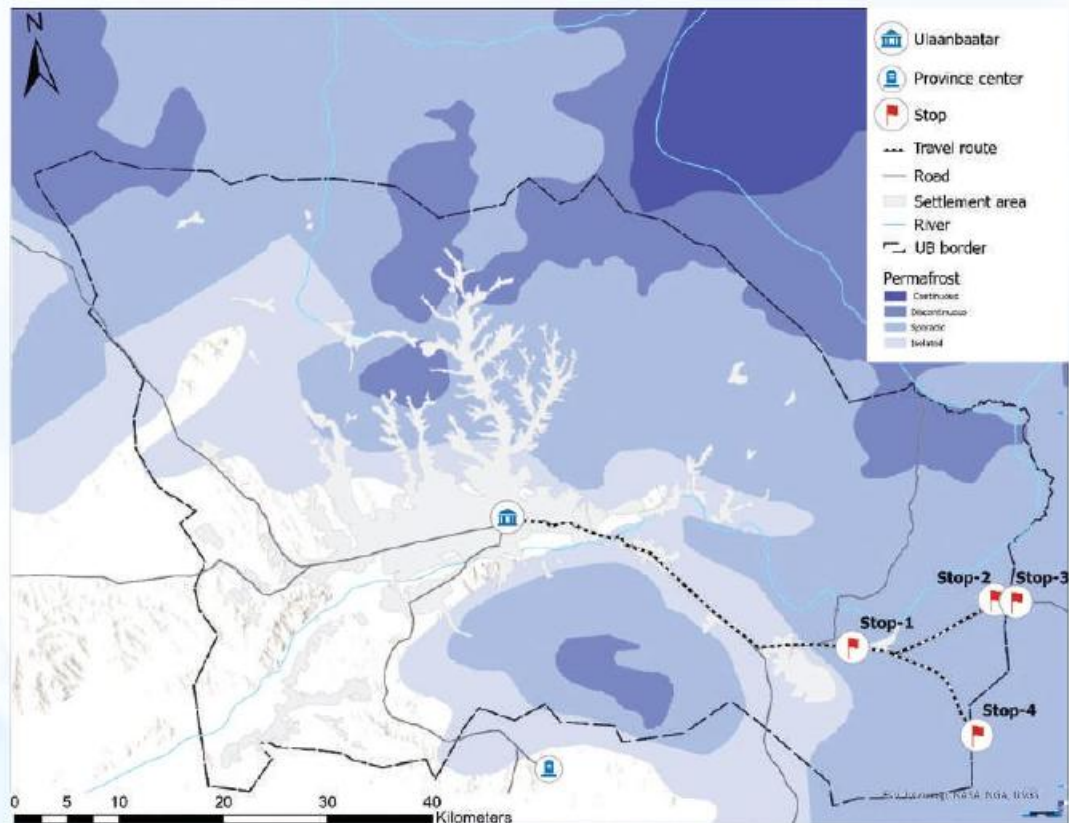


Figure 1. Stop-1 “Bus lake”, Stop-2 “Chinggis Khaan Statue Complex”, Stop-3 “Uuhain Duu restaurant”, Stop-4 “Olon Dov AWS”

Guide: Saruulzaya Adiya

Duration: 1 days (2 July 2026)

Description:

This field guide supports a one-day permafrost field trip from Ulaanbaatar to the Chinggis Khaan Statue Complex along the Ulaanbaatar-Undurkhaan State Road. The excursion traverses a representative section of the southeastern Mongolian forest-steppe landscape, highlighting key permafrost sites and their environmental significance. The itinerary includes four main stops, most of which are accessible via paved roads, with occasional short walks to observation points and automatic weather stations (AWS) (Figure 1).

Some of the information presented in this field guide has been adapted from previous field guides and published research conducted in the study area. We hope that participants of the ACOP 2026 conference will enjoy this excursion and gain a deeper understanding of the permafrost conditions and landscape characteristics surrounding Ulaanbaatar.

Permafrost Distribution in the Surrounding Area of Ulaanbaatar

Geographically, Ulaanbaatar is located in the southern part of the Khentii Mountain permafrost region. Elevation within the study area ranges from approximately 1,300 m to 2,300 m above sea level, resulting in a relief difference of about 1,000 m. Based on extensive field investigations, permafrost scientists have developed a permafrost distribution map for the area surrounding Ulaanbaatar, including the occurrence of relict permafrost (Figure 2). According to this map, Ulaanbaatar is situated within a zone of isolated and sporadic permafrost (Jambaljav et al., 2016).

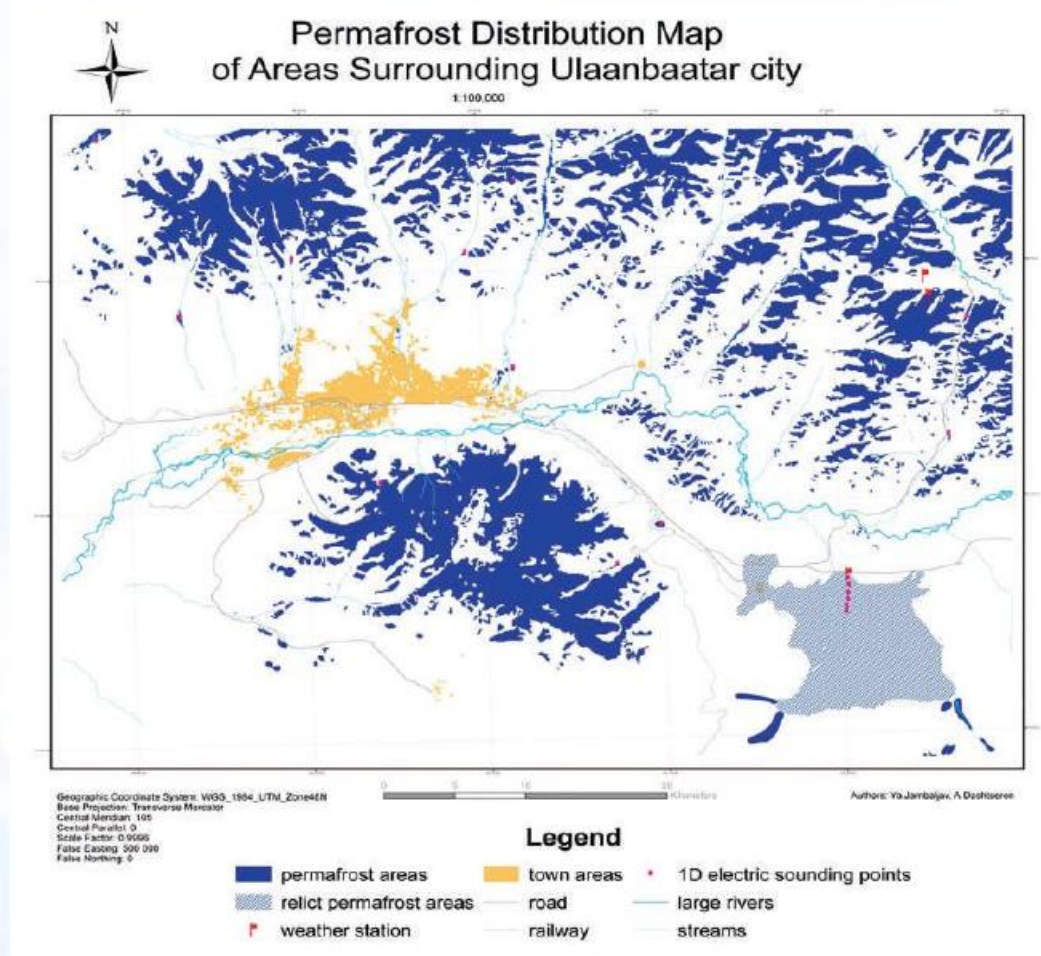


Figure 2. Permafrost distribution map in surrounding area of Ulaanbaatar city (Jambaljav, 2009).

Detailed program:

Time	Activity / Stop
Day-1	Ulaanbaatar – Bus lake- Chinggis Khaan Statue- Uuhain Duu- Olon Dov- Ulaanbaatar
08:30-09:00	Meet at the near of Galleria Ulaanbaatar, board your designated bus, and get ready for an exciting day in the field.
09:00-10:00	Driving toward Bus nuur Lake.
10:00-10:45	Stop-1. Bus Lake. Field stop for approximately 1 hour. Observation of pingo, landscape features, and regional geomorphological conditions.
10:45-11:00	Driving toward Chinggis Khaan Statue Complex
11:00-12:30	Stop-2. You can visit and explore the Chinggis Khaan Equestrian Statue Complex, dedicated to the founder of the Mongol Empire. You will also have the opportunity to visit the museum and learn more about the history and legacy of Chinggis Khaan. In addition, you can enjoy a traditional Mongolian folk performance(11:30-12:00) featuring throat singing, long songs, morin khuur (horsehead fiddle), traditional dances, and contortion acts.
12:30-12:45	Driving toward Uukhain Duu restaurant.
12:45-14:10	Stop-3. Lunch stops at Uukhain Duu restaurant.
14:10-14:30	Driving toward Olon Dov AWS.
14:30-15:00	Stop -4. Olon Dov AWS and Pingo.
15:00- 16:30	Driving toward the Galleria of Ulaanbaatar.

STOP 1. Bus Lake (47°48'26.78"N, 107°24'36.66"E)

The first stop is Bus Lake, located approximately 40 km southeast of Ulaanbaatar city. The lake is located on a flat semi-arid pasture plain within the Nalaikh depression in southeastern Mongolia. The Nalaikh depression is situated in a discontinuous permafrost zone, where the extent of the permafrost area is approximately 75%. Bus Lake is a thermokarst lake developed in warm permafrost, where ground temperatures are close to 0°C (approximately -0.1°C) (Ishikawa, 2012; Saruulzaya, 2017). Previous studies reported that the active layer with a depth of 7 m was under dry conditions at the site (Ishikawa et al., 2006).

South-facing mountain slopes and some hill tops within the depression are generally without permafrost. The unconsolidated perennially frozen sediments in the depression are of epigenetic origin. Permafrost developed in unconsolidated Quaternary and Neogene sediments is characterized by low to moderate ground-ice content. In contrast, ice-rich permafrost with well-developed segregated ice and layered cryostructures commonly occurs in coal bearing semi-consolidated silt and clay deposits (Cr1).

The terrain surrounding the site is relatively flat and smooth. Bus Lake is approximately 180 m in diameter and 1-3 m deep. A pingo, approximately 5 m high and surrounded by a thermokarst pond about 50 m in diameter, is located adjacent to the lake (Figure 3).

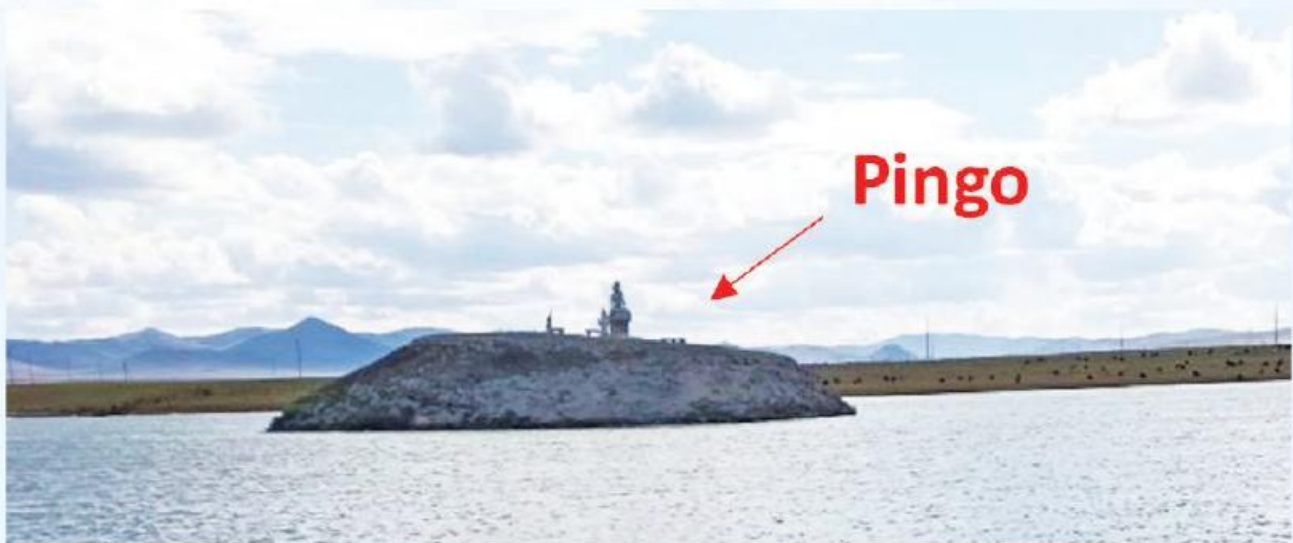


Figure 3. Bus lake in Nalaikh depression in 2023.

STOP 2. Chinggis Khaan Statue Complex

The distance from Bus Lake to the Chinggis Khaan Statue Complex (47°41'36.80"N, 107°29'21.50"E) is approximately 15 km. The complex is home to the Chinggis Khaan Equestrian Statue, a 40-m-high stainless-steel monument depicting Chinggis Khaan on horseback. Standing at 40 m in height, it is recognized as the world's tallest equestrian statue. The statue faces east, symbolically pointing toward the birthplace of Chinggis Khaan. It was designed by sculptor D. Erdenebileg and architect J. Enkhjargal and was inaugurated in 2008 to commemorate the 800th anniversary of the establishment of the Mongol Empire.

Participants will have an opportunity to visit the museum within the complex and learn more about the history, achievements, and legacy of Chinggis Khaan. In addition, a traditional Mongolian cultural performance (11:30–12:00) will be presented, featuring throat singing, long-song performances, morin khuur (horsehead fiddle) music, traditional dances, and contortion acts.



Figure 4. Chinggis Khaan statue complex.

STOP 3. Uukhain Duu restaurant.

"Uukhain Duu restaurant offers a selection of delicious, high-quality traditional Mongolian dishes alongside a variety of vegetarian options."



Figure 5. Uukhain Duu restaurant

STOP 4. Olon Dov (47°41'36.80"N, 107°29'21.50"E)

The distance from Stop 3 to Olon Dov is approximately 17.5 km. The Olon Dov pingo is located near Arjargalan in the Nalaikh depression, about 50 km southeast of Ulaanbaatar. The site features moderately moist steppe vegetation overlying ice-rich permafrost and contains several well-developed pingo landforms (Wang et al., 2022). The pingo reaches a height of up to 10 m, and its summit has subsided due to thawing, forming a thermokarst depression. At the time of the study, the pingo had a diameter of 39 m, while the thermokarst depression measured 8.7 m in diameter and 8.5 m in depth. The side slopes inclined at approximately 45°.

In 2006, the Ministry of the Environment of Japan (MOE) initiated the project “Establishment of a Network for Early Detection of the Impact of Global Warming” to monitor ecosystem responses to climate change. The project combines MODIS satellite observations with ground-based measurements to investigate permafrost dynamics, carbon fluxes, meteorological conditions, and ecosystem processes.

As part of this initiative, and through collaboration among the Ministry of the Environment of Japan (MOE), the Chinese Academy of Sciences (CAS), and the Mongolian Academy of Sciences (MAS), a long-term ecological observation site was established at Olon Dov. The station has been used to monitor exchanges of water vapor, energy, and carbon dioxide between the land surface and the atmosphere (Figure 6).

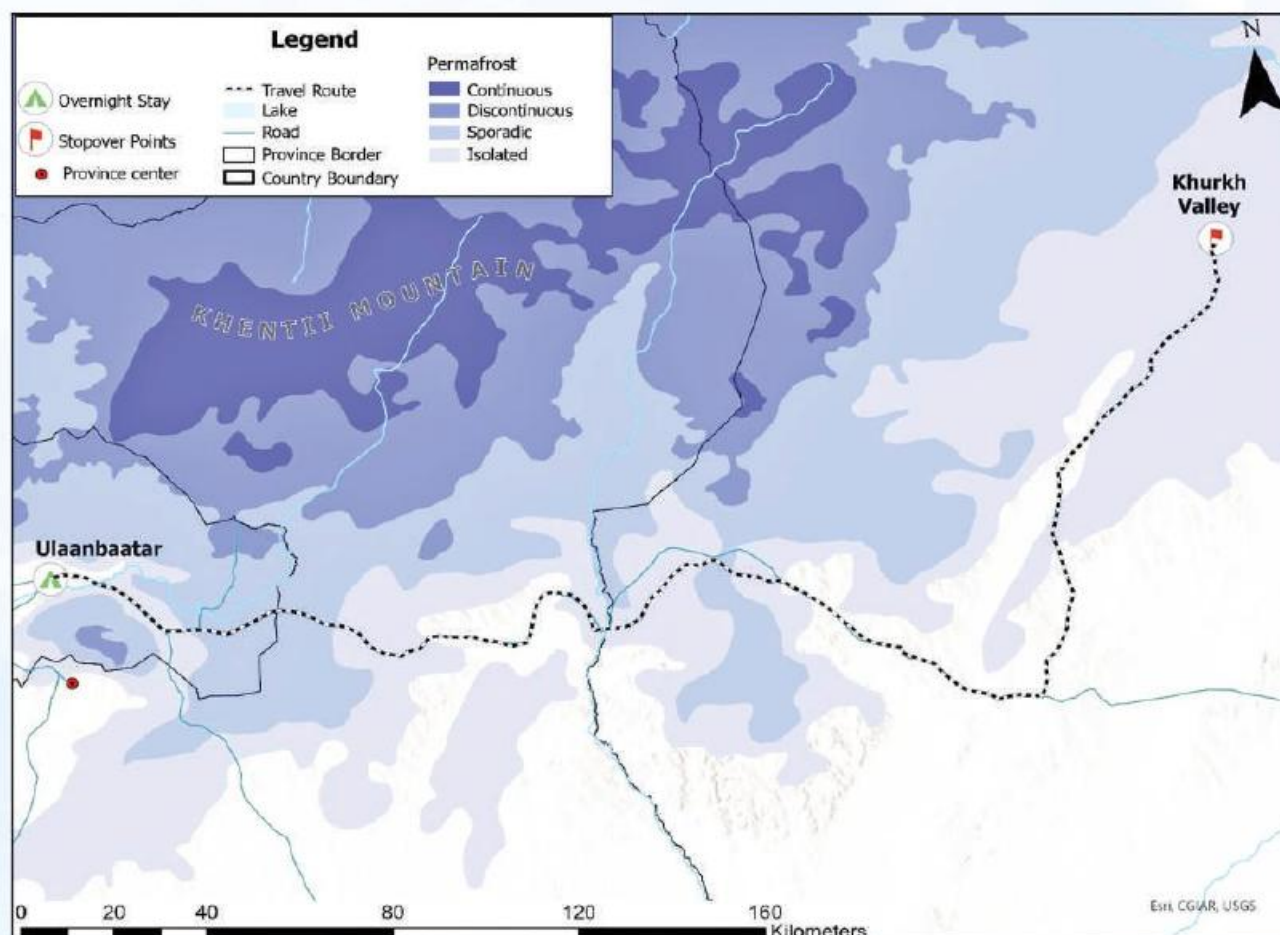


Figure 6. The observed pingo at the Olon Dov (Photo by Tsogterdene Gansukh).

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KHURKH VALLEY TRIP



Permafrost Dynamics and Ecosystem Monitoring in Khurkh Valley field trip

Guides: Nyambayar Batbayar, Nandintsetseg Nyam-Osor

Duration: 3 days (June 25-27, 2026)

Description:

Khurkh Valley, located in the Khentii Province of northeastern Mongolia, represents a climatically sensitive transition zone between permafrost-boreal systems and seasonally frozen grassland steppes. This valley lies within the Eurasian discontinuous permafrost zone, where isolated patches of permafrost exist due to the combined effects of cold climate, high soil moisture, and peat accumulation.

The valley bottom, situated approximately 1100 m above sea level, is composed of peatlands, meadows, and riparian wetlands that are seasonally or perennially water-saturated. These landscapes foster the formation of ecosystem-driven permafrost, in which peat soil, snow cover, and dense vegetation act as thermal insulators, maintaining ground temperatures close to 0°C despite relatively positive mean annual air temperatures.

The Khurkh Ecological Research Station (KERS), established in 2014 by the Wildlife Science and Conservation Center of Mongolia (WSCC), has become a leading site for integrated environmental monitoring at the southern margin of the discontinuous permafrost zone. The station conducts long-term permafrost and ecosystem monitoring through a comprehensive suite of research activities, including:

The station conducts long-term permafrost and ecosystem monitoring through a comprehensive suite of research activities, including:

1. Long-term permafrost and hydrological monitoring using instrumented boreholes along valley transects, together with river inflow and outflow measurements.
2. Continuous climate monitoring using an automatic weather station recording meteorological variables at high temporal resolution.
3. Experimental studies investigating the effects of climate change and grazing on wetland ecosystem characteristics.
4. Closed chamber and eddy covariance measurements to assess CO₂ and CH₄ fluxes from climate-sensitive permafrost and peatland ecosystems.
5. Permafrost and peat layer investigations using Electrical Resistivity Tomography (ERT) and Ground Penetrating Radar (GPR).
6. Drone-based remote sensing approaches for land-use and land-cover mapping, vegetation change detection, and thermokarst lake monitoring.
7. Ecological monitoring activities, including biodiversity surveys, migratory bird monitoring, and GPS tracking of livestock and dogs to better understand habitat pressures and ecosystem interactions.

Through these integrated datasets and interdisciplinary approaches, the KERS provides a unique platform for studying the complex interactions among ecosystem structure, cold environment processes, hydrology, and climate variability in the vulnerable steppe–wetland transition zone in semiarid Mongolia. In addition, the site makes a substantial contribution to scientific data and environmental monitoring efforts on national and regional scale impacts, including national climate reporting, wetland conservation planning, and the development of region-specific adaptation strategies.

Detailed program:

Time	Activity
Day 1	Travel & Orientation
08:00	Departure from Sukhbaatar Square, Ulaanbaatar
11:00 - 11:30	Short stop at the Chinggis Khaan Statue Complex in Tsonjin Boldog for a group photo
11:30 – 13:00	Lunch at the local restaurant in Umnudelger soum
13:00 – 15:30	Travel from Umnudelger soum to Khurkh Valley
15:30	Arrival at KERS
15:30 – 16:00	Tea and coffee break followed by station safety briefing
16:00 – 18:00	Site Introduction - 1: Landscape and Ecosystem Overview: Guided field excursion around key landforms near the KERS, including peatlands, wet meadows, thermokarst lakes, BH-01, and BH-02
18:00 – 19:30	Welcome dinner reception: History and goals of KERS in Khurkh
Day 2	Permafrost Monitoring & Ecosystem Assessment
06:00 - 08:00	Optional birdwatching session: White-naped and Demoiselle Cranes
08:00 - 09:00	Breakfast at the KERS
09:00 - 10:30	Site Introduction - 2: Permafrost and Climate Monitoring: Visit to the permafrost monitoring borehole BH-04, the automatic weather station, and experimental monitoring plots
10:30 - 12:00	Soil profile observation and discussion of permafrost characteristics
12:00 - 13:00	Lunch by the Khurkh River
13:00 - 15:30	Site Introduction - 3: Greenhouse Gas Monitoring: Visit to the eddy covariance tower with demonstrations of chamber-based CO ₂ and CH ₄ flux measurements
15:30 - 17:00	Rest break and informal networking
17:00 - 18:00	Dinner (Mongolian traditional meal)
19:00 - 20:00	Evening Session: Peats and Ice – informal discussion and networking
Day 3	Travel & Return
07:00 - 08:00	Breakfast
08:00 - 09:00	Packing and loading
09:00 - 11:00	Site Introduction – 4: Vegetation and Environmental Monitoring: Visit to vegetation monitoring, borehole BH-06, and experimental monitoring plots
11:00 - 12:00	Visit to historical sites at Arshaant Rock
12:00 - 13:30	Lunch at Oglogchiin Kherem Castle and wrap-up discussion: key findings and future monitoring directions
13:30 - 18:00	Departure from Khurkh Valley and return journey with a short break
18:00 - 19:00	Dinner at a local restaurant in Baganuur district
20:00 - 20:30	Arrival at Sukhbaatar Square, Ulaanbaatar

Accommodation

The participants will be hosted by the Khurkh Ecological Research Community Center (KERCC), located within the Khurkh-Khuiten Nature Reserve in northeastern Mongolia. We will prepare additional ger accommodation outside of the KERCC building to accommodate the participants. Wi-Fi connection is available at the KERCC building. The mobile network services (Unitel and Mobicom) are available within the region however the signal is very weak and unreliable.

- **Address:** Khurkh Ecological Research Community Center, Binder-Umnudelger Rd, Khentii, 79X3+4M Bumda Bayan

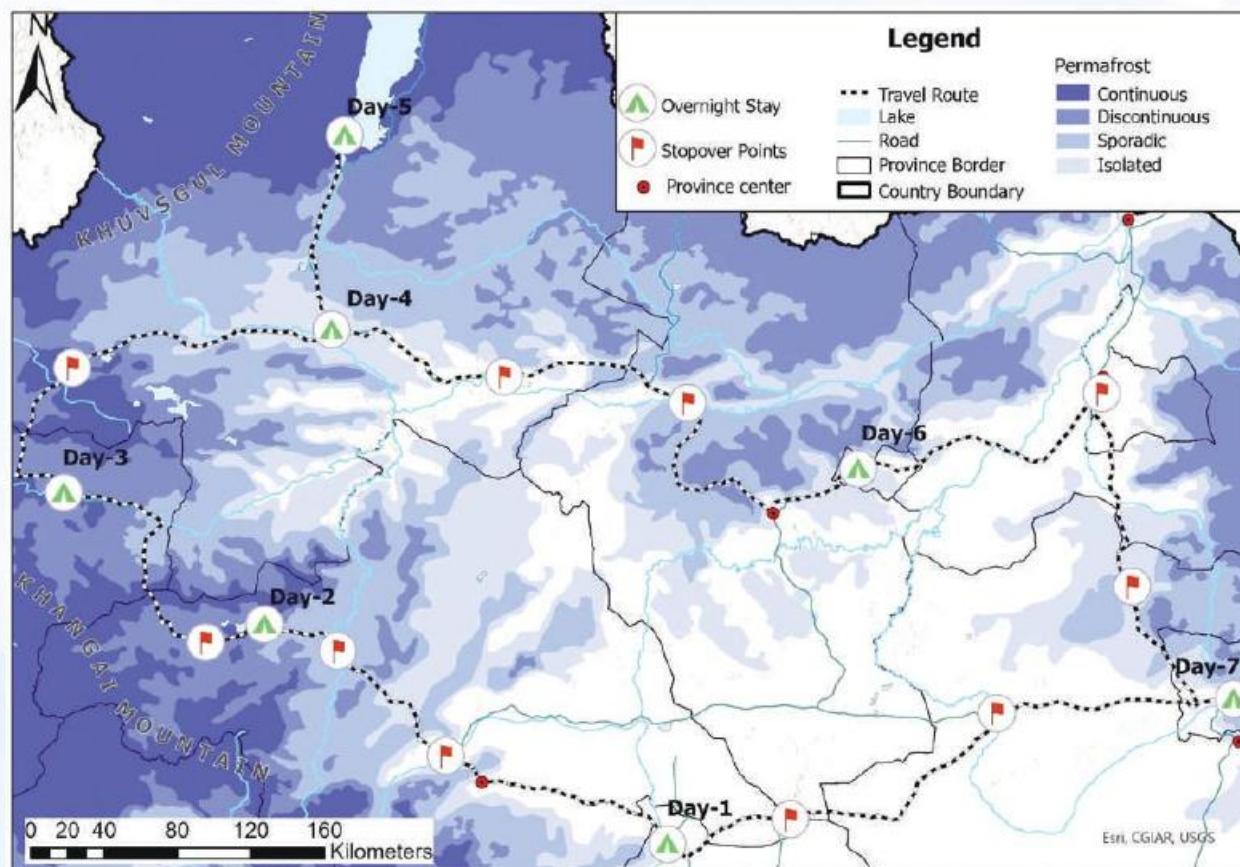


Contacts

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KHOVSGOL AND KHANGAI TRIP



Characteristics, mapping, monitoring, and engineering of mountain permafrost

Guide: Temuujin Khurelbaatar

Duration: 7 days (3–9 July 2026)

Description:

The Khovsgol–Khangai field excursion route crosses two of Mongolia’s most important mountain permafrost regions, linking the Khovsgol mountainous region in northern Mongolia with the Khangai high mountain region in central Mongolia. This route provides a unique opportunity to observe the spatial transition from predominantly continuous and discontinuous mountain permafrost in the Khovsgol region to high-elevation valley permafrost, volcanic landscapes, lacustrine-alluvial sediments, and cryogenic landforms in the Khangai region.

The field excursion focuses on the characteristics, mapping, monitoring, and engineering aspects of mountain permafrost. Along the route, participants will visit several long-term permafrost monitoring sites, boreholes, valleys, river systems, volcanic landforms, and geomorphologically significant locations. These sites represent different permafrost environments controlled by elevation, slope aspect, vegetation cover, snow conditions, ground composition, soil moisture, and hydrological processes.

The Khovsgol region is characterized by mountain permafrost associated with forested slopes, lake terraces, river valleys, and high mountain watersheds. Study sites such as Ardag Mountain and Khatgal provide important examples of continuous and discontinuous permafrost distribution, permafrost monitoring, and engineering

challenges related to construction on ice-rich frozen ground. In particular, Khatgal village illustrates the practical importance of permafrost engineering, where thaw settlement, frost heave, supra-permafrost water, and building foundation stability have been documented.

The Khangai region includes broad intermountain valleys, volcanic landscapes, ancient lacustrine and alluvial sediments, and active cryogenic processes. Sites such as Terkh, Chuluut, and Sharga are important for understanding permafrost formation in high mountain valleys, thermokarst and thermos-erosion processes, active layer dynamics, frost mounds, icings, and groundwater–permafrost interactions. The Terkh and Chuluut areas also demonstrate how volcanic lava flows and valley sedimentation have influenced permafrost development and landscape evolution.

The field excursion includes a series of thematic observations and scientific discussions, including:

1. Long-term permafrost monitoring using boreholes and ground temperature measurements in Khovsgol and Khangai mountain regions.
2. Observation of discontinuous and continuous mountain permafrost controlled by elevation, slope aspect, vegetation, and ground composition.
3. Study of active layer thickness, mean annual ground temperature trends, and recent permafrost degradation under climate warming.
4. Field visits to cryogenic landforms such as frost mounds, thermokarst features, thermos-erosion sites, icings, and frost-heave-related surface deformation.
5. Examination of permafrost-related hydrological processes, including supra-permafrost water, groundwater flow, spring systems, and aufeis formation.
6. Discussion of permafrost engineering problems in settlement areas, specially building deformation, thaw settlement, frost heave, and foundation design in permafrost terrain.
7. Observation of major natural and cultural landscapes, including Lake Khovsgol, Ardag Mountain, Khatgal village, Sharga Valley, Terkh Valley, Khorgo Volcano, Chuluut Canyon, Elsen Tasarkhai, Kharkhorin, and Erdene Zuu Monastery.

Through these field observations and discussions, the Khovsgol–Khangai field excursion provides an integrated platform for understanding mountain permafrost systems in Mongolia. The route connects long-term scientific monitoring sites with practical examples of permafrost-related environmental and engineering issues. It also highlights the importance of permafrost research for climate change assessment, infrastructure planning, water resources, ecosystem stability, and regional adaptation strategies in cold and dry mountain environments.

In addition, the excursion demonstrates Mongolia's long history of permafrost research and monitoring, including studies conducted over the last several decades in boreholes, valleys, lake terraces, and mountain slopes. The field trip therefore serves not only as a scientific excursion but also as a practical training opportunity for understanding the interaction between climate, permafrost, hydrology, ecosystems, and human activities in the Khovsgol and Khangai mountainous regions.

Detailed program:

Time	Activity / Stop
Day-1	Ulaanbaatar – Lun – Elsen Tasarkhai – Kharkhorin
09:00	Meet participants and depart from Ulaanbaatar by car.
10:30–10:45	Rest stops on the way.
12:00–13:00	Lunch stops at Lun area.
15:00–16:00	Observation of sand dunes, landscape features, and regional geomorphological conditions in Elsen Tasarkhai.
16:00–17:30	Continue driving toward Kharkhorin.
17:30–18:30	Check in the tourist camp in Kharkhorin.
18:30–19:30	Dinner in Kharkhorin.
Overnight	Accommodation in Kharkhorin.
Day-2	Kharkhorin – Taikhar Rock – Chuluut Borehole – Chuluut Canyon – Terkhiin Tsagaan Lake
07:30–08:30	Breakfast at Tourist camp.
09:00	Depart toward Arkhangai Province.
12:00–13:30	Lunch and short visit and observation of Taikhar Rock and surrounding landscape.
15:00–15:40	Field explanation on borehole monitoring, ground temperature, permafrost conditions, and local geological setting.
15:40–16:30	Visit Chuluut Canyon and observe basaltic landscape and river incision.
16:30–18:00	Continue driving to Terkhiin Tsagaan Lake.
18:00–18:30	Check in to camp/guesthouse near Terkhiin Tsagaan Lake.
18:30–19:30	Dinner at accommodation.
Overnight	Accommodation near the lake.
Day-3	Terkhiin Tsagaan Lake – Khorgo Volcano – Terkh Station and Boreholes – Tosontsengel
08:00–09:00	Breakfast at accommodation.
09:00–10:30	Visit Khorgo crater. Observation of volcanic landforms, lava field, and surrounding geomorphology.
10:30–11:10	Travel to the Terkh station and borehole monitoring sites.
11:10–11:40	Field presentation on permafrost monitoring, borehole temperature measurements, active layer conditions.
11:40–13:00	Lunch near Terkh site.
13:00–15:30	Long drive toward Tosontsengel with short rest stops.
15:30–16:30	Check in to accommodation in Tosontsengel.
16:30–18:00	Dinner in Tosontsengel.
Overnight	Accommodation in Tosontsengel.
Day-4	Tosontsengel – Mungushiin Sair – Shargyn Valley – Murun – Jankhai
08:00–09:00	Breakfast at accommodation.
09:00	Depart toward northern Mongolia.
09:00–11:30	Field stop and presentation on slope deposits, seasonal water flow, surface materials, and possible aufeis-related conditions.
12:30–13:30	Lunch on the road / field site around Sharga valley.
13:30–14:30	Field explanation on valley geomorphology, permafrost-related landscape conditions, and aufeis formation potential.

17:30–18:30	Dinner stop in Murun.
18:30–20:30	Continue driving from Murun to Jankhai, Khovsgol Lake area.
20:30–21:00	Check in to accommodation in Capitan tourist camp.
Overnight	Accommodation in Capitan tourist camp.
Day-5	Jankhai – Ardag Mountain – Khatgal Boreholes – Jankhai
08:00–09:00	Breakfast at accommodation.
09:00–10:00	Depart for field visits around Khovsgol Lake area.
10:00–12:00	Visit Ardag Mountain area. Observation of landscape, elevation conditions, vegetation, permafrost environment.
12:00–13:00	Lunch at Capitan tourist camp.
13:30–15:30	Field presentation on borehole locations, permafrost monitoring, ground temperature observations, and cave study around Khatgal.
15:30–17:00	Return drive to Capitan tourist camp.
17:00–18:00	Dinner at Camp.
Overnight	Second night in Capitan tourist camp.
Day-6	Jankhai – Murun – Bulgan – Erdenet
07:30–08:30	Breakfast at accommodation.
08:30–10:30	Depart toward Erdenet.
10:30–10:45	Rest stop / fuel stop in Murun.
12:30–13:30	Lunch on the way, depending on road conditions.
15:30–15:45	Short stop on the way to Bulgan/Erdenet.
17:30–18:30	Check in to hotel in Erdenet.
18:30–19:30	Dinner in Erdenet.
Overnight	Accommodation in Erdenet.
Day-7	Erdenet – Ulaanbaatar
08:00–09:00	Breakfast at hotel.
09:00–11:00	Depart for Ulaanbaatar.
11:00–11:15	Rest stop on the way.
12:30–13:30	Lunch on the road, possibly near Darkhan / main road service area depending on travel time.
15:30–15:45	Rest stop before Ulaanbaatar.
18:00–19:00	Arrival in Ulaanbaatar and end of the field trip.

Accommodation

On the first day, the team will travel from Ulaanbaatar to Kharkhorin. Accommodation will be arranged at *Urgoo Tourist Camp*, located near Kharkhorin, one of Mongolia's most historically significant areas and the ancient capital region of the Mongol Empire.



On the second day, the group will travel from Kharkhorin to Terkhiin Tsagaan lake. Along the route, participants will travel through the central Mongolian landscape. Stay overnight at *Dalaivan Tsagaannuur Tourist Camp* in Terkhiin Tsagaan lake.



On the third day, the team will travel from Terkhiin Tsagaannuur to Tosontsengel soum. This part of the route will allow participants to observe the natural environmental conditions of central and northern Mongolia. Stay overnight at *Khojuuliin Gol Tourist Camp*, located near Tosontsengel soum.



On the fourth and fifth days, the team will travel to the Khatgal and Jankhai area near Lake Khovsgol, one of the most beautiful and important freshwater lakes in Mongolia. During these two days, participants will have the opportunity to explore the surrounding landscapes and observe the natural environment of the region. The team will stay overnight at ***Captain Tourist Camp***, located in the Jankhai area near Khatgal.



On the sixth day, the team will travel from the Jankhai to Erdenet city. Along the route, participants will pass through northern Mongolia's diverse landscapes, including forest-steppe, mountain, and rural settlement areas. The team will stay overnight at ***Deedes Hotel***, located in the Erdenet.



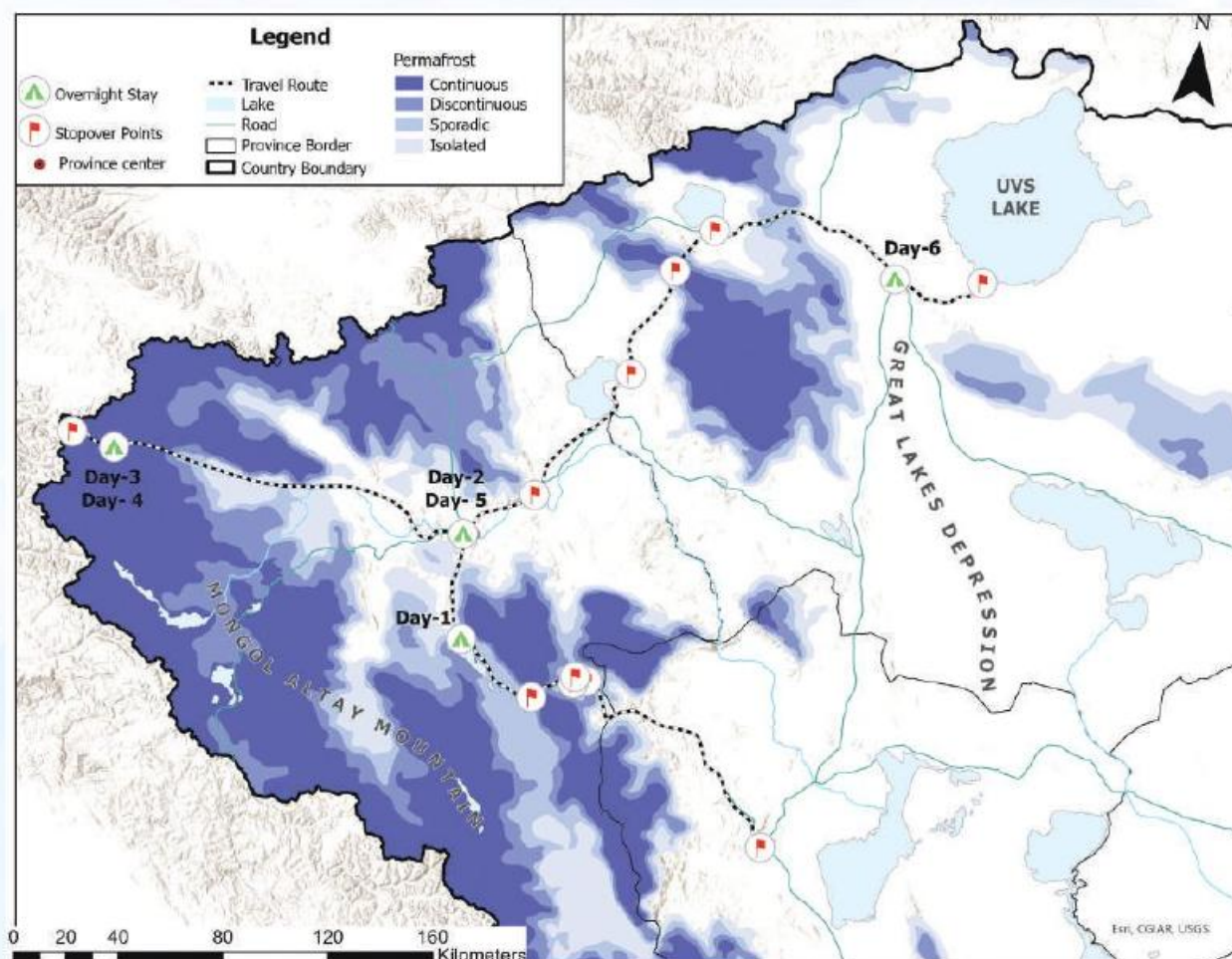
On the seventh day, the team will travel from Erdenet city back to Ulaanbaatar.

Contacts

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ALTAY MOUNTAINS TRIP



Guide: Jambaljav Yamkhin, Ulambayar Ganbold

Duration: 7 days (3–9 July 2026)

Description:

The Altay Mountain field trip route crosses high mountain regions in the western part of the country, characterized by rugged alpine terrain, extensive glaciation, and diverse cryogenic and periglacial landforms. The route also includes permafrost-affected road sections, where pavement deformation, thaw settlement, and slope instability occur due to ice-rich ground conditions. Along the route, participants will observe mitigation measures for cold-region infrastructure, including thermosyphon-based ground temperature stabilization techniques used to reduce the impacts of permafrost degradation on roads.

The field trip focuses on the characteristics, geomorphology, monitoring, and environmental processes of high mountain glacial, periglacial, and permafrost-affected landscapes. Along the route, participants will visit glaciers, glacial valleys, moraines, river basins, mountain passes, long-term environmental observation sites, and engineering structures. These areas represent different alpine environments shaped by elevation, slope orientation, glacial activity, permafrost distribution, temperature regimes, precipitation patterns, and hydrological processes.

The field trip includes a series of thematic observations and scientific discussions, including:

1. Observation of active glaciers, glacier termini, and glacial retreat dynamics in the Tavan Bogd area.
2. Examination of high mountain periglacial processes, including freeze–thaw activity, slope dynamics, and frost-related landforms.
3. Analysis of mountain hydrology, including glacier-fed rivers, meltwater systems, and seasonal discharge variation.
4. Discussion of climate change impacts on glacier mass balance, snow cover, and high mountain water resources.
5. Observation of permafrost-related infrastructure challenges, including road deformation and mitigation measures such as thermosyphon techniques and ground stabilization systems.
6. Observation of major natural and cultural landscapes, including the Tavan Bogd massif, Altay mountain passes, river valleys, and remote nomadic settlements.

Through these field observations and discussions, the Altay Mountain field trip provides an integrated platform for understanding high mountain glacial, periglacial, and permafrost systems in Mongolia. The route connects active glacier environments with permafrost-affected infrastructure and downstream valley systems, highlighting the interaction between cryosphere, hydrology, climate, geomorphology, and engineering.

In addition, the trip demonstrates the scientific importance of Mongolia's Altay region as a key area for studying glacier dynamics, permafrost processes, water resource sustainability, climate change impacts, and cold-region engineering challenges in high mountain environments. The field trip therefore serves not only as a scientific journey but also as a practical training opportunity for understanding the evolution of cold-region mountain landscapes and their role in regional environmental systems.

Detailed program:

Time	Activity / Stop
Day-1	Ulaanbaatar – Khovd – Khashaat Pass – Tolbo Lake
06:30-07:00	Participants gather at Galleria Ulaanbaatar.
07:00-08:30	Proceed to Chinggis Khaan Airport.
10:50-12:00	Depart from Chinggis Khaan Airport for Khovd Airport. <i>* Local time is set back by one hour.</i>
13:00-15:00	Lunch at Zura Restaurant in Khovd province.
15:00-16:30	Travel by bus to Khashaat Pass.
16:30-17:15	Observation of the glaciers of Tsambagarav Mountain and an introduction to recent research findings.
17:15-18:15	Transfer to Tolbo Lake Resort.
18:30-19:00	Check in at Tolbo Lake Resort.
19:00-20:00	Dinner at Tolbo Lake Resort Restaurant.
Overnight	Overnight stay at Tolbo Lake Resort.
Day-2	Tolbo Lake – Khongor Ulun – Buraat Pass – Ulgii
07:30-09:30	Breakfast at the Tolbo Lake Resort Restaurant.
10:00-11:00	Travel to the Khongor Ulun Permafrost Monitoring Borehole.
11:00-11:40	Field explanation on borehole monitoring, ground temperature observations, permafrost conditions, and the local geological setting.
11:40-12:30	Field presentation of road embankment thermosyphons and permafrost monitoring.
12:30-13:30	Lunch near the Khongor Ulun site.
13:30-14:00	Continue the journey to Buraat Pass.
14:00-15:00	Field presentation on slope and spiral thermosyphon embankments.
15:00-16:30	Travel to Ulgii.
16:30-17:00	Hotel check-in.
17:30-18:30	Visit a local Kazakh souvenir shop.
18:30-20:00	Kazakh traditional dinner.
Overnight	Overnight stay at Maxum Hotel.
Day-3	Ulgii – Tavan Bogd
07:00-09:30	Breakfast at the hotel.
10:00-12:30	Depart for the Tavan Bogd Glacier by 4WD vehicle.
12:30-13:30	Lunch on the way to the Tavan Bogd Glacier.
13:30-17:00	Long drive to the Tavan Bogd Glacier with short rest stops.
17:00-17:30	Check in at the tourist camp.
18:00-20:00	Dinner at the tourist camp.
Overnight	Overnight stay at the tourist camp.

Day-4	Tavan Bogd – Botanin – Tavan Bogd
08:00–09:30	Breakfast at the tourist camp.
10:00–11:00	Transfer from the camp to the Tavan Bogd base area by car.
11:00–12:30	Trekking to the lower part of the glacier.
12:30–13:30	Lunch on the way.
13:30–14:30	Field presentation on the Tavan Bogd Glacier.
14:30–16:30	Walk back to the base area.
16:30–17:30	Return to the tourist camp by car.
18:00–22:00	Farewell dinner at the tourist camp.
Overnight	Overnight stay at the tourist camp.
Day-5	Tavanbogd – Ulgii
07:00–09:30	Breakfast at the tourist camp.
10:00–12:30	Return to Ulgii.
12:30–13:30	Lunch on the way to Ulgii.
13:30–17:00	Long drive to Ulgii with short rest stops.
17:00–17:30	Hotel check-in.
18:00–20:00	Kazakh traditional dinner.
Overnight	Overnight stay at Maxum Hotel.
Day-6	Ulgii – Ulaangom
07:00–09:30	Breakfast at the hotel. <i>*Some participants return to Ulaanbaatar.</i>
10:00–12:30	Depart toward Ulaangom.
12:30–13:30	Lunch on the way.
13:30–17:00	Long drive to Ulaangom with short rest stops.
17:00–17:30	Check in at Chandmani Luxe Tour Resort.
18:00–20:00	Dinner at Chandmani Luxe Tour Resort.
Overnight	Overnight stay at Chandmani Luxe Tour Resort.
Day-7	Ulaangom – Ulaanbaatar
07:00–09:30	Breakfast at Chandmani Luxe Tour Resort.
10:00–11:30	Depart for Uvs Lake.
11:30–12:00	Sightseeing at Uvs Lake.
12:00–13:00	Lunch at Uvs Lake.
13:00–14:00	Return to Ulaangom Airport.
16:10–18:50	Arrival at Chinggis Khaan International Airport. <i>* Local time is set forward by one hour.</i>
19:00–20:30	Transfer to Galleria Ulaanbaatar and end of the trip.

Accommodation

On the first day: Participants will fly from Ulaanbaatar to Khovd. Upon arrival in Khovd, they will continue their journey to **Tolbo Lake Resort**, where accommodation will be arranged near Tolbo Lake, a glacial-origin lake and one of the most scenic natural areas in western Mongolia.



On the second day: Participants will travel from Tolbo Lake to Khongor Ulun, passing through the mountainous landscapes of western Mongolia. The route offers opportunities to observe regional geological features and natural scenery. The journey continues through Buraat Pass, where participants will observe slope and spiral thermosyphon embankments in permafrost conditions in the high mountains, before proceeding to Ulgii for hotel check-in, a visit to a local Kazakh souvenir shop, and a traditional Kazakh dinner. Overnight stay at **Maxum Hotel**.



On the third and fourth days: Participants will travel from Ulgii to the Tavan Bogd Glacier area, passing through the vast steppe landscapes and mountainous terrain of western Mongolia. Along the route, they will observe alpine scenery, river valleys, and the remote natural environment of the Altay Mountain range. Upon arrival, they will conduct field activities in the glacier area, including observation of the Tavan Bogd Glacier and surrounding alpine landscapes such as glacial valleys and moraines, as well as trekking in the lower glacier zone. On the final evening, a farewell dinner will be held at the tourist camp. Overnight stay at the **tourist camp**.



On the fifth day: Participants will travel back from the Tavan Bogd area to Ulgii, passing through the mountainous landscapes of western Mongolia. Upon arrival in Ulgii, they will stay overnight at *Maxum Hotel*.

On the sixth day: Participants will travel from Ulgii to Ulaangom. Along the route, they will experience an interesting landscape featuring distant views of major glaciated mountains, close views of large lakes, canyon landscapes, and mountain passes. Overnight stay at *Chandmani Luxe Tour Resort*.



On the seventh day: Participants will visit Uvs Lake, the largest lake in Mongolia, to observe its unique natural landscape. After the visit, they will return to Ulaanbaatar from Ulaangom by flight.

Contacts

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3rd ASIAN CONFERENCE ON PERMAFROST

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CHALLENGES POSED BY ASIAN PERMAFROST THAW TO THE GLOBAL COMMUNITY

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