VIII Congreso Ibérico Permafrost

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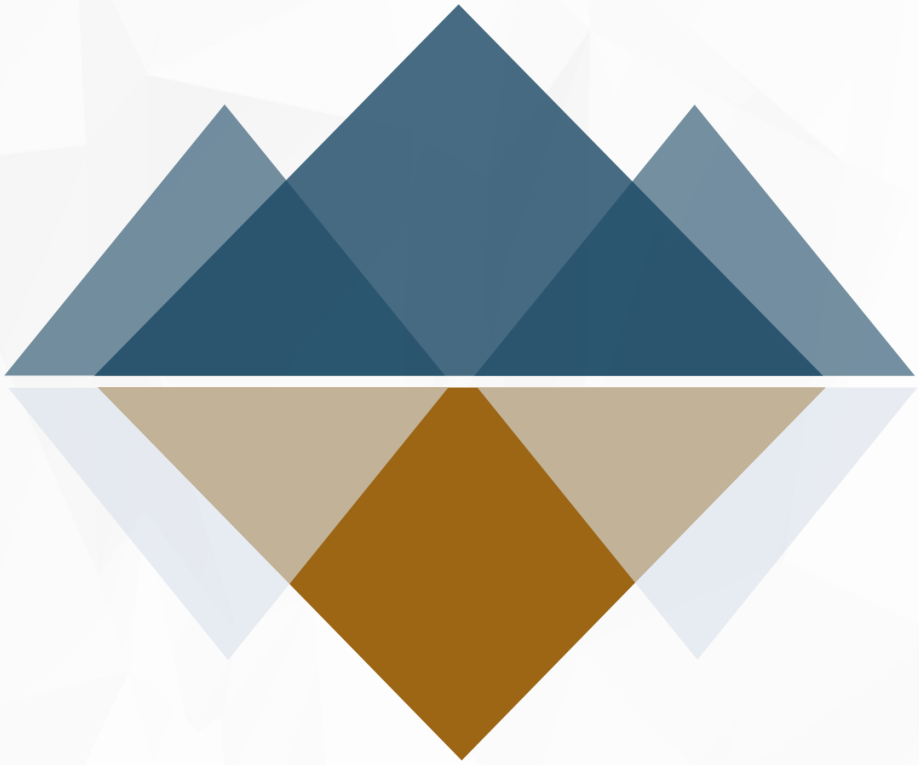

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Session 1:
Frozen Ground Matters

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VIII Congreso Ibérico Permafrost

The PERMAPYRENEES project: Permafrost in the Pyrenees

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Abstract. The Pyrenean cryosphere is undergoing rapid and profound changes driven by climate warming. These shifts are altering not only the region's hydrology and geomorphology but also its ecological and environmental dynamics. Over recent decades, rising temperatures have dramatically reduced snow cover and accelerated the retreat of glaciers, which are expected to vanish entirely in the near future. While glacial and snow processes are relatively well documented, permafrost—another key component of the high-mountain cryosphere—remains poorly understood in this region.

The Pyrenees, located at the southern limit of permafrost distribution in Europe, represent a particularly sensitive and understudied area. Permafrost is currently limited to the highest elevations, generally above 2,600 m, with rare isolated patches found as low as 2,350–2,400 m. The unique climatic and topographic conditions of the range introduce complex challenges for identifying, monitoring, and modeling permafrost dynamics. Although its spatial extent is limited, the degradation of permafrost appears to be accelerating in response to regional warming. This process is increasingly impacting slope stability, leading to rockfalls, landslides, and moraine collapses—phenomena that pose growing risks to hiking trails and infrastructure in heavily visited areas such as Aneto and Vignemale.

To address these knowledge gaps, the PERMAPYRENEES project is developing a pioneering, integrated approach to detect and monitor permafrost and assess associated geohazards. Combining in-situ measurements with advanced remote sensing techniques, the project's strategy includes: (i) Geophysical prospection

to identify frozen ground in key high-altitude areas; (ii) Six deep boreholes for continuous subsurface temperature monitoring; (iii) Thermal loggers installed on steep rock walls to capture permafrost behavior in bedrock; (iv) InSAR data to track ground deformation and slope instability over time; (v) Reconstruction of past permafrost activity, focusing on the development and evolution of rock glaciers; (vi) Analysis of rock properties to improve understanding of heat transfer and freeze-thaw dynamics; and (vii) Detailed permafrost mapping to identify areas at risk of climate-sensitive hazards.

After a year of monitoring and fieldwork, the project is producing highly promising data. Notably, evidence suggests that sporadic permafrost may occur at elevations lower than previously documented in the literature. This discovery opens new perspectives on the role of high mountain regions as water reserves and underscores the importance of these landscapes as legacies of past cold periods that have shaped the high Pyrenees. Beyond its scientific contributions, the project also aims to raise awareness about the impacts of climate change in mountain environments. By providing critical data, it supports land managers, planners, and policymakers in developing informed strategies for risk mitigation and sustainable development in these vulnerable high-altitude areas. The identification of such significant natural heritage highlights the imperative for its formal recognition and integration into territorial planning and conservation frameworks, thereby advancing the promotion of geoheritage and environmental preservation.

Acknowledgements. We are grateful to the support provided by the PERMAPYRENEES project (Interreg Poctefa EFA063/01).

Keywords: Pyrenees, permafrost, climate warming, geomorphology, hazards.

Modelling the permafrost evolution over the last 70 years in Antarctic Peninsula

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Abstract. The temperature dynamics of permafrost is crucial for ecosystem processes in the ice-free areas of the Antarctic Peninsula, where a strong long-term warming trend with an increase of 3.4 ºC in the mean annual air temperature since 1950 has been recorded[1]. The consequences of this warming on past and future permafrost degradation are still not fully understood, mainly due to the sparse spatial coverage and short time span of borehole data, only available after the mid to late 2000's[2,3]. To overcome this limitation, we assessed the applicability of the CryoGrid Community Model as a complement to the permafrost monitoring network. CryoGrid is an adaptable toolbox for simulating the ground thermal regime and the ice/water balance for permafrost[4,5]. The modular structure allows combinations of classes that represent the snow conditions and the subsurface materials. In this study, permafrost temperatures from four PERMANTAR observatories along the western Antarctic Peninsula (62º - 64º S), with depths between 8 and 15 m, were used to set up the CryoGrid model and run long-term simulations from 1950 to 2022, forced with ERA5 reanalysis data. Model configuration was first established using a stratigraphy scheme based on the temperature boundary conditions, where air temperatures from the observatories were used to force the model. Parameter adjustments were made to maximize correlations and minimize Mean Absolute Errors (MAE) between estimated and measured ground temperatures. The final stratigraphy configuration was then used in simulations incorporating the surface energy balance scheme, forced with ERA5 reanalysis data. The results show strong correlations ($r > 0.9$) between estimated and measured ground temperatures in the first 10 m. However, deeper temperature correlations weaken due to differences in heat propagation and the lack of temperature oscillation on the records when compared with the simulation. Despite this, MAE values at depth remain low (0.1 – 0.2 ºC). The active layer thickness was overestimated in the simulations, and thaw propagation exhibited a delay compared to observations. Long-term simulations indicate a warming trend, with the Mean Annual Ground Surface Temperature increasing by approximately 3 ºC since 1950. At 20 m depth, permafrost temperatures rose by 2 ºC, corresponding to a warming rate of ~0.24 ºC/decade. Notably, since 2016, warming has accelerated, driven by the increasing frequency and intensity of extreme climatic events, also leading to a further increase in ALT. This research was funded by the project THAWIMPACT (FCT2022.06628.PTDC) and by CEG/IGOT (UIDP/00295/2020). Joana Baptista is supported by an FCT doctoral grant (2021.05119.BD).
Keywords: Permafrost; CryoGrid; ERA5; Antarctic Peninsula.

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Enhancing DInSAR Measurements of Rock Glaciers Using a Novel Active Reflector for Sentinel-1 C-Band

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Abstract.

The accelerating impacts of climate change on the mountain cryosphere underscore the urgent need for advanced tools to monitor permafrost dynamics and associated geohazards. In this study, we introduce a novel active reflector designed for C-band synthetic aperture radar (SAR), specifically optimized for Sentinel-1 missions. The reflector is engineered to receive vertically polarized signals and reflect them in both vertical and horizontal polarizations, significantly enhancing the signal-to-noise ratio in DInSAR processing.

To validate its utility, the reflector was deployed on the Clot de la Menera rock glacier in Andorra. Through DInSAR analysis, we detected subtle surface movements indicative of an active permafrost layer. The dual-polarization capability of the reflector allows to obtain a brighter measurement point, improving measurement accuracy and reliability.

This work demonstrates the potential of advanced SAR instrumentation to refine cryospheric monitoring in complex terrain, contributing to a better understanding of permafrost dynamics and informing adaptation strategies in the face of climate change.

Keywords: SAR; Sentinel-1; Rock Glacier; Permafrost.

The Inventory and chronology of rock glaciers in the Upper Noguera Pallaresa basin (southern Central Pyrenees)

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Abstract. This communication presents a comprehensive inventory and chronology of rock glaciers (RG) and protalus lobes in the Upper Noguera Pallaresa basin (1,920 km²). These geomorphological features were identified using high-resolution optical and infrared orthophotos (25 cm), 3D imagery from Google Earth, and a 2×2 m digital terrain model derived from airborne laser scanning (LIDAR), following the guidelines of the RGIK (2023)[1].

We mapped 230 RGs covering a total area of 9.8 km², along with 128 protalus ramparts occupying 0.6 km². The identification process was exhaustive, with particular attention paid to distinguishing RGs from paleo debris-covered glaciers—landforms frequently encountered in the region. RGs are exclusively found in massifs that were glaciated during the Last Glacial Cycle, spanning 12 massifs in total. Their presence is limited in areas where peaks are below 2,500 m. The majority are relict forms, with frontal altitudes ranging from 1,540 m to 2,795 m. Notably, 67.8% of the RGs are located between 2,100 m and 2,500 m of average elevation.

Most RGs are situated on north-facing slopes (68.2%) and exhibit an average surface area of 4.3 ha (max: 35 ha), an average length of 249 m (max: 1.2 km), and an average width of 223 m (max: 1.5 km). The largest and most complex features are polymorphic, characterized by intricate arrangements of furrows and ridges, and often include overlapping units from different generations (typically between 2 and 5). Lithology plays a significant role in RG distribution. They are commonly found in areas composed of slates and quartzites, are very abundant in granitic massifs, and are rare in regions where limestone alternates with slate. Although granitic rocks represent only 11.1% of the territory above 1,600 m, they host 71 RGs (30.8%), covering 363.3 ha (37.1%) and exhibiting the highest density observed in the study area (0.59 RG/km²).

Based on geomorphological and morphostratigraphic criteria, we interpret that 67% of the RGs have a cryogenic origin, 13% a clearly glaciogenic origin, and the remaining 20% developed from debris-covered glaciers. InSAR measurements, combined with geomorphological and geophysical observations (on a subset of RGs), identified 36 active RGs (15.6%), with a mean altitude of 2,473 m. However, it remains unclear to what extent their activity is linked to the presence of permafrost or buried ice cores within the landforms.

The elevation range of RG fronts (approximately 1,250 m) suggests that their formation and evolution are linked to distinct morphogenetic phases, spanning from the onset of the last deglaciation to present-day dynamics. Using the cosmic-ray exposure dating method, we have been able to estimate stabilization ages for three RGs located in different altitudinal bands:

1. In the Peguera valley, a single-unit RG with a front at 2,045 m yielded an age of approximately 16 ka, corresponding to Heinrich Stadial 1 (HS1).
2. In the Bonabé cirque, a multi-unit RG provided two distinct ages: 13.9 ± 1.0 ka at its outermost front (2,360 m), corresponding to the Bølling-Allerød interstadial, and 12.3 ± 1.0 ka in its upper unit (2,390 m), linked to the Younger Dryas period.
3. In the Ratera cirque, another multi-unit RG showed stabilization ages of 8.8 ± 0.8 ka in its lower unit (2,480 m), dating to the Early Holocene, and 5.8 ± 0.6 ka in its upper unit (2,540 m), corresponding to the Mid-Holocene.

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Keywords: Rock glaciers, inventory, Central Pyrenees, cosmic-ray exposure dating.

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Rock glaciers in the Central Andes of Chile and Argentina: a non-permafrost case?

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Abstract. Rock glaciers (RGs) play a key role as water reservoirs in the central Andes of Chile and Argentina. Although they are commonly associated with permafrost conditions, this study questions such an automatic link, suggesting that at least some of these landforms could originate, or even persist, without requiring permafrost conditions. This debate has both scientific and legal relevance, as RGs have different degrees of protection in both countries due to their status as glaciers; thus, removing their qualification as glaciers could strip them of legal protection from mining and/or industrial projects.

We present the results of an ongoing work focused on four Andean catchments: Aconcagua, Maipo, Tunuyán and Mendoza. Air and soil temperature data, permafrost probability models Gruber (2012) and Obu (2019), automatic weather stations (AWS) and radiosondes (IGRA) data were collected. We derived from the latter the altitude of different isotherms (0, -2, -3 and -6 °C) associated with cryogenic and permafrost conditions. This information is compared with the location and elevation of RGs on the official glacier inventories of Chile and Argentina.

Our results show that a significant proportion of the RGs within the study area are located outside permafrost environments or conditions. Only 17% of the RGs fall within areas with more than a 50% probability of permafrost according to Gruber (2012), while this percentage increases to 67% based on Obu (2019). Additionally, 37.5% of the RGs are located below the -2 °C mean annual air temperature (MAAT) isotherm.

We discuss our results in terms of: (1) the limitations of the data employed, mainly the RGs inventories, which are inaccurate as they are based solely on optical sensors; (2) the lack of a clear relationship with permafrost models, and (3) the “glacier-debris covered glacier-rock glacier continuum” model, which proposes a natural transition from uncovered glaciers to RGs, and, at the same time, explains the presence of RG in

regions where active RG exist at lower elevations with higher mean annual temperatures than those associated with permafrost conditions.

In conclusion, our study suggests that many RGs in the Central Andes could be of glaciogenic origin rather than cryogenic and should not be used as reliable indicators of the presence of permafrost.

Permafrost degradation and rock glaciers in the Pyrenees. The relationship between flow and atmospheric temperatures

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Abstract. Rock glaciers are the best indicators of permafrost in the Pyrenees. Their presence in high mountains places them among environments with discontinuous and continuous permafrost, above 2,700 m altitude. Currently, the cryosphere of the high Pyrenean mountains is subject to degradation, which involves changes in the snow cover, the rapid retreat of glaciers, including their disappearance, and the deterioration of permafrost environments.
The aim of this study is to understand the changes in the dynamics of rock glaciers, their response to atmospheric temperature changes, and the recent rates of permafrost degradation.
This work is based on geomatic monitoring of the surface dynamics of four rock glaciers (Argualas, years 1991-2000; Posets, years 2000–2011; Maladeta, years 2008–2023; and La Paúl, years 2013–2023) carried out using a total station, GPS-RTK, and UAV photogrammetry. The displacement speeds and vertical variations have been correlated with thermal anomalies for the months of July, August, and September compared to the period 1950–2023, estimated in the high mountains of the Pyrenees using a reanalysis with Era-land.
The flow variations show that the rock glaciers have not significantly increased their extension, but they indicate an increase in deformation and deterioration of the fronts with proximity in time. All of this coincides with the periods of most pronounced thermal anomalies. A rapid response in the behavior of rock glaciers to changes in ambient temperatures and a recent increase in the degradation of frozen bodies and therefore of permafrost in the Pyrenees are observed.

Acknowledgements. We are grateful to the support provided by the CRYODEM project (PID2020-113247RB-C21, Ministerio de Ciencia e Innovación).

Key words: Pyrenees, permafrost degradation, rock glaciers.

PERMATHERMAL: 25 years monitoring frozen ground in Livingston and Deception Islands, Antarctica

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In early 2000, researchers from the University of Alcalá drilled the first two boreholes for continuous monitoring of seasonal and permanently frozen ground on Livingston Island[1], part of the South Shetland Islands archipelago in Antarctica. Since then, additional boreholes have been established on Livingston Island and the nearby Deception Island, expanding the monitoring network, known as PERMATHERMAL network[2]. These installations have been equipped not only with temperature sensors at various depths but also with instruments measuring air and surface temperatures, snow thickness, and, more recently at some sites, ground moisture, heat flux, and vertical ground movements. The primary aim of these efforts is to improve our understanding of the thermal state of soils and its temporal evolution in the most-northern ice-free areas of Antarctica. Infrastructure improvements have been progressively implemented, including the standardization of measurement protocols and data management and processing procedures, alongside upgrades to instrumentation technology. Furthermore, two grids for active-layer thickness measurements were established using manual mechanical probing according to the Circumpolar Active Layer Monitoring (CALM) protocol[3]—one on each island, in 2006 and 2009, respectively. These monitoring stations are integrated into the Global Terrestrial Network for Permafrost (GTN-P)[4], an initiative of the International Permafrost Association (IPA).

As of January 2025, the PERMATHERMAL network has completed 25 years of continuous operation[2]. It currently includes 108 monitoring instruments distributed across 12 primary stations focused on frozen-ground monitoring, 7 auxiliary stations tracking environmental variables, 2 CALM sites dedicated to active-layer thickness monitoring, provided with 1 snow measurement station, 3 phenomenological cameras, and additional boreholes and instruments specifically dedicated to active layer studies at CALM grids. The challenges for the next five years include expanding the installation of soil moisture and heat flux sensors at all stations and deploying distributed surface temperature sensors across the CALM grids.

Data collected by the PERMATHERMAL stations are integrated into the GTN-P and CALM databases and contribute to other international monitoring networks such as SoilTemp[5] and PhenoCam[6]. Additionally, metadata and datasets are accessible through Spain's National Polar Data Centre and the Polar Master Directory, and

selected data and derived products are progressively being integrated into the international open-access repository Zenodo[7].

The development and maintenance of the network have involved collaborative efforts from researchers at the University of Alcalá (Spain), the University of Lisbon (Portugal), and Masaryk University (Czech Republic). Their contributions have included station maintenance and financial support for instruments acquisition and drilling operations. Funding for these 25 years of research has primarily come from projects under the National Research Plan within the Polar Programme of the Spanish Research Agency, supplemented by contracts and agreements with various agencies and organizations[2]. These activities have represented substantial economic and personal efforts from the researchers involved and collaborators, supported by technical staff from the Spanish Antarctic Stations "Juan Carlos I" and "Gabriel de Castilla," the Byers Field Camp, and oceanographic vessels operated by the Spanish Navy and the Spanish National Research Council (CSIC).

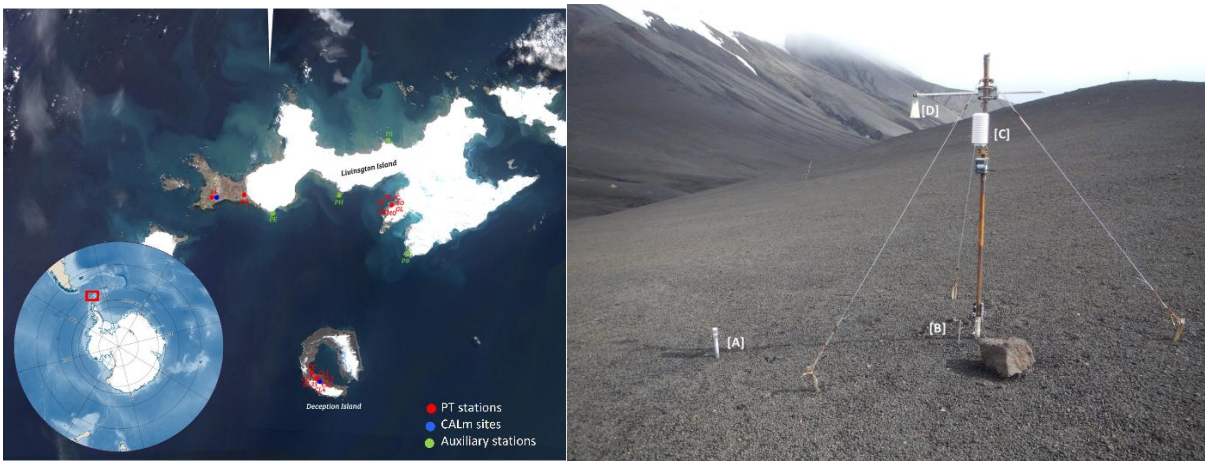

Figure 1: (left) Location map of the monitoring sites in Livingston and Deception Islands, and (right) example of a PERMATHERMAL network station with the typical instrumentation, including devices for measuring the temperature of frozen soils at different depths [A], surface temperature [B], and air temperature [C], as well as snow cover thickness [D].

Keywords: Permafrost; Active layer; Antarctica; Monitoring.

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Session 2:
Frozen Biogeochemistry

Chairs: Gerard Rocher-Ros, Dermot Antoniades

Permafrost Thaw–Induced Irreversible Changes in Phosphorus Cycling in Subarctic Palsa Mire Ecosystems

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Abstract. Phosphorus (P) is an essential nutrient for all life forms and frequently acts as a limiting factor for primary productivity in both terrestrial and aquatic ecosystems. Histosols are particularly rich in P due to their high organic matter content and their efficient P sorption capacity. Climate warming accelerates permafrost degradation and enhances organic matter decomposition, inducing profound alterations in the geochemical cycling of carbon (C) and nitrogen (N). To evaluate the impact of permafrost thaw on P dynamics, we quantified available P, characterized Hedley P fractions, and measured phosphatase enzymatic activity along a permafrost thaw gradient in a palsa mire complex located in Stordalen, Abisko (68°N, Sweden). A space-for-time substitution approach was employed by sampling three distinct stages of permafrost thaw: intact palsa, transition zone, and fully collapsed palsa. At each site type, samples were collected at four peat depths: 5–10 cm, 40–45 cm, 70–75 cm, and 95–100 cm. Results indicated that available or labile P concentrations were substantially higher in surface layers than in deeper peat across both intact and collapsed palsa sites. The dominant P fractions in these samples were organic P and P bound to iron (Fe) and aluminum (Al), extracted with NaOH (NaOH-Porg), comprising between 40% and 70% of total phosphorus (TP). In the collapsed palsa, the relative contribution of Fe- and Al-bound P was reduced, while both organic and inorganic labile P fractions and phosphatase activity were elevated—particularly in the surface layer. These observations suggest that increased temperature, microbial activity, and changes in redox conditions associated with thawing promote the transformation of Fe- and Al-bound P into more bioavailable forms. A significant decrease in TP content (15–30%) was observed in deep layers (>50 cm) following permafrost thaw, whereas TP concentrations in the surface layer (5–10 cm) increased by approximately 60%. This vertical redistribution of P indicates a notable shift in nutrient storage and availability resulting from the loss of permafrost. The results demonstrate that permafrost thaw leads to enhanced P availability for plant and microbial communities and a diminished capacity of deep peat to retain P. The mobilization of P in subarctic peatlands under thawing conditions may result in reduced N:P ratios at the

surface, potentially altering ecosystem productivity and carbon sequestration dynamics. Furthermore, the hydrological and geochemical changes induced by permafrost degradation in discontinuous permafrost regions are likely to play a key role in regulating the release of P and its interactions with C, N, Fe, and Al biogeochemical cycles.

Keywords: Palsa mire; Phosphorus cycle; Permafrost thawing

Unveiling the Role of Groundwater in Arctic Lake Greenhouse Gas Dynamics: Evidence from Radon Tracing and Biogeochemical Analyses

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Abstract. Arctic lakes and thaw ponds are recognized as major sources of greenhouse gases (GHGs), particularly CO_2 and CH_4. While traditionally attributed to microbial activity within the water column and sediments, recent findings reveal that groundwater inflows from thawing permafrost are a critical and often overlooked pathway for transporting dissolved inorganic and organic carbon into these systems, contributing substantially to GHG emissions.

In this presentation, I will summarize recent research showing that groundwater discharge from thawing permafrost can substantially influence CH_4 and CO_2 dynamics in high-latitude lakes. Using radon (^{222}Rn) as a tracer, we quantified groundwater inflow rates into Arctic lakes and linked them to lake depth and peatland cover, observing also significant seasonal patterns. Notably, in sub-Arctic thaw ponds, biogeochemical analyses showed that consumers in ponds with higher CH_4 groundwater inputs via groundwater had increased trophic reliance on methane-oxidizing bacteria (MOB) and reduced nutritional quality. Furthermore, our wintertime study in a small Arctic lake revealed that groundwater remains an active contributor to GHG budgets even under ice cover, challenging the prevailing notion that winter GHG accumulation is solely driven by internal lake processes and highlight the importance of lateral inputs from the surrounding landscape.

Building on these insights, I will introduce my current project PERMAFLOW, which takes a multidisciplinary approach—combining hydrology, geophysics, limnology, biogeochemistry, and microbial ecology—to better understand how permafrost thaw and changing hydrological connectivity shape groundwater-driven GHG fluxes from Arctic freshwater ecosystems. Together, this research underscores that groundwater is not a passive conduit, but an active driver of Arctic lake GHG dynamics—essential for accurately modeling future GHG emission scenarios in a warming climate.

Hydrology controls thermokarst and alters carbon cycling and methane emissions in peatlands near the southern limit of permafrost

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Abstract. Permafrost peatlands store vast reservoirs of frozen carbon across northern landscapes, making them highly sensitive components of the climate system. As thermokarst expands within these ecosystems, it amplifies climate feedbacks, yet the roles of ground ice, hydrology, and vegetation in driving thaw and altering carbon fluxes remain uncertain. We used the process-rich ecosystem model *ecosys* to simulate thermokarst development from 1950 to 2018 at a well-instrumented peatland in Canada's Northwest Territories. After validating the model against site observations, we explored a range of excess ground ice contents and hydrologic boundary conditions typical of permafrost near the southern limit. Our simulations revealed distinct degradation regimes shaped by the interaction of permafrost and water table (WT) dynamics. Rates of simulated lateral permafrost retreat (the horizontal thaw-driven expansion of thermokarst wetlands into adjacent permafrost peat plateaus) varied from 0 to over 2 m yr^{-1} under identical meteorological forcing, consistent with observations at the site and underscoring the influence of WT position and excess ice. Simulations further suggest that black spruce mortality cannot be attributed to anoxia alone, as post-collapse oxygen levels often remain sufficient when WTs stay below the surface, pointing to the importance of additional stressors such as root instability or disease. While thermokarst alters local hydrology and vegetation, net CO_2 exchange remained a modest carbon sink, whereas CH_4 emissions increased by one to two orders of magnitude depending on post-collapse WT. Scaling our results across the 1.7 million km² permafrost peatland domain suggests that thermokarst could raise greenhouse gas emissions by 0.1 to 10 Mt CO_2-eq per decade, depending on post-collapse hydrology. These findings highlight the importance of incorporating both ground ice heterogeneity and water table dynamics in projections of permafrost–climate feedbacks.

Keywords: Thermokarst; Peatlands; Methane; Ecosystem modeling

Genetic potential of nitrogen and methane cycling genes in microbial communities of lithic biofilms in high-Arctic streams

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Abstract

The Arctic is undergoing rapid climate change, with declines in the extent of the cryosphere, including glaciers, seasonal snow, and permafrost[1]. In response, tundra ecosystems are experiencing widespread changes in vegetation and nutrient cycles, with potential implications for the delivery of organic carbon (C) and nitrogen (N) into streams[2]. Small streams act as active biogeochemical hotspots areas within the landscape, largely due to the activity of benthic microbial biofilms; however, their functional roles remain poorly understood.
Here, we examined the spatial and temporal diversity of prokaryotes and their genetic potential of key functional genes involved in N and methane (CH_4) cycles in high-Arctic streams. Biofilm communities on cobbles were sampled three times during open-water season from 14 environmentally diverse streams in northeast Greenland [3]. We employed targeted metagenomics to identify the genes involved in mineral N transformations and methane production and consumption[4] and conducted 16S rRNA gene sequencing to assess prokaryotic diversity.
Across all samples, the *nifH* gene -encoding nitrogenase enzyme responsible for N fixation- showed the highest relative abundance (35.1%). Arctic regions are remote areas with limited N inputs, resulting in frequent N limitation for biological growth[5]. In these N-limited environments, the energetically costly process of N fixation may be promoted[6]. The second highest genetic potential was related to

nitrate reduction with *narG* (21.6 %) that, together with *napA* (10.8 %), encode nitrate reductases. These genes are involved in the first step for subsequent nitrate reducing pathways, either denitrification or dissimilatory nitrate reduction to ammonium (DNRA). The denitrification vs. DNRA dichotomy is paramount for the fate of N, being lost to the atmosphere in N gas forms or being recycled and retained as ammonium, respectively[7]. The genetic potential of denitrification-involved genes (*nirS* 3.1%, *nirK* 7.79%, *norB* 4.9%, and *nosZ* 14.2%) was higher than DNRA (*nrfA* 0.82%), suggesting a net balance towards N losses in the system. Nitrification potential was low (*amoA* 0.63%) and anaerobic ammonium oxidation (anammox) was not detected (*hdh* 0%). The genetic potential related to CH_4 cycling was lower than the N cycling. The potential for methane consumption (p*moA* 0.8%, and *mmoX* 0.08%) was higher than the potential for methane production (*mcrA* 0.3%), as expected in these biofilms from oxygenated waters.
The prokaryotic composition across our study sites was dominated by the phylum Cyanobacteria, Proteobacteria, and Bacteroidota, consistent with previous findings from Arctic glacier-fed streams[8]. Overall, the taxonomic and functional gene compositions remained relatively stable, with spatial variation (site differences) exerting a stronger influence than seasonal dynamics across the open-water period. This finding suggests that the genetic potential for N and methane cycling functions remain consistent throughout summer, supporting the idea of community-level functional plasticity, where different taxa within the biofilm can become transcriptionally active in response to environmental changes[9].
The understanding of how stream environmental variables and biofilm properties determines taxonomic and functional roles will offer key insights into the role of stream microbial communities in N and methane cycling, and their potential responses to ongoing climate change in Arctic ecosystems.

Keywords: Microbiome; biofilm; freshwater; biogeochemistry.

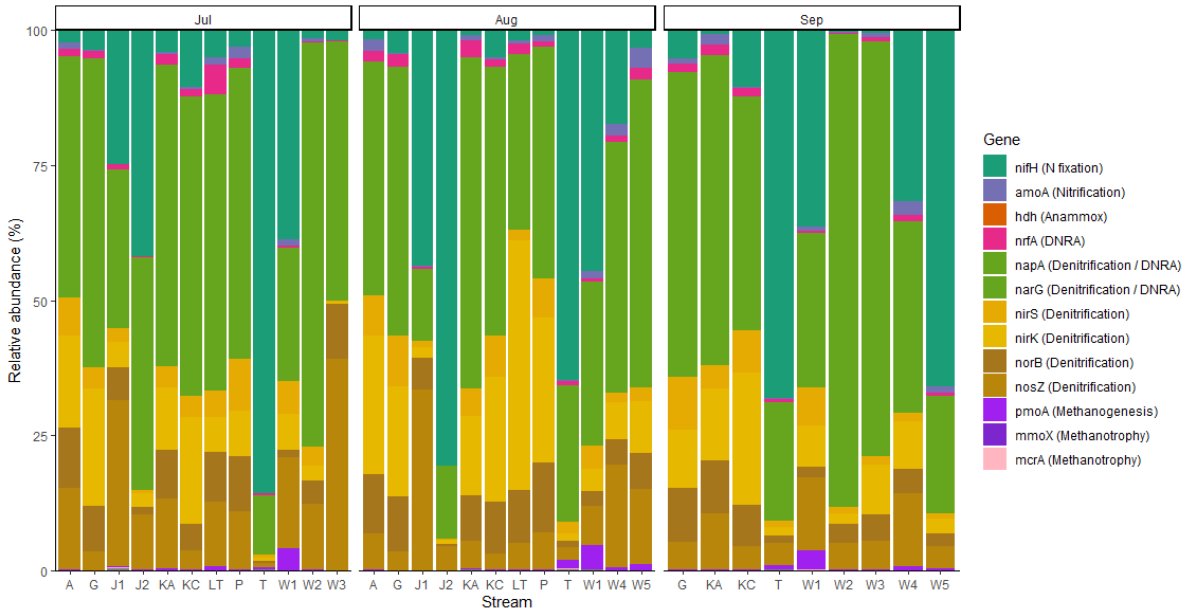

Fig 1. Relative abundance of nitrogen and methane cycling genes and linked function in stream microbial biofilm communities in high Arctic streams across open-water season (July, August, September)

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Session 3:
Periglacial and snow dynamics

Chairs: Carolina Olid, Marcelo Fernandes

Stable water isotopes variation during the ablation season in the streamflow of the Maladeta catchment

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Abstract. The Maladeta catchment receives the meltwater melt from Maladeta glacier (15.6 ha in 2023). This study analyses the daily and seasonal fluctuations of water levels, temperature, conductivity and stable isotopes composition of δ^2H and $\delta^{18}O$ of stream water during three summer seasons (from June to September, from 2020 to 2022). The objective of this study was threefold: firstly, to comprehend the hydrological processes associated with snowmelt and glacier fusion during the ablation periods; secondly, to delineate the temporal evolution of the isotopic streamwater; and thirdly, to simulate the percentage of streamwater that results from glacier melting.

The analyses indicate that the water of the Maladeta catchment is low in mineral content and slightly alkaline, and its composition remained relatively constant during the study period. As observed in other study areas, there was a high variability of the stable δ^2H and $\delta^{18}O$ isotopic composition depending on elevation, which could be attributed to intermittent melting processes. The variability of the isotopes exhibited an increasing trend along the ablation periods, with $\delta^{18}O$ values ranging from -11.472 to -10.069 and δ^2H values from -70.133 to -64.936. This increase in variability was concomitant with an increase in conductivity, which ranged from 11.8 to 35.5 µS, coinciding with the shift from snow to ice melt. Furthermore, in the case of the conductivity, when the ice began to melt, the daily conductivity values (morning and afternoon) exhibited greater disparity, due to the presence of elevated ion levels in the glacier meltwater. Consequently, during the hours of maximum glacier fusion, the meltwater exhibited higher conductivity. This study has also enabled the analysis of how precipitation events affect the δ^2H and $\delta^{18}O$ isotopic composition, thereby increasing the stream water values. Finally, the simulation of melt informed that in some days when the ice (instead of snow) dominated the percentage of stream water due to fusion was 100%. In contrast, during periods of snow cover, the percentage of streamwater due to fusion remains more constant at around 70%.

To summarise, the present study has facilitated the analysis of the variation of the δ^2H and $\delta^{18}O$ isotopic compositions during the ablation period, with consideration also given to precipitation events.

Shrub effects on marginal snowpacks distribution in central Pyrenees

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Abstract.
The spatio-temporal distribution of marginal snowpacks is influenced by local mass and energy fluxes related with meteorological conditions, microtopographic properties and vegetation presence. These seasonal snowpacks typically occur between 1600 – 2100 m a.s.l, exhibit relatively shallow and patchy patterns, and are subject to multiple accumulation-ablation cycles throughout the winter season. The interaction of marginal snowpacks with vegetation, focusing on shrubs remain poorly study in the Pyrenees Mountains.
This research adopts an ecohydrological approach, combining spatial and micro-meteorologic monitoring techniques to improve understanding of shrub influence on the snowpack distribution. The study is conducted near the Cotefablo mountain pass at 1700 m a.s.l (between Ara and Gállego valleys), a transition zone from treeline forest to subalpine belt. The area is covered by sparce forest with *Pinus sylvestris* and scattered - shrubland area covered by *Buxus Sempervirens*, *Echinospartum horridum* and *Juniperus communis*. Though relatively small, the site is topographically stable and highly exposed to strong winds.
Since December 2021, we have conducted 24 UAV surveys using drones equipped with LiDAR and RGB Cameras to generate 3D Point clouds of the surface and then very high spatial resolution (<1m) raster layers. These datasets allow the derivation of snow depth, snow presence and vegetation-topographic variables, which are used to train machine learning models (Gradient Boosted models). Additionally, we deployed sensors to measure air and soil temperatures at various depths and positions - between brushes, trunks and leaves of shrubs, as well as in adjacent open areas- aiming to detect thermal emissions from vegetation and asses the sensitivity of marginal snowpacks to imminent ongoing temperatures trends.
Preliminary results highlight the importance to incorporate shrub-vegetation variables to better understand the marginal snowpack distribution. Moreover, the long-term monitoring approach has revealed strong interannual variability in these snowpacks, emphasizing the specific needs for monitoring, understanding and simulating techniques to improve the knowledge of these snowpacks. These factors are essential to estimate the potential impacts of climate warming on marginal snowpacks in the Pyrenees and their associated hydrological and ecological functions.

Keywords: Snow–shrub interactions, Marginal snowpack, Unmanned Aerial Vehicle(UAV), Pyrenees Mountains.

Changing snowpack dynamics in Disko Island, Western Greenland and implications for permafrost

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Abstract. Arctic snowpack is rapidly changing due to climate warming, with significant implications for ecosystems and hydrology. This study simulates the future evolution of the snowpack at Qeqertarsuaq (Disko Island, Greenland) using the physical-based Flexible Snow Model 2, driven by CMIP6 projections under SSP2-4.5 and SSP5-8.5 emission scenarios from CanESM5 and MIROC6 models. Results indicate substantial reductions in snowpack characteristics, with projected snow depth anomalies ranging from -38% to -74% (CanESM5) and -38% to -57% (MIROC6) by the late 21st century. Snowfall shows complex responses, with CanESM5 projecting a slight winter snowfall increase (around 5%) until the 2060-2070 period, while MIROC6 anticipates an increase of more than 10% under SSP5-8.5 for winter months across all periods analyzed. The ablation rate shows the largest sensitivity to climate change, with increases ranging from -2% to +23% (MIROC6) and -23% to +57% (CanESM5). Additionally, more frequent rain-on-snow (ROS) events due to higher precipitation and temperatures are expected, which will intensify snowmelt, further reduce snowpack, and increase the risks of flooding. These results underscore the need for improved understanding of snowpack evolution in Arctic regions, as the projected reductions in snow cover will have cascading effects on regional hydrology, ecosystem dynamics, and permafrost stability. Changes in snow dynamics will impact the local flora and fauna, alter hydrological cycles, and contribute to permafrost degradation.

Keywords: Snowpack, Greenland, Arctic, Climate change.

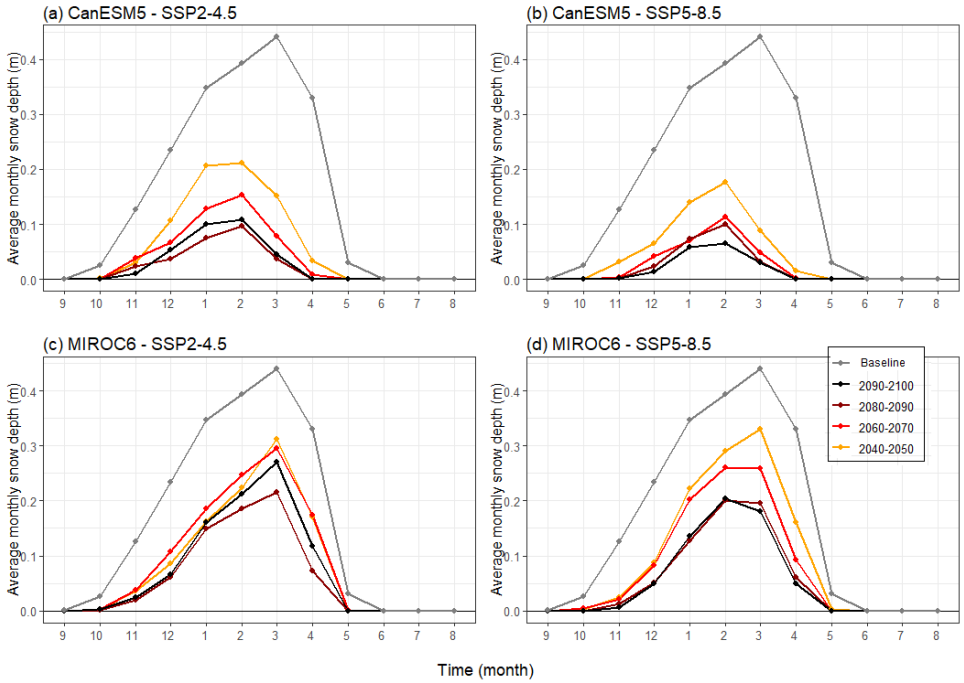

Fig 1. Seasonal snowpack evolution under different CMIP6 SSP2-4.5 and SSP5-8.5 emission scenarios and CanESM5 and MIROC6 models. Data is shown for different temporal periods (colors).

New evidence from the past glacial and periglacial dynamics in the Drakensberg, southern Africa

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Abstract. Geomorphological evidence of past cold environments in the Drakensberg, southern Africa, remains incomplete and debatable. While previous studies employing geomorphological analysis, micromorphology, and numerical modeling have proposed glacial conditions above ~3000 m a.s.l., information on the full extent of Quaternary glaciation in the region is yet to be established. To this end, our study aims to contribute new evidence of former glacial and periglacial conditions for high elevations of this mid-latitude mountain environment.

To achieve this, a geomorphological map at a scale of 1:25,000 was produced near the Sani Pass, based on a Digital Surface Model derived from Pleiades satellite imagery and verified through field investigations. Detailed mapping at 1:5,000 resolution is under construction after having applied Unmanned Aerial Systems (UAS) from three selected areas: the Sehonghong Plateau, the KwaNtuba Valley, and the Mangaung Catchment. In addition, sixteen samples for Cosmic-Ray Exposure (CRE) dating were collected from well-preserved glacial and periglacial landforms, so as to constrain the chronology of stabilization and are currently being processed. Finally, Schmidt Hammer measurements were carried out to establish a relative age chronology of landforms.

The Sehonghong Plateau, located near the Great Escarpment between 3250 and 3300 m a.s.l., is characterized by gentle NE-facing slopes with extensive bare bedrock surfaces and common weathering pits. Shattered convex outcrops supply material to block fields reworked by periglacial processes, including large unsorted-stone circles (Fig. 1-A) and finer micro-unsorted-stone circles. At lower elevations, dry wetlands exhibit turf exfoliation, hummocky ground (cryogenic earth hummocks), and degraded soil surfaces controlled by cryogenic-, fluvial- and wind- related processes.
The KwaNtuba Valley, oriented ESE from 2800 to 3300 m a.s.l., incises the SW-NE trending Great Escarpment. On its left flank, a 200-m-high amphitheatre-

shaped headwall (3300–3100 m) transitions into a large debris deposit extending down to the valley floor. This deposit, composed of angular to subangular meter-sized boulders in a sandy matrix, includes five SE-facing elongated ridges stretching from 3100 to 2800 m, typically observed in debris-covered glaciers.
In the Mangaung Catchment, two cirque-like basins facing south were investigated. The eastern basin preserves two parallel moraine ridges, composed of sandy-matrix-supported, subangular to subrounded meter-sized boulders. Central to the basin, polished and striated bedrock surfaces provide clear evidence of glacial abrasion (Fig. 1-C). In the western basin, a 1-km-long, 60-m-wide boulder stream with elongated ridges and matrix-free clasts shows downvalley alignment.

Future results from CRE dating will provide chronological constraints for the climatic conditions under which these landforms developed and offer new insights into the glacial and periglacial history of southern Africa.

Fig. 1. Unsorted-stone circle in the Sehonghong plateau (A) and glacial features in the KwaNtuba valley (B) and Mangaung catchment (C).

Keywords: Drakensberg; Geomorphology; Geochronology; Late Pleistocene.

Addressing challenges in monitoring snow cover at the Aigüestortes i Estany de Sant Maurici National Park using remote sensing technique

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Keywords: Remote sensing; snow cover; radiometric correction; kNN classifier.

The presence or absence of snow in high mountain landscapes regulates the surface energy balance and controls the hydrological cycles, thereby shaping key ecosystem functions[1]**.** Traditionally, snowpack studies have relied on in situ observations, involving significant risks and difficulties. Current remote sensing techniques offer numerous advantages for studying the snowpack more safely, providing a broader view of the territory, access to remote areas, and continuous monitoring with multispectral data. However, remote sensing of snow in high mountain landscapes, still faces significant limitations due to the complex orographic terrain, the changes in solar radiation and atmospheric conditions[2] making it difficult to accurately detect snow cover.

In this presentation, we will discuss the development of a high-temporal resolution snow cover database for the Central Pyrenees using Landsat and Sentinel data from 1984 to 2024 and 2015 to 2024, respectively. The contribution will also highlight the key methodological challenges faced throughout the development process.

Although the preliminary results using Landsat data were promising, differences in radiometric correction were detected between the sensors on Landsat 4, 5 and 7, and the more recent sensors on Landsat 8 and 9. This has made it difficult to compare data over time. To overcome this, first we developed a consistent methodology to homogenize the original data (non-radiometrically corrected images) to radiometrically homogenized through atmospheric and topographic corrections. The main challenge is to improve snow detection in shadowed areas[2,3]. In these areas the solar radiation is basically diffuse, and consequently the signal is very low (the sensor receives very little energy), making it difficult to standardize the radiometric variability of the same pixel due to different solar illumination or varying atmospheric conditions. Secondly, to further improve snow detection in areas with topographic shadows and instead of using a subjective NDSI threshold, our efforts are focused on improving the snow classifier with a non-parametric classifier, kNN (k-Nearest Neighbours), to generate the binary mask for snow presence or absence. The ultimate goal is to create a high temporal resolution, open-access, snow cover database for the Central Pyrenees, imputing data gaps caused by clouds or sensor errors using different satellites, climate data such as temperature, precipitation[4] or solar radiation[5], alongside in situ observations (e.g., snow poles, automatic snow gauges) and real-time imagery or orthophotos. This database will be a valuable resource for studying snow persistence and its impact on hydrology and ecosystem functions in the Pyrenees.

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PERMATHERMAL: 25 years monitoring frozen ground in Livingston and Deception Islands, Antarctica

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In early 2000, researchers from the University of Alcalá drilled the first two boreholes for continuous monitoring of seasonal and permanently frozen ground on Livingston Island[1], part of the South Shetland Islands archipelago in Antarctica. Since then, additional boreholes have been established on Livingston Island and the nearby Deception Island, expanding the monitoring network, known as PERMATHERMAL network[2]. These installations have been equipped not only with temperature sensors at various depths but also with instruments measuring air and surface temperatures, snow thickness, and, more recently at some sites, ground moisture, heat flux, and vertical ground movements. The primary aim of these efforts is to improve our understanding of the thermal state of soils and its temporal evolution in the most-northern ice-free areas of Antarctica. Infrastructure improvements have been progressively implemented, including the standardization of measurement protocols and data management and processing procedures, alongside upgrades to instrumentation technology. Furthermore, two grids for active-layer thickness measurements were established using manual mechanical probing according to the Circumpolar Active Layer Monitoring (CALM) protocol[3]—one on each island, in 2006 and 2009, respectively. These monitoring stations are integrated into the Global Terrestrial Network for Permafrost (GTN-P)[4], an initiative of the International Permafrost Association (IPA).

As of January 2025, the PERMATHERMAL network has completed 25 years of continuous operation[2]. It currently includes 108 monitoring instruments distributed across 12 primary stations focused on frozen-ground monitoring, 7 auxiliary stations tracking environmental variables, 2 CALM sites dedicated to active-layer thickness monitoring, provided with 1 snow measurement station, 3 phenomenological cameras, and additional boreholes and instruments specifically dedicated to active layer studies at CALM grids. The challenges for the next five years include expanding the installation of soil moisture and heat flux sensors at all stations and deploying distributed surface temperature sensors across the CALM grids.

Data collected by the PERMATHERMAL stations are integrated into the GTN-P and CALM databases and contribute to other international monitoring networks such as SoilTemp[5] and PhenoCam[6]. Additionally, metadata and datasets are accessible through Spain's National Polar Data Centre and the Polar Master Directory, and

selected data and derived products are progressively being integrated into the international open-access repository Zenodo[7].

The development and maintenance of the network have involved collaborative efforts from researchers at the University of Alcalá (Spain), the University of Lisbon (Portugal), and Masaryk University (Czech Republic). Their contributions have included station maintenance and financial support for instruments acquisition and drilling operations. Funding for these 25 years of research has primarily come from projects under the National Research Plan within the Polar Programme of the Spanish Research Agency, supplemented by contracts and agreements with various agencies and organizations[2]. These activities have represented substantial economic and personal efforts from the researchers involved and collaborators, supported by technical staff from the Spanish Antarctic Stations "Juan Carlos I" and "Gabriel de Castilla," the Byers Field Camp, and oceanographic vessels operated by the Spanish Navy and the Spanish National Research Council (CSIC).

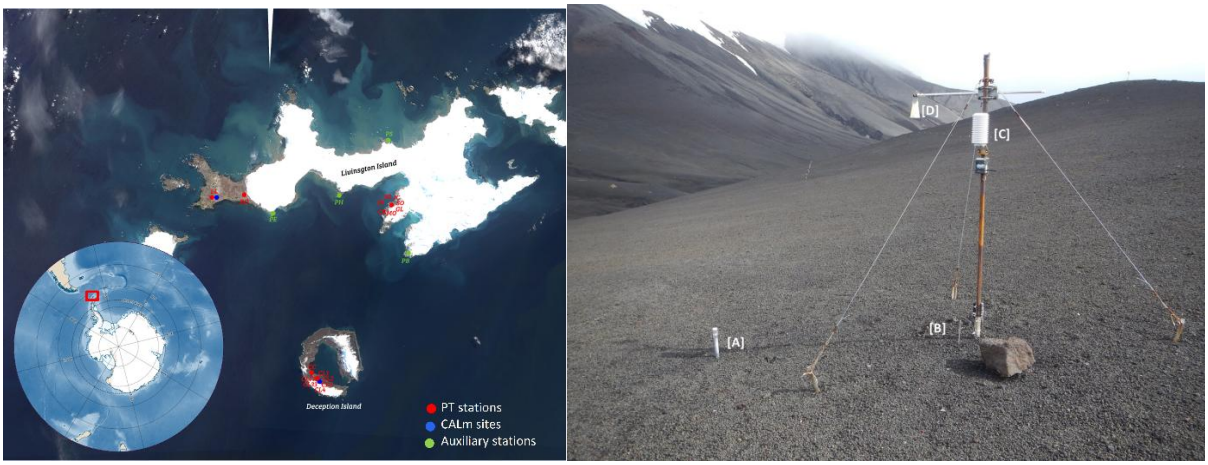

Figure 1: (left) Location map of the monitoring sites in Livingston and Deception Islands, and (right) example of a PERMATHERMAL network station with the typical instrumentation, including devices for measuring the temperature of frozen soils at different depths [A], surface temperature [B], and air temperature [C], as well as snow cover thickness [D].

Keywords: Permafrost; Active layer; Antarctica; Monitoring.

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Session 4:
Sculpted by Cold: Glacial-periglacial geomorphology

Chairs: Jose Maria Fernández-Fernández, Attila Çiner

The transformations of the Dyrjökull glacier after the passage of a massive rock avalanche (northeastern Iceland).

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Abstract. The Dyrfjöll mountain range is located in the NE corner of Iceland, between the Lagarfljót valley—which drains into Héraðsflói Bay—and the valley of Fjarðará, which flows into Borgarfjörður near the village of Bakkagerði. The range's two highest peaks are Súla (1,136 m) to the north and Stöpull (1,074 m) to the south. Between them lies the Dyr Pass (856 m; coordinates: 65°30'44.70'' N, 13°56'45.85" W). The name Dyr means "gate" in Icelandic, a fitting name for this dramatic mountain pass, which resembles a saddle flanked by nearly vertical rock walls on both its eastern and western sides. The Dyrfjöll Mountains are composed primarily of Tertiary basalt lavas and pyroclastic rocks. However, at the Dyr Pass itself, the rock is a distinctive type of black tephra (BT)—a pyroclastic deposit made up of highly consolidated fragments of various sizes, notable for its intense black coloration. Geomorphological evidence suggests that the Dyr Pass was formed by a large rock avalanche (sturzström). On the western side of the pass lies Urðardalur valley, a glacier-free area whose floor is covered with massive BT blocks, some over 50 m in length. On the eastern side lies Jökuldalur valley, where a small glacier—Dyrjökull, measuring 0.6 km in length—still persists beneath the pass. Approximately 4 km east of the Dyr Pass, near the outlet of Jökuldalur valley, a well-preserved avalanche deposit spans an area roughly 2 km long and 4 km wide. It consists of BT blocks up to 10 m in axis, arranged in characteristic hummocky mounds separated by closed depressions. Between the current glacier front and the avalanche deposit, six series of push moraines can be identified. The two innermost ridges, based on lichenometric dating, are relatively recent and likely formed during the waning stages of the Little Ice Age.

The other four moraine ridges are of the hummocky type, interspersed with collapse depressions. No BT (black tephra) blocks are preserved within these moraines—only sand-sized BT pyroclasts remain. The only plausible explanation is that the avalanche originated from the Dyr Pass—the sole location capable of producing such a deposit—travelled across the glacier, and accumulated at the valley's outlet, where its remnants are found today. The portion of the avalanche that fell onto the glacier was crushed by the ice flow; due to the highly friable nature of the tephra, only the more resistant basaltic lava boulders survived and were later deposited in these outer moraine series. To determine the chronology of these events, 20 samples were collected for cosmic-ray exposure (CRE) dating using ^{36}Cl exposure, targeting boulders from both the avalanche deposit and the four outer hummocky moraine ridges in the Jökuldalur valley. The avalanche deposit yielded a CRE age of approximately 10.0 ± 1.2 ka. The

two outermost moraine ridges returned very similar ages, around 8.0 ± 0.4 –8.7 ± 0.4 ka. The third ridge produced an age of 5.4 ± 0.7 ka, while the fourth, closest to the current glacier front, was dated to 4.1 ± 0.4 ka.

We know that the Iceland Ice Sheet experienced a significant readvance during the Preboreal period, between approximately 11.3 and 10.4 cal ka BP. However, by 9 ka, it had largely disappeared, and Icelandic glaciers had diminished to extents similar to or smaller than those observed today. During the Holocene Thermal Maximum (ca. 8.5–6 cal ka BP), most glaciers in Iceland are believed to have vanished entirely[1].

The CRE dating results from the avalanche deposit and the associated series of hummocky moraines provide a foundation for a hypothesis about glacier behavior during this period—a dynamic that may have operated independently of prevailing climatic conditions. The rock avalanche was likely triggered by decompression following major deglaciation at the onset of the Holocene or shortly after the Preboreal, a phenomenon frequently observed in Iceland[2]. The glacier, buried beneath avalanche debris, was effectively insulated from surface ablation. This cover allowed the glacier to advance, even during the warmest intervals of the Holocene. Eventually, as the glacier retreated, it left behind a sequence of push moraines, likely driven by the initial phases of Neoglacial cooling.

Acknowledgements. This research was framed within the NEOICE project: “Reconstruction of Neoglacial oscillations in Iceland”, ref. PID2020-113798GB-C32, funded by MCIN/AEI/10.13039/501100011033.

Keywords: Iceland; rock avalanche; hummocky moraine, cosmic-ray exposure (CRE) dating.

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Topographic control and divergent geomorphic evolution during the Neoglaciation in the Tröllaskagi Mountains (northern Iceland).

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Abstract. New research[1,2,3,4,5] has demonstrated the significant impact of the Neoglacial cold phases on the mass balance of small alpine glaciers in the Tröllaskagi Mountains (northern Iceland), particularly since the 4.2 ka event. *In-situ* ^{36}Cl cosmic-ray exposure (CRE) dating has constrained glacier advances at approximately 3.2- 2.6 ka, 1.2-0.9 ka and during the Little Ice Age across several glaciers, including Tungnahryggsjökull, Gljúfurárjökull, and those in the cirques of Hofsdalur, Nautárdalur, and Fremri-Grasárdalur. However, this sequence of advances resulted in very different landforms across the various cirques (Fig 1). In the case of Tungnahryggsjökull and Gljúfurárjökull (both debris-free glaciers), a large, well-preserved sequence of moraines was formed. The moraine ages in all valleys consistently show that each successive advance reached a slightly lower extent than the previous one. In Hofsdalur and Nautárdalur, moraines built by each advance overlapped those of earlier events preserved underlying ice cores. This process ultimately led to the development of debris-covered glaciers in both cirques. In contrast, the small glaciers of Fremri-Grasárdalur were constrained by rocky prominences that hindered the forward movement of glacier termini. As a result, the moraine from each advance were superimposed by younger ones and, due to the presence of these rocky obstacles, the glaciers formed characteristic ice-cored moraines—similar to those described by Østrem (1964)[6] in the Scandinavian Peninsula. These observations reveal that the geomorphological expression of the Neoglacial cold climatic events in the Tröllaskagi Mountains was strongly influenced by the specific topographic settings of each cirque—such as headwall height, aspect, altitude, and cirque floor slope—rather than by climatic variability alone. CRE dating of these debris bodies has further clarified their origin as initially debris-free glaciers that subsequently evolved into distinct glacial and periglacial landforms.

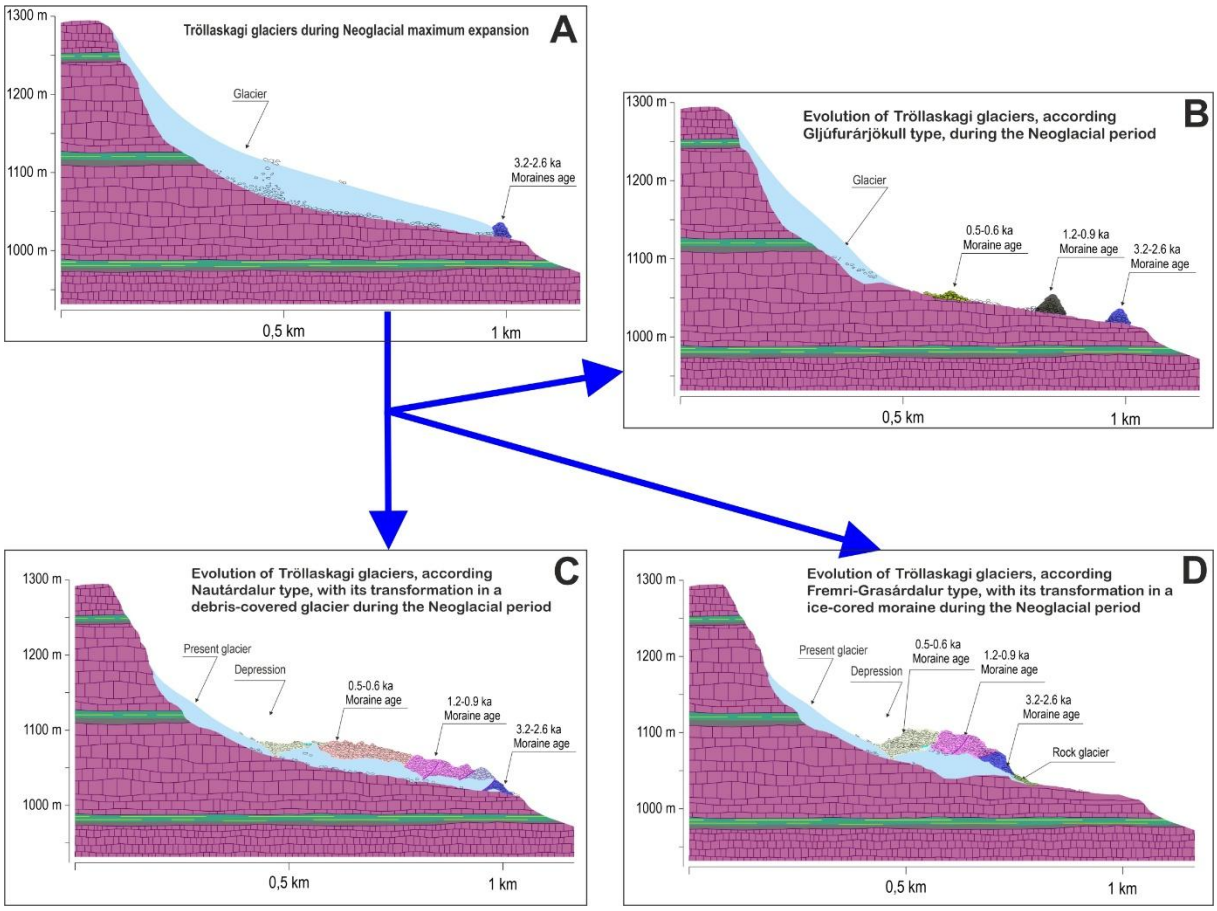

Fig 1. Divergent evolution of Tröllaskagi glaciers from the maximum Neoglacial advance at 3.2-2.6 ka (A). The Gljúfurárjökull-type glaciers remain debris free and leave a sequence of moraines (B). Nautárdalur-type glaciers were transformed into debris-covered glaciers by aggregation of moraines (C). Fremri-Grasárdalur type glaciers form ice-cored moraines by overlapped different advances.

Acknowledgements. This research was framed within the NEOICE project: "Reconstruction of Neoglacial oscillations in Iceland", ref. PID2020-113798GB-C32, funded by MCIN/AEI/10.13039/501100011033.

Keywords: Tröllaskagi Mountains; Iceland; Glacial landforms; Periglacial landforms.

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Deglaciation, permafrost, and rock glacier activity in the Central-Eastern Pyrenees: Insights from the Clot de la Menera cirque (Andorra)

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Abstract. Understanding postglacial environmental evolution in mid-latitude mountain ranges is crucial for assessing how past climate changes shaped present-day landscapes and for predicting future dynamics under ongoing warming. In the Clot de la Menera cirque (Grau Roig, Andorra), located in the Central-Eastern Pyrenees, we carried out a multidisciplinary investigation to reconstruct the environmental evolution from the Late Pleistocene to the present. Our study combines cosmogenic exposure dating, remote sensing (DInSAR), geomorphological mapping, geophysical surveys and ground thermal monitoring to trace the evolution and dynamics of rock glaciers and frozen ground features.

The research addresses critical questions regarding the timing of deglaciation, the formation and activity of rock glaciers, and the possible presence of buried ice or permafrost in this high mountain cirque. In particular, the study focuses on rock glaciers that formed shortly after cirque deglaciation and are currently undergoing slow downslope movement. Preliminary results suggest that these rock glaciers originated in the Early Holocene and continue to be active, offering a rare opportunity to examine the long-term persistence of permafrost below the regional 0 ºC isotherm. These features serve as key indicators of cryospheric dynamics, and their analysis sheds light on how internal frozen masses can sustain movement despite rising air temperatures.

Part of this research was carried out as part of the European project PERMAPYRENEES (Interreg POCTEFA EFA063/01), which aims to improve knowledge of the distribution and evolution of permafrost in the Pyrenees. Future borehole investigations at the Clot de la Menera cirque may clarify the nature and depth of the frozen cores, offering key insights into their climate resilience and reinforcing the site's value as a reference for mid-latitude alpine permafrost under climate change.

Keywords: rock glaciers; deglaciation; Pyrenees; Andorra.

Reconstruction of glacial chronology and climate evolution since the penultimate glacial cycle in the Upper Garonne basin, Central Pyrenees

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Abstract. The Upper Garonne basin constituted the largest paleoglacier of the Pyrenean range during the Late Pleistocene glacial cycles. The paleoglacier was part of the large Pyrenean ice field that flowed down valleys from the highest areas above 3000 m a.s.l. to the lowest terminal basins at 300-400 m. Within this altitudinal range, widespread evidence of glacial dynamics is preserved in the form of erosional and accumulation geomorphological features, which can be used to infer the past glacial evolution. The chronology of past glacial oscillations has been increasingly unveiled during the last decade, allowing the compilation of the previous studies from the Upper Garonne basin during the Mid-Late Pleistocene.

Here, we review the glacial and periglacial chronology existing in the Upper Garonne basin, including geomorphological observations, a dataset of 39 ^{10}Be Cosmic-Ray Exposure (CRE) ages and two lake records encompassing the complete postglacial environmental evolution. These studies are organized in three moraine complexes at i) the Loures-Barousse-Barbazan basin (LBBBb), ii) valleys, and iii) glacial cirques.

The most externally degraded moraine, preserved at 420–480 m in the Loures-Barousse-Barbazan basin (LBBBb), marks the maximum ice extent of the Penultimate Glacial Cycle (MIS-6), as indicated by CRE ages of ~130 ka. During the Last Glacial Cycle, the Garonne paleoglacier again advanced into the LBBBb before 40–32 cal ka BP, representing the local Last Glacial Maximum (LGM) in the Pyrenees. However, by the time of the global LGM, the Marignac basin slopes—12 km upstream—were already ice-free, as evidenced by polished surfaces at 520–540 m dated to 21–24 ka. As temperatures rose during the last deglaciation, glaciers retreated upvalley, with polished surfaces in the Ruda Valley at 1860–1900 m yielding CRE ages of 14–15 ka. This retreat, driven by the initial Bølling–Allerød warming, was briefly interrupted by two glacier advances or standstills around 13.5 and 13.0 ka, likely due to short-lived cold events. During the Younger Dryas, glacial readvance occurred, with glaciers reaching 2370–2470 m in the Bacivèr and Sendrosa cirques, where moraine boulders stabilized at 12.9 and 12.6 ka, respectively. Subsequent warming intensified paraglacial processes, transforming the last debris-free glaciers into debris-covered and rock glaciers in cirques below 2800 m. Continued Holocene

warming led to further ice loss and the evolution of debris-rich features, with final boulder stabilization dated to ~11.9 ka in the Lòcampo Cirque rock glacier and ~7.2 ka in the Bacivèr Cirque debris-covered glacier.
This comprehensive synthesis underscores the Upper Garonne Basin's potential as a key reference site for reconstructing the spatiotemporal evolution of glacial and periglacial dynamics in the Pyrenees from the Mid-Pleistocene through the Holocene.

Keywords: Upper Garonne basin; Glacial evolution; CRE dating; Late Pleistocene.

Topographic control and divergent geomorphic evolution during the Neoglaciation in the Tröllaskagi Mountains (northern Iceland).

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Abstract. New research[1,2,3,4,5] has demonstrated the significant impact of the Neoglacial cold phases on the mass balance of small alpine glaciers in the Tröllaskagi Mountains (northern Iceland), particularly since the 4.2 ka event. *In-situ* ^{36}Cl cosmic-ray exposure (CRE) dating has constrained glacier advances at approximately 3.2- 2.6 ka, 1.2-0.9 ka and during the Little Ice Age across several glaciers, including Tungnahryggsjökull, Gljúfurárjökull, and those in the cirques of Hofsdalur, Nautárdalur, and Fremri-Grasárdalur. However, this sequence of advances resulted in very different landforms across the various cirques (Fig 1). In the case of Tungnahryggsjökull and Gljúfurárjökull (both debris-free glaciers), a large, well-preserved sequence of moraines was formed. The moraine ages in all valleys consistently show that each successive advance reached a slightly lower extent than the previous one. In Hofsdalur and Nautárdalur, moraines built by each advance overlapped those of earlier events preserved underlying ice cores. This process ultimately led to the development of debris-covered glaciers in both cirques. In contrast, the small glaciers of Fremri-Grasárdalur were constrained by rocky prominences that hindered the forward movement of glacier termini. As a result, the moraine from each advance were superimposed by younger ones and, due to the presence of these rocky obstacles, the glaciers formed characteristic ice-cored moraines—similar to those described by Østrem (1964)[6] in the Scandinavian Peninsula. These observations reveal that the geomorphological expression of the Neoglacial cold climatic events in the Tröllaskagi Mountains was strongly influenced by the specific topographic settings of each cirque—such as headwall height, aspect, altitude, and cirque floor slope—rather than by climatic variability alone. CRE dating of these debris bodies has further clarified their origin as initially debris-free glaciers that subsequently evolved into distinct glacial and periglacial landforms.

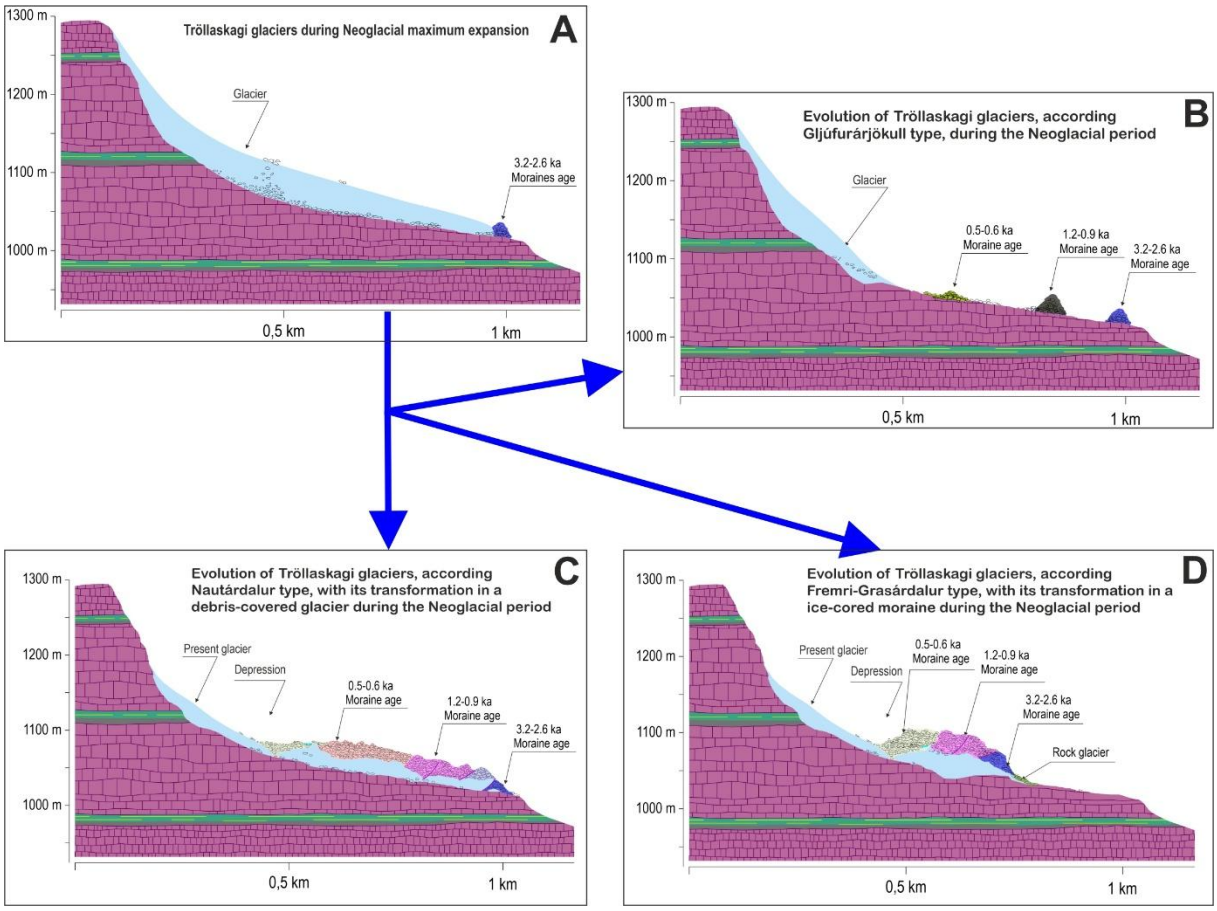

Fig 1. Divergent evolution of Tröllaskagi glaciers from the maximum Neoglacial advance at 3.2-2.6 ka (A). The Gljúfurárjökull-type glaciers remain debris free and leave a sequence of moraines (B). Nautárdalur-type glaciers were transformed into debris-covered glaciers by aggregation of moraines (C). Fremri-Grasárdalur type glaciers form ice-cored moraines by overlapped different advances.

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Keywords: Tröllaskagi Mountains; Iceland; Glacial landforms; Periglacial landforms.

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Towards More Frequent and Intense Late-Summer Meltwater Events in the Greenland Ice Sheet

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Abstract. The Greenland Ice Sheet (GrIS) has experienced a marked increase in extreme melting events during the late summer, particularly since the 1990s. These extreme events are becoming more frequent and intense, with record-breaking events such as those in August 2021 and 2023, which were previously rare, now contributing significantly to the ice sheet's overall summer meltwater runoff. This study analyzes extreme melting events across the GrIS from 1950 to 2023, with a particular focus on the most recent extreme events of 2021 and 2023. Extreme melting days account for approximately 35-40% of the total accumulated summer melt. The probability, magnitude and spatial extension of extreme melt events to the total summer melt have all increased, particularly in the ablation area of the GrIS, with the largest trends observed in the northern and northwestern regions. Over the past three decades, total summer meltwater production from these extreme events has increased sixfold, from 12.7 Gt/decade (1950–1990) to 82.4 Gt/decade (1990–2023). Record-breaking melt episodes, exceeding 10 Gt/day, have become regular occurrences, with the August 2023 event exceeding 23 days, far longer than the historical average of 3 days. These changes are closely tied to increased thermodynamic contributions, as well as shifts in atmospheric circulation patterns. The results underscore the growing impact of extreme melt events on global sea-level rise and highlight the importance of understanding these trends in future climate projections.

Keywords: Greenland, Arctic, Climate change, Extreme melting

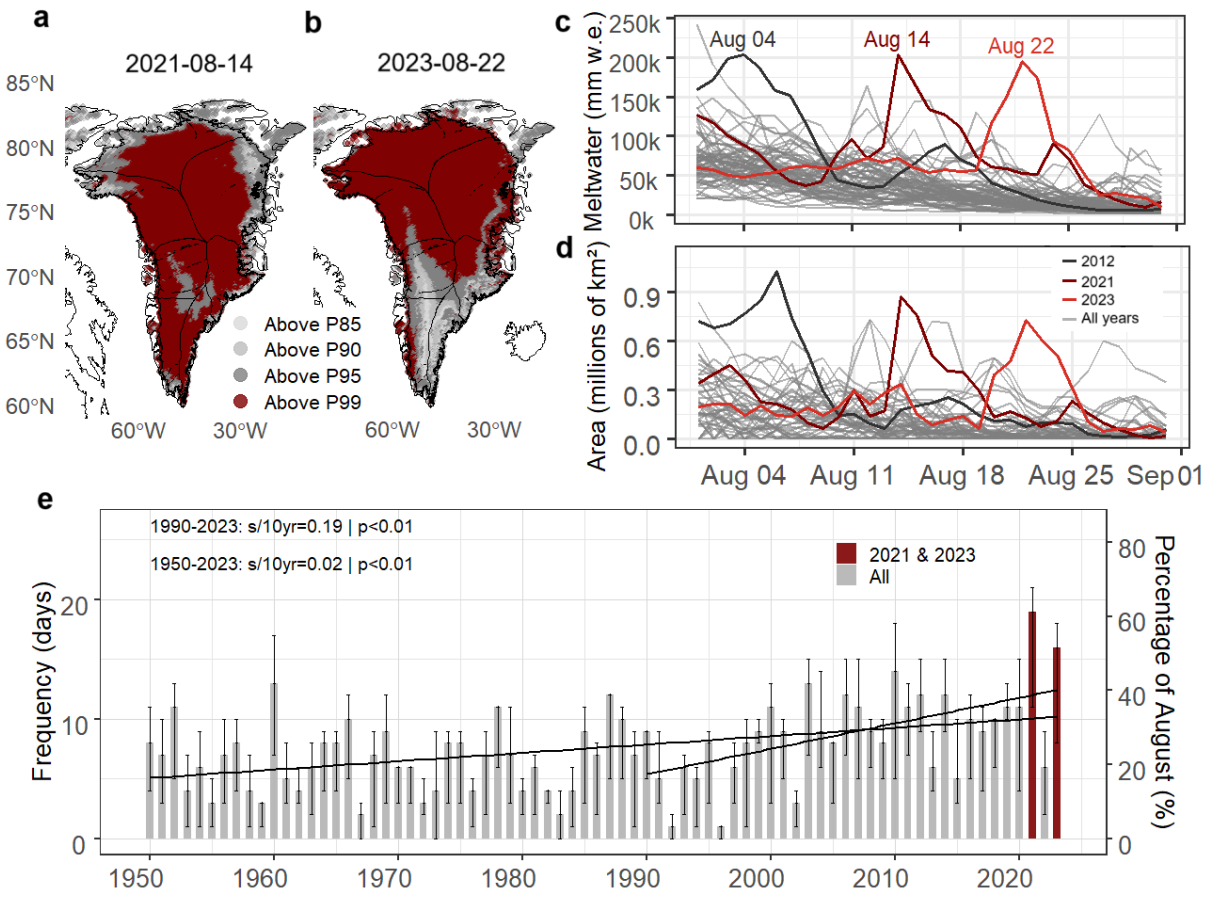

Fig 1. Map of the extreme percentile reached (85, 90, 95 and 99th) for different zones of GrI for the August 2021 (a) and August 2023 (b) melt events. Daily accumulated meltwater modeled with MAR (c) and melting area extension obtained from passive microwave satellite SSM/I and SSMIS (d) for August, with peak meltwater and area per day, corresponding to 2012 (black), 2021 (dark red) and 2023 (red). The remaining years are shown in grey. Temporal evolution of August extreme melting days (e). The lower and upper bar show the percentiles 90 and 99th respectively, whereas the column shows the 95th percentile for the month of August (1950-2023). The secondary y-axis indicates the percentage of days corresponding to August.

Session 5:
Warming Realities: Polar and Alpine Cryosphere Responses

Chairs: Chairs: Josep Bonsoms; Antonio Correia

Glacial to Ice-Free: Decoding Arctic Environmental Change in a Warming World

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Abstract. This contribution synthesizes the findings of several (inter)national research projects involving more than 40 scientists from 18 institutions across 10 countries, all focused on key regions of the Arctic. The region's rapidly accelerating warming is driving profound ecological and environmental transformations that must be interpreted in the context of long-term natural climate variability. Throughout the Holocene, alternating warm and cold phases—driven by shifts in atmospheric circulation—have produced significant geo-ecological changes, including glacial advances and retreats. However, the timing and extent of these glacial dynamics remain insufficiently constrained.

To address these gaps, coordinated fieldwork has been conducted in recent years across the Atlantic Arctic, particularly in northeastern and western Greenland and northeastern and eastern Iceland. The research is structured around three complementary thematic areas: (i) Glacial geomorphology and dating – Detailed geomorphological mapping, combined with absolute and relative dating techniques, has enabled reconstructions of glacial dynamics from the last glacial cycle to the present. These efforts provide insights into landscape evolution across diverse topographic and lithological settings; (ii) Lake sediment analysis – High-resolution, multi-proxy analyses of lacustrine sequences formed during deglaciation are yielding fine-scale records of glacial fluctuations, environmental change, and climate variability on decadal to centennial timescales. These records contribute to our understanding of North Atlantic teleconnections, polar–mid-latitude interactions, and the mechanisms of Arctic amplification; (iii) Postglacial ecosystem development – Chronologies of deglaciation serve as a foundation for examining postglacial processes such as soil formation, vegetation succession, and nutrient cycling. Multi-proxy studies in this domain are advancing knowledge of the biogeochemical functioning of contemporary Arctic ecosystems.

While research is ongoing, initial results highlight the pronounced sensitivity of Arctic and sub-Arctic glaciers to climatic shifts throughout the Holocene, marked by a strikingly uniform response. Present-day warming is accelerating glacial retreat and intensifying interactions with paraglacial and periglacial processes, resulting in the emergence of new landscapes and ecosystems. These ongoing transformations underscore the critical need for sustained monitoring to better

understand the Arctic's evolving role within the broader context of global climate dynamics.

Acknowledgements. We are grateful to the support provided by the PALEOGREEN (CTM2017-87976-P), the NEOARCTIC (PID2020-113798GB-C31+ PID2020-113798GB-C32+ PID2020-113798GB-C33) and the GRELARCTIC (PID2023-146730NB-C31) projects funded by the Ministry of Science and Innovation, the research group ANTALP (Antarctic, Arctic, Alpine Environments; 2017-SGR-1102) and the Portuguese/Spanish Polar Committees.

Keywords: Polar regions, North Atlantic, geomorphology, deglaciation, climate.

On the evolution of the hydrothermal structure of polythermal glaciers

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Abstract. The hydrothermal structure of polythermal glaciers (i.e. its internal distribution of cold and temperate ice) undergoes changes under climate changes. It is of much interest to analyse its current state and to project its expected evolution under various scenarios of future greenhouse gas emissions. For this, a combination of thermomechanical modelling, field/remote sensing observations and climate reanalysis/modelling/downscaling data are needed. Ground-penetrating radar (GPR) has been shown to be an effective tool to infer the hydrothermal structure of polythermal glaciers by detecting the cold-temperate transition surface (CTS). Over the last decades, Spanish, Russian and Polish researchers (occasionally in cooperation with Norwegian and German colleagues) have conducted joint extensive fieldwork campaigns in Svalbard aimed at determining the glacier ice thickness and the depth of the CTS of polythermal glaciers. The focus has been on Nordenskieöld Land, Wedel Jarlsberg Land, Sabine Land and Austfonna glaciers/ice fields/ice caps. Repeated campaigns at certain glaciers has allowed to observe the evolution of the CTS over recent decades, which shows decreases of the temperate ice layer thickness in the order of 2-3 m/year for the last decade. More recently, the Spanish team has developed deep-learning tools, based on convolutional neural networks (CNN), to automate the detection of the CTS from radargrams. The use of synthetic radargrams generated using gprMax software, as well as data augmentation techniques, has allowed to increase the dataset of radargrams used to train the CNN. Simultaneously, under the Horizon Europe LIQUIDICE project, we are initiating an effort to model the evolution of the CTS using the thermomechanically-coupled Informed Glacier Model (IGM), which speeds up the solution of the Blatter-Pattyn model approaching the Stokes system governing glacier dynamics, by using a CNN that emulates the flow equations, reducing drastically the computation time required to numerically solve the Stokes system.

Keywords: cold-temperate transition surface; ground-penetrating radar; convolutional neural network, thermomechanical modelling

Temperature evolutions in ice caves of Picos de Europa high mountain (Northern Spain).

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Abstract. Ice caves are one of the least studied cryological topics in specific scientific tradition, despite being widely recognized in some cases since the 18th century in certain areas of Central Europe. However, the importance of their ice blocks as multiproxy records in climate and paleoenvironmental studies has been demonstrated, particularly in the last two decades. This is of greater interest, and even more important, in areas where past records for such reconstructions are scarce, such as those currently completely deglaciated areas. This is the case of the Picos de Europa, whose high mountains still preserve more than two hundred such cavities (based on speleotopographies); however, their existence is compromised by changing global climate patterns.
The results of continuous thermal monitoring over the last decade and a half in three experimental cavities of this type located in the high mountains of the Central massif of Picos de Europa are presented here: the Altáiz, Verónica, and Castil ice caves. Their temperature evolution is highlighted, with reconstructed trends, absolute and relative thermal increases depending on the different ventilation periods to which these cavities are thermodynamically subjected, as well as their implications for the relevant mass balances. These trends have been compared with a series of meteorological stations from the Spanish National Parks Network and with the surface temperature provided by the ERA5-Land model.
These types of studies and cavities represent an urgent need for continued endoclimatic monitoring and control, as these periglacial environments are highly sensitive to the current global change in which the cryosphere is being rapidly depleted.

Keywords: Ice caves; Temperature evolution; Climate monitoring, Picos de Europa.

The Cryosphere and Bofedales Sustain Water Security in the Arid Andes of Southern Peru

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Abstract

The Coropuna volcanic complex (15º31'S, 72º39'W; 6377 m a.s.l.) is located on the western slope of the Peruvian Andes. It comprises several stratovolcanoes whose summits exceed 6,000 m in elevation and are covered by the most extensive glacial system in the tropical zone (40 km² as of 2024). These glaciers, which may have persisted throughout the Pleistocene, likely descended multiple times to the surrounding Altiplano, potentially following the ~100 ka cyclicity inferred from proglacial sediments of Lake Junín over the past ~700 ka[1].

Cosmogenic exposure dating[2] indicates that around ~14 ka, Coropuna's glaciers descended to altitudes below the Altiplano (<4,000 m), coinciding with the transgressions of paleolakes in the Bolivian Altiplano[3] and a southward displacement of the Intertropical Convergence Zone driven by Northern Hemisphere cooling. According to reconstructions from the Bolivian Altiplano[4], the depression of the paleo-ELA at Coropuna (~1,000 m) suggests that the climate was colder (−6.4 °C) and more humid than today, with precipitation rates 1.2–2.8 times higher than present[2].

Throughout the Holocene, permafrost has developed where glaciers retreated to summit areas under favorable conditions of high surface albedo and south-facing orientation. Both glacier retreat[5] and the cycles of permafrost development and degradation[6] have been linked to La Niña/El Niño phases of the ENSO phenomenon. Currently, Coropuna represents a tropical high mountain environment characterized by extreme conditions: high elevation, intense solar radiation, and a semi-arid climate, with precipitation concentrated during the austral summer and reaching ~600 mm annually in the highest areas.

Under these conditions, the cryosphere (glaciers, rock glaciers, and permafrost) is highly sensitive to the impacts of contemporary climate change, and its melting sustains tropical high-altitude peatlands. Unlike other types of peatlands, the *bofedales*—as these wetland ecosystems are known in the Central Andes—develop in cold, semi-arid environments, generally between 3,800 and 5,000 meters, and are dominated by plant species such as *Distichia muscoides* Nees & Meyen, *Oxychloe andina* Phil., *Plantago* sp., and *Carex* sp. These peatlands play a crucial ecological role: they function as natural sponges, storing water during the wet season and releasing it gradually during the dry season. In doing so, the high Andean *bofedales* regulate water resources that support livestock, wildlife at higher elevations, and tens of thousands of people and their economic activities downstream within the drainage basins. Furthermore, *bofedales* are key ecosystems for climate change mitigation due to their high carbon sequestration capacity.

Periglacial landforms identified during fieldwork (e.g., rock glaciers, cryoplanation terraces, polygonal soils, and tors) provide evidence of active permafrost dynamics at elevations above 4,500 m. Down-valley, *bofedales* have been documented between 3,800 and 4,500 m, occurring in various geomorphological contexts, with peat thicknesses reaching 4 meters in isolated Altiplano sectors and up to 10 meters in the floors of deeply incised glacial valleys.

The objective of this study is to highlight the interactions among glaciers, permafrost, and peatlands, and their collective role in sustaining water reserves in the context of an arid mountain landscape inhabited by ancestral communities (Fig. 1).

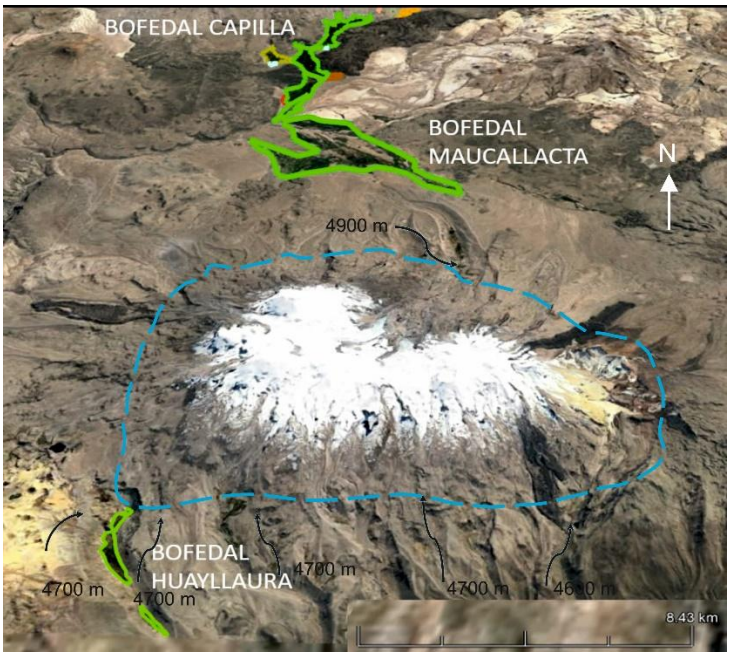

Fig. 1: Relationship between the lower limit of permafrost and the location of the bofedales surrounding Coropuna.

Keywords: Permafrost, Bofedales, Cryosphere, High-Andean hydrology.

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Addressing challenges in monitoring snow cover at the Aigüestortes i Estany de Sant Maurici National Park using remote sensing technique

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Keywords: Remote sensing; snow cover; radiometric correction; kNN classifier.

The presence or absence of snow in high mountain landscapes regulates the surface energy balance and controls the hydrological cycles, thereby shaping key ecosystem functions[1]**.** Traditionally, snowpack studies have relied on in situ observations, involving significant risks and difficulties. Current remote sensing techniques offer numerous advantages for studying the snowpack more safely, providing a broader view of the territory, access to remote areas, and continuous monitoring with multispectral data. However, remote sensing of snow in high mountain landscapes, still faces significant limitations due to the complex orographic terrain, the changes in solar radiation and atmospheric conditions[2] making it difficult to accurately detect snow cover.

In this presentation, we will discuss the development of a high-temporal resolution snow cover database for the Central Pyrenees using Landsat and Sentinel data from 1984 to 2024 and 2015 to 2024, respectively. The contribution will also highlight the key methodological challenges faced throughout the development process.

Although the preliminary results using Landsat data were promising, differences in radiometric correction were detected between the sensors on Landsat 4, 5 and 7, and the more recent sensors on Landsat 8 and 9. This has made it difficult to compare data over time. To overcome this, first we developed a consistent methodology to homogenize the original data (non-radiometrically corrected images) to radiometrically homogenized through atmospheric and topographic corrections. The main challenge is to improve snow detection in shadowed areas[2,3]. In these areas the solar radiation is basically diffuse, and consequently the signal is very low (the sensor receives very little energy), making it difficult to standardize the radiometric variability of the same pixel due to different solar illumination or varying atmospheric conditions. Secondly, to further improve snow detection in areas with topographic shadows and instead of using a subjective NDSI threshold, our efforts are focused on improving the snow classifier with a non-parametric classifier, kNN (k-Nearest Neighbours), to generate the binary mask for snow presence or absence. The ultimate goal is to create a high temporal resolution, open-access, snow cover database for the Central Pyrenees, imputing data gaps caused by clouds or sensor errors using different satellites, climate data such as temperature, precipitation[4] or solar radiation[5], alongside in situ observations (e.g., snow poles, automatic snow gauges) and real-time imagery or orthophotos. This database will be a valuable resource for studying snow persistence and its impact on hydrology and ecosystem functions in the Pyrenees.

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The downstream geochemical imprint of Chilean glaciers

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Abstract:

Glaciers cover ~10% of the Earth's land surface, but they are shrinking rapidly, leading to cascading impacts on downstream systems. While decades of research have explored how different land-water interfaces regulate the mobilization and processing of major biogeochemical elements (e.g., carbon and nutrients) into freshwater ecosystems, efforts to assess the role that glacier-stream boundaries play in the biogeochemical balance of mountain landscapes remain rare. Glaciers differ from other landscape units (e.g., soils) in that they store (and thus export) considerably less organic matter for decomposition and carbon dioxide (CO_2) production, but transport large quantities of freshly exposed sediments available for weathering reactions consuming atmospheric CO_2. To examine whether glaciers impart unique footprints on the sources and transport of C in glacierized landscapes, we in-situ measured dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC) concentrations, DIC isotopic composition, net gaseous emissions of CO_2, and concentration of major weathering products (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, and DSi) along a longitudinal transect spanning 15 glacier-fed rivers in the Chilean Andes during the 2022 ablation season. We found that most of the studied glacier-fed rivers will act as CO_2 sinks due to the overwhelming influence of weathering reactions. Yet we also expect that both the magnitude response direction (source to sink of CO_2), and its fate (downstream persistence) will depend on both local biophysical and broader landscape factors. Given that climate change is hitting high mountains more brutally than the world on average, capturing the forms and fates of C exported from glaciers is fundamental to pinpoint the future of those vulnerable landscapes in the global carbon cycle.

Keywords: glacier-fed streams, climate change, biogeochemical cycles

POSTER SESSIONS

New georreferenced avalanche accidents database of Andorra

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Abstract. Although avalanches have long been a natural hazard in Andorra, the first fatality officially recorded by rescue services occurred in the winter of 1964. Since then, avalanches have claimed the lives of 21 people and injured at least 35 others. Andorra Research + Innovation has compiled records of avalanche accidents in the country from 1964 to the present, drawing on diverse sources such as newspapers, reports from Andorran fire and police mountain rescue teams, and, more recently, user-generated content shared on social media. As a result, the dataset is highly heterogeneous.

This work presents the first comprehensive geo-referenced database of avalanche accidents and incidents in Andorra, covering a total of 108 documented incidents. While this is a relatively low number of cases for statistical analysis, the spatial dimension of the data allows for novel insights into terrain characteristics and accident patterns that had not been considered in previous studies. However, the dataset has several limitations, including underreporting of non-severe accidents and a lack of detail for older incidents. These biases must be considered when interpreting the results.

Future work will aim to explore relationships between avalanche size, hazard level, and meteorological conditions. Additional efforts are also underway to analyze the specific causes of death in fatal incidents. In the long term, there are plans to integrate the Andorran database with the avalanche accident database from the neighboring Catalan Pyrenees. A combined dataset will offer a broader perspective on avalanche accidents in the eastern Pyrenees and contribute to more effective prevention and awareness strategies.

Keywords: Avalanche accidents, avalanche database, Pyrenees.

Permafrost-Related Landforms in the Boí Valley, Central Pyrenees: Distribution, Morphometry, and Climatic Implications

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Abstract: Rock glaciers and protalus lobes are key geomorphological indicators of permafrost conditions in the Pyrenees. Their spatial distribution and chronostratigraphic positions within valley systems provide valuable insights into the climatic and environmental conditions that promoted their development.

This study investigates the occurrence and spatial configuration of permafrost-related landforms in the Boí Valley, Central Pyrenees. The valley, shaped by past glacial activity, exhibits a classic U-shaped profile and spans from approximately 850 to 3000 m. We generate a detailed geomorphological map at a scale of 1:150.000 m, covering an area of 250 km² and including the headwaters and drainage basins of the Noguera de Tor River and its three main tributary valleys: Sant Nicolau, Sant Martí, and Durro. It provides a robust framework for analyzing the distribution and morphological characteristics of permafrost-related landforms across the valley.

A total of 134 permafrost-related landforms were identified in the Boí Valley, with 61 rock glaciers and 71 protalus lobes. Most of these features —93% and 81%, respectively— are located within glacial cirques, with fewer found along the slopes of formerly glaciated valleys. Both landform types are predominantly oriented towards the NW, N and NE, indicating favorable local topographic and microclimatic conditions for permafrost occurrence. Approximately 70% of the rock glaciers are situated between 2300 and 2600 m, with only four entirely located above 2600 m. The lowest rock glacier has its front at 1960 m, which likely represents the minimum elevation at which permafrost conditions existed during their formation. Protalus lobes are mostly found between 2300 and 2700 m (76%), with the lowest at 2010 m and only six occurring above 2700 m, and the highest with its front at 2865 m. Several rock glaciers and protalus lobes located below 2300–2400 m exhibit clear signs of inactivity, including surface vegetation, smooth frontal and lateral slopes, and poorly defined ridges and furrows. In contrast, many landforms situated above this elevation appear to remain active, characterized by steep, fresh slopes, well-defined frontal ridges, and an absence of vegetation, which may indicate the persistence of permafrost conditions in the higher-altitude zones of the Boí Valley.

Keywords: Central Pyrenees; Permafrost; Rock glaciers; Protalus lobes.

Evolução do *permafrost* ao longo de um perfil de resistividade elétrica junto à Estação Antárctica Coreana King Sejong

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Abstract. No âmbito do projeto HYDROPERMA-3 e do Programa Polar Coreano do Instituto Polar Coreano (KOPRI), em janeiro de 2024 iniciou-se um estudo geoelétrico junto da Estação Antárctica Coreana King Sejong com o objetivo de delinear a estrutura geoelétrica do sítio POND que se situa a cerca de 300 metros a sudeste da estação. A Estação Antárctica Coreana King Sejong está localizada na Ilha Rei Jorge do arquipélago das ilhas Shetland do Sul. O principal objetivo do trabalho de prospeção geoelétrica foi o de tentar determinar a extensão lateral, a espessura e a profundidade do *permafrost* que se pensa existir no sítio POND. O sítio POND é uma área de 15 metros por 15 metros com diferentes tipos de vegetação, a saber, musgos e líquens; assim, como segundo objetivo pretendeu-se verificar se existe alguma correlação entre a existência de *permafrost* e a distribuição dos musgos e líquens na zona. À superfície da zona onde o estudo geoelétrico foi realizado existem essencialmente areias e areias silto-argilosas. O substrato é composto por andesitos e andesitos basálticos.
Um dos 17 perfis tomográficos de resistividade elétrica que já tinha sido realizado em 2017 foi realizado, de novo, em 2024; os valores da resistividade elétrica aparente foram obtidos com o mesmo equipamento e com a mesma configuração de elétrodos; i.e., para cada perfil foi utilizada uma configuração tipo Wenner com 40 elétrodos com uma distância entre elétrodos consecutivos de 0,5 m; para medir a resistência elétrica das formações geológicas foi utilizado um resistivímetro Lippmann 10W. Os valores da resistividade elétrica aparente foram convertidos em modelos bidimensionais de resistividade elétrica do solo (secções geoelétricas), por inversão matemática, através do *software EarthImager*. Esses modelos representam secções de resistividade elétrica real com comprimentos de 19 metros e profundidades de cerca de 3 metros. Os modelos indicam que o *permafrost* tem uma distribuição irregular, mas contínua ao longo dos dois perfis de resistividade elétrica. Verifica-se que as zonas onde a vegetação é menos abundante, ou mesmo inexistente, apresentam *permafrost* menos espesso. Por outro lado, entre 2017 e 2024 é possível verificar, ainda, uma degradação do *permafrost* através de uma diminuição da sua espessura.

Keywords: Tomografias de resistividade elétrica; *Permafrost*; Estação Antárctica Coreana.

Estudo do *permafrost* no sítio KGL junto à Estação Antárctica Coreana King Sejong, Antártida Marítima

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Abstract. No âmbito do projeto HYDROTOMO iniciou-se uma campanha de prospeção geoelétrica em janeiro de 2018 na Estação Antártica Coreana King Sejong com o objetivo de estudar a possível influência do *permafrost* e da camada ativa na evolução de musgos e líquenes. A área do estudo geofísico está localizada na Península de Barton, na Ilha Rei George na Antártida Marítima, e tem uma forma retangular com 40 m de comprimento por 6 m de largura.
Todos os perfis de tomografia de resistividade elétrica foram orientados de acordo com o lado maior do retângulo mencionado; por outro lado, com o objetivo de detetar possíveis variações temporais na espessura do *permafrost* e da camada ativa, duas vezes por semana, durante três semanas consecutivas, três perfis tomográficos paralelos foram realizados com 3 metros de distância. Cada perfil tinha 40 elétrodos ativos (ou seja, controlados por computador) com 1 metro de distancia entre elétrodos consecutivos, usando uma configuração Wenner; cada perfil tomográfico tinha um comprimento de 39 m. O equipamento utilizado é da marca Lippmann LG High Power.
Os dados de resistividade elétrica aparente obtidos foram processados utilizando o *software EarthImager*, obtendo-se, assim, perfis de resistividade elétrica real (modelos de resistividade elétrica real a duas dimensões) ao longo da área de estudo e ao longo do tempo. A campanha de prospeção geoelétrica permitiu detetar o *permafrost*, a camada ativa e áreas com maior quantidade de água subterrânea. O topo do *permafrost* foi confirmado através de pequenas escavações.
Os modelos geoelétricos obtidos indicam que, para aquela área, existe uma correlação entre a distribuição de áreas de alta resistividade elétrica e a ausência de musgos e vice-versa. Por outro lado, parece claro que, durante o período em que as tomografias de resistividade elétrica foram repetidas (cerca de três semanas) nenhuma mudança significativa na geometria da camada ativa e do *permafrost* foi detetada.

Keywords: Tomografia de resistividade eléctrica; *Permafrost*; Estação Antárctica King Sejong.

Radiación global potencial y temperatura superficial distribuidas durante el periodo de descongelación en la península Hurd, Isla Livingston, Antártida.

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At the monitoring stations of the PERMATHERMAL network on Livingston Island (Antarctica), surface ground temperature is recorded hourly at 2 cm depth to assess the thermal evolution of seasonally and perennially frozen soils, as well as the presence and influence of snow cover during the freezing period. However, in an environment lacking vegetation and soil development, we ask: What role does daily potential global solar radiation play in the ground temperatures recorded during the thawing period? What differences are observed between the various stations? Does their location influence the potential amount of radiation they receive? What is the effect of local shading? Do the stations evolve synchronously throughout the thawing period?

To address these questions, this study analyzes the daily evolution of ground temperatures (maximum, mean, minimum, and range) and the thawing degree days index (TDD) at six stations of the network, located in different settings with varying substrates and altitudes, during the thawing period from December 2023 to March 2024. In parallel, daily potential global radiation is evaluated with hourly resolution, considering the effect of local shading for every day of the study period.

For this purpose, we used a Geographic Information System (QGIS software with the GRASS tools r.sun.insoltime and r.sun.incidout included) and a Digital Elevation Model (DEM) derived from a drone flight conducted in 2020, resampled to 20 cm/pixel resolution (Fig. 1), from which slope and aspect models were generated. This allows us to investigate, on one hand, the hourly evolution of ground temperatures and their relationship with hourly global radiation and modeled illumination hours at each station. On the other hand, we correlate daily temperature statistics with daily potential global radiation to assess the influence of non-radiative factors on ground thermal behavior. Preliminary results are presented and discussed.

Keywords: Radiation; Ground surface temperature; Thaw period; Antarctica.

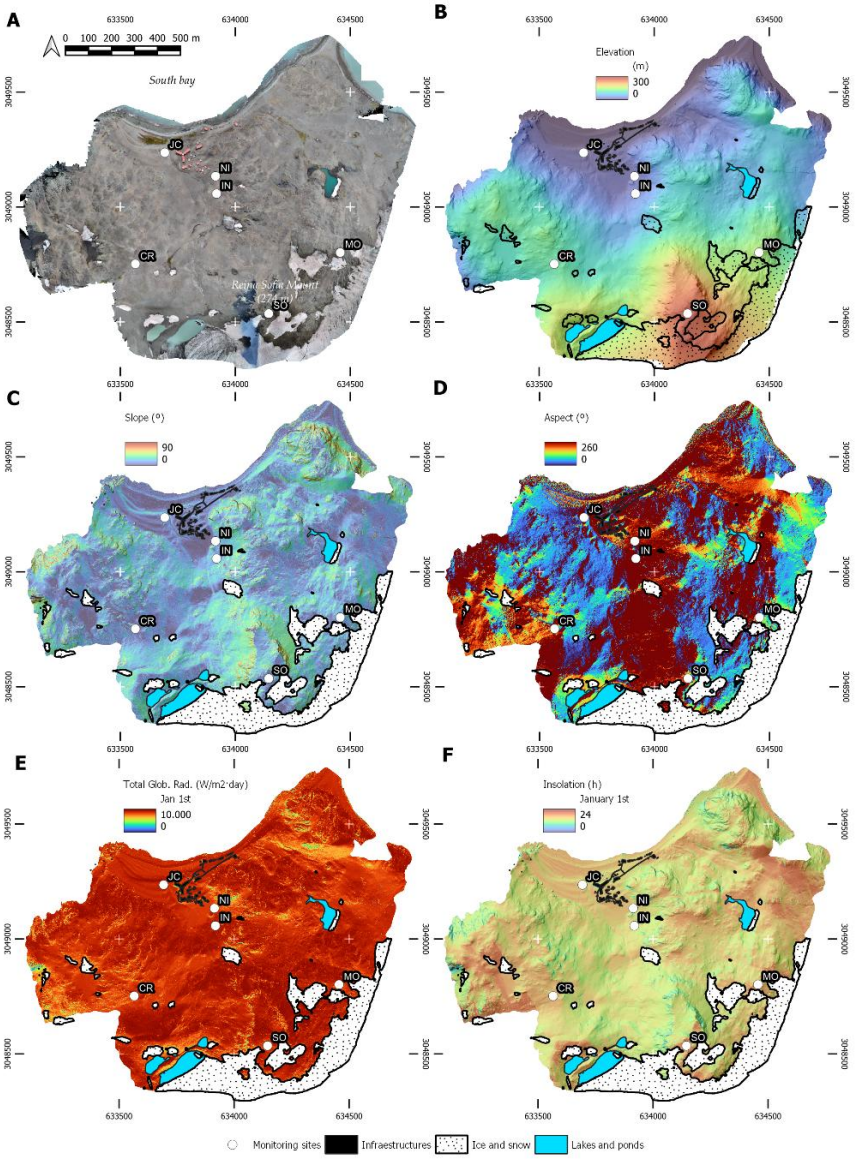

Fig.1: (A) UAV-derived orthoimage of the study area in Hurd peninsula, Livingston Island, Antarctica and (B) resulting DEM, used to calculate slopes (C) and aspect (D) maps, necessary on the calculation of the daily total global potential radiation (E) and total daily insolation hours (F) modeled for January 1st including the effect of the local shadows, in W/m^2 (right).

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Recent detection of permafrost in the highest lands of the Pica d'Estats massif (Lleida, Spain)

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Abstract. This study presents the preliminary results of the field campaigns carried out in autumn 2022 and 2024 to detect and monitor the thermal state of permafrost on the rock glacier of Broate cirque, situated at the foot of Pic de Sotllo in the Central Southern Pyrenees (Lleida, Spain). During the October 2022 field campaign, four HOBO loggers were installed at 5, 15, 35, and 75 cm depths on the upper debris lobe. Ground surface temperatures at depth suggest the existence of a frozen layer consistent with permafrost occurrence, as further supported by Magnetic Resonance Sounding (MRS) data collected during the October 2024 campaign. Ground temperature remained negative from November to May, and it stabilized at ca.-4ºC during the winter season, indicating the presence of a frozen mass body within the rock glacier. MRS data confirm the presence of a frozen body at depths of 3 to 7 m, with liquid water flux above and below this layer. Based on these results, and within the framework of the PERMAPYRENEES project—in collaboration with various institutions and international initiatives—a 15-meter-deep borehole will be drilled in summer 2025 to enable continuous monitoring of the state and evolution of permafrost in the highest massif of the Catalan Pyrenees.

Acknowledgements. We are grateful for the support of the CRIOPIRINEUS project Alt Pirineu Natural Park, Government of Catalonia) and the PERMAPYRENEES project (Interreg Poctefa EFA063/01). We also received additional support from the ANTALP research group (Antarctic, Arctic, Alpine Environments; 2021-SGR-00269), which is funded by the AGAUR - Generalitat de Catalunya.

Keywords: Pyrenean permafrost; rock glacier; temperature monitoring; MRS.

What two years of A-ERT monitoring reveal about permafrost on James Ross Island

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Abstract:
This study investigates the relationship between ground electrical resistivity, temperature, and water content in a permafrost environment on James Ross Island, in the northeastern Antarctic Peninsula. The area features continuous permafrost and a semi-arid polar continental climate, with a mean annual air temperature of approximately -7 °C. An automated electrical resistivity tomography (A-ERT) system using a 4POINTLIGHT_10W (Lippmann) device was installed near the Czech Antarctic Station Johann Gregor Mendel in February 2023. The setup measures daily ground resistivity along a 23-meter transect with 47 electrodes spaced 0.5 m apart. The profile spans two distinct lithologies – a Holocene marine terrace and finer-grained Cretaceous sediments – and reaches depths down to approximately 4.5 m below the ground surface in the middle of the profile.
Complementary temperature sensors (at depths of 5, 10, 20, 30, 50, 75, 100, 150, and 200 cm) and soil moisture sensors (at depths of 5, 35, 55, and 75 cm) provide additional data along the transect. With nearly two full years of observations now available, we compare seasonal and interannual patterns in thermal, moisture, and resistivity dynamics in the active layer and shallow permafrost. Resistivity values remain high during winter (typically 1–2 kΩm) and drop sharply during the thawing period (10–100 Ωm), with the thaw front visibly progressing in the resistivity profiles (Fig 1).
Differences between the 2023 and 2024 thawing seasons suggest sensitivity to interannual climatic variability, including changes in snow cover and melt timing. Furthermore, variations between the two lithologies emphasize the importance of substrate type in controlling ground thermal and hydrological regimes. A-ERT has proven to be a rugged and reliable method for long-term permafrost monitoring under the harsh conditions of Antarctica, providing continuous, spatially extensive data that enhance and complement traditional borehole-based measurements.

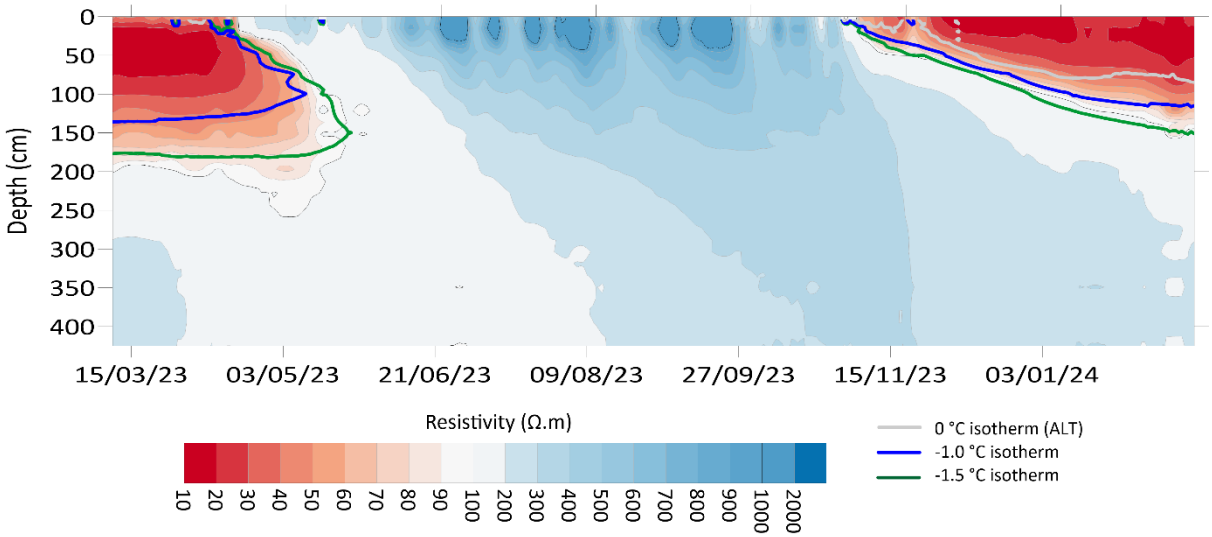

Fig 1. Seasonal variability of specific resistivity within the virtual borehole located approx. in the middle of the A-ERT profile

Keywords: electrical resistivity tomography; Antarctica; permafrost monitoring; soil moisture

Estudio geoeléctrico comparativo 2018-2024 alrededor de la Estación Antártica Machu Picchu, Isla Rey Jorge, Antártida Marítima

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Abstract. En el marco del proyecto HYDROTOMO, el Programa Polar Peruano, el Programa Polar Portugués y el Programa Polar Uruguayo; iniciaron en enero de 2018 un estudio geoeléctrico en la Estación Científica Antártica Peruana Machu Picchu, Bahía del Almirantazgo, Isla Rey Jorge (Islas Shetland del Sur). El objetivo principal fue intentar determinar la extensión lateral, el espesor y la profundidad del acuífero que abastece de agua a la estación, para que se puedan implementar las acciones más adecuadas para su explotación, gestión y prevención. Además, dado que el acuífero está cerca del mar, el trabajo también intenta localizar zonas de posible intrusión salina. Por lo tanto, el trabajo proporcionará información útil al Programa Polar Peruano que busca transformar su estación antártica en una estación permanente ya que actualmente es temporal.
El área donde se realizó el estudio geoeléctrico tiene una superficie de aproximadamente 90.000 m^2 y, en la superficie, se encuentran depósitos glaciales, glacio-aluviales, aluviales, aluviales-fluviales, lagunares y marinos (principalmente gravas arenosas y gravas areno-limosas). Sobre el acuífero se realizaron 17 perfiles de tomografía de resistividad eléctrica (ERT) con longitudes que iban desde 100 a 400 metros, con separación de 5 y 10 m entre electrodos. También se obtuvo información hidrogeológica a través de piezómetros superficiales ubicados dentro del área donde se realizaron los perfiles ERT. En 2024, en el marco del proyecto HYDROPERMA-4, se realizaron nuevamente dos líneas de ERT que muestran, en un caso, que el suelo congelado ha disminuido y en otro caso, el nivel freático del acuífero no cambió de manera apreciable.

Keywords: Tomografías de resistividad eléctrica; Suelo congelado; Acuífero; Estación Antártica Machu Picchu.

Periglacial landforms on the Central Western coast of Greenland (69-71ºN)

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Abstract. The study area focuses on the coast of central-west Greenland, to the west of the Greenland ice sheet, between 69ºN and 71ºN. The study was carried out around the Quingaussarsuaq and Nuussuaq peninsulas.

The research area is mostly formed of metamorphic rocks of the Paleozoic age. Both peninsulas were entirely shaped by glaciers during the Late Pleistocene, which receded and exposed the current ice-free environment during the Late Glacial and Late Holocene. The glacier forelands include several moraine complexes and proglacial environments that are being reworked by periglacial dynamics. The entire study area is underlain by continuous permafrost that is of moderate active layer thicknesses, with measurements ranging 20-40 cm thick.

The aim of this communication is to present the spatial distribution of periglacial landforms and their relationship with processes that have occurred in continuous permafrost environments of Greenlandic ice-free areas.

We used geomorphological mapping as the first approach to the analysis of landforms, processes and landscape evolution. Geomorphological mapping was based on in situ mapping during the fieldwork carried out in the summers of 2022 and 2023 combined with satellite image interpretation, and maps were produced following the geomorphological classification of the French and IGUL systems. Both maps include more than fifteen periglacial landforms. Geomorphological mapping allows the identification of major morphogenetic units, develops understanding of the spatial relations between periglacial processes, landforms, and establishes a relative chronological sequence.

Periglacial processes are very intense and have reshaped all previous landforms such as moraines, disperse till, exposed bedrock, glacial valleys, slopes and lacustrine or fluvioglacial deposits. The last major deglaciation phase must have been contemporaneous with the development of the largest periglacial phenomena, mainly on the south-facing slopes where rock glaciers and protalus lobes have developed. The landforms have been grouped in four main physiographic units: High plateaus, Mountain slopes, Glacial valley floor and Recent moraine complexes (Fig. 1).

Physiographic units	Inventoried Landforms	Main processes
High plateaus	Block fields	Frost heave Ground freezing and thawing
	Patterned grounds	Frost heave Cryoturbation Thermal contraction cracking
	Block streams	Solifluction
	Debris slopes	Ground freezing and thawing Rock weathering
	Nivation niches Nival accumulations	Nivation
Mountain slopes	Rock glacier Protalus lobe Stone-banked lobes Turf-banked lobes Stone stripes	Solifluction Cryoturbation Permafrost creep
	Block slopes Debris slopes (talus and cones)	Frost heave Thermal contraction cracking Rock weathering
	Nivation niches Nival accumulations	Nivation
Glacial valley floors	Patterned ground Ice-wedge polygons Earth hummocks	Frost heave Thermal contraction cracking Cryoturbation
	Flat bottom valleys	River runoff
Recent moraine complexes	Frost mounds Sorted circles	Frost heave Cryoturbation
	Solifluction lobes	Solifluction
	Sand dunes	Aeolian activity

Fig 1. Physiographic units, periglacial landforms and processes in the studied area.

Acknowledgements. We are grateful for the support provided by the project NEOGREEN - Reconstruction of Neoglacial oscillations in Greenland. Ministerio de Economía y Competitividad, Spain, PID2020-113798GB-C31; ant the research groups ANTALP (Antarctic, Arctic, Alpine Environments; 2017-SGR-1102) and GIR Pangea-UVa.

Keywords: Periglacial, Polar environments, geomorphology, Greenland.

Debris cone dynamic. La Vueltona (Picos de Europa): 2009-2024

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Abstract. Taluses and debris cones are one of the quickest mechanisms of sediment transference in temperate highlands. The materials originate from walls due to weathering and channels and the processes involved are highly varied. While rockfalls, snow avalanches and debris flows are the primary processes in the debris dynamic, surface processes such creep, rolling, solifluction, physical and chemical weathering, and surface runoff are also present. The dynamics of debris cones and active taluses are currently interpreted in the context of paraglacial settings that support rockfalls, mass displacements, and debris talus changes. The processes involved are nivation, debris flows, solifluction, or gelifluction, plant colonization, trampling by animals, and anthropogenic intervention, such as paths and infrastructure, which all contribute alterations with high spatial and temporal variability.
The study area is the central massif of the Picos de Europa, a massif characterized by an oceanic climate with intense snowfall and precipitation, which surpasses 2500 $mm \cdot y^{-1}$ at the summits. The relief of the Picos de Europa is characterized by its geological structure, karst and glacial morphogenic systems. The high mountain environment is today dominated by nival and periglacial processes.
The aim of this study is the analysis of the dynamic of two debris cones. Terrestrial Laser Scanning (TLS) technology was used for their continuous assessment every August over a period of 16 years (2009–2024).
TLS has shown a high level of efficiency in accurately tracking short- and medium-term trends in surface movement, as well as yearly surface changes. Data on yearly topographic changes and the movement of sediments from the walls to the cones in a cascade sediment system were obtained during independent TLS data collection from two debris cones in the temperate high mountain (Picos de Europa, Spain). This study's TLS accuracy was ±2 cm for every measurement site. In the DEMs, scanning the same cone twice on the same day resulted in generation discrepancies of less than 10 cm. Only a few isolated instances showed variances of 15 cm or less, which corresponded to the size of the clasts. The variances between the two DEMs created on the same day were more than 15 cm and nearly 1 m.
The debris cone shows a changing profile with undulating flow in the distal portion, dominated by slide, flow and mass wasting. the dominant processes in the middle and upper portions are the solifluction, creeping and rolling. The profile is stable indicating the permanence of the spatial organization of processes over fourteen years of geomatic monitoring.

Key Words: Picos de Europa, debris cones, Geomorphology, geomatic applications.

Snow cover evolution at Livingston and Deception Islands, Antarctica, in 2006-2023 period, as measured with snow poles

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The thermal regime of seasonally and permanently frozen soils is influenced, among other factors, by the presence of snow, which insulates and regulates heat transfer to substrate1. Therefore, the onset and melting dates, duration of the snow season, and snowpack properties such as thickness, density, and water and ice content are key factors for characterizing the snow cover and quantifying its influence on soil thermal dynamics[1]. The PERMATHERMAL monitoring stations located on Livingston and Deception Islands (Antarctica)[2] have been equipped, between 2006 and 2023, with miniature temperature loggers to estimate snow presence and thickness using temperature data recorded at various heights above the ground (snow poles)[3].
This contribution describes the calculations performed and the monitoring results from 12 stations distributed across these Antarctic islands, based on a recently proposed method involving the moving average of thermal variability[4]. This approach helps filter out short-term fluctuations in temperature readings, improving the reliability of snow presence detection. Additionally, to better characterize the snow cover, the following parameters were derived from the results: the start (snow onset) and end (snow offset) dates of snow accumulation (from which snow season duration was calculated), maximum snow thickness, and the Snow Index computed as the cumulative sum of daily mean thicknesses. In this way, this study reanalyzes, completes, and finalizes previous assessments of snow thickness[5,6] using the standardized measurement technique[3]. However, inherent uncertainties in snow depth estimation arise due to factors such as precision, or snow melting around the snow pole, which should be considered when interpreting results. Although the time series are not complete at every station, and despite the known limitations of the method, temporal variability was observed at individual stations (Fig. 1), along with altitude and spatial heterogeneity within the local geomorphology—both across different islands and among nearby stations located in proximity, such as those on Deception Island, all situated within 200 meters of one another in a homogeneous terrain.

Keywords: Snow; Monitoring; Active layer; Antarctica.

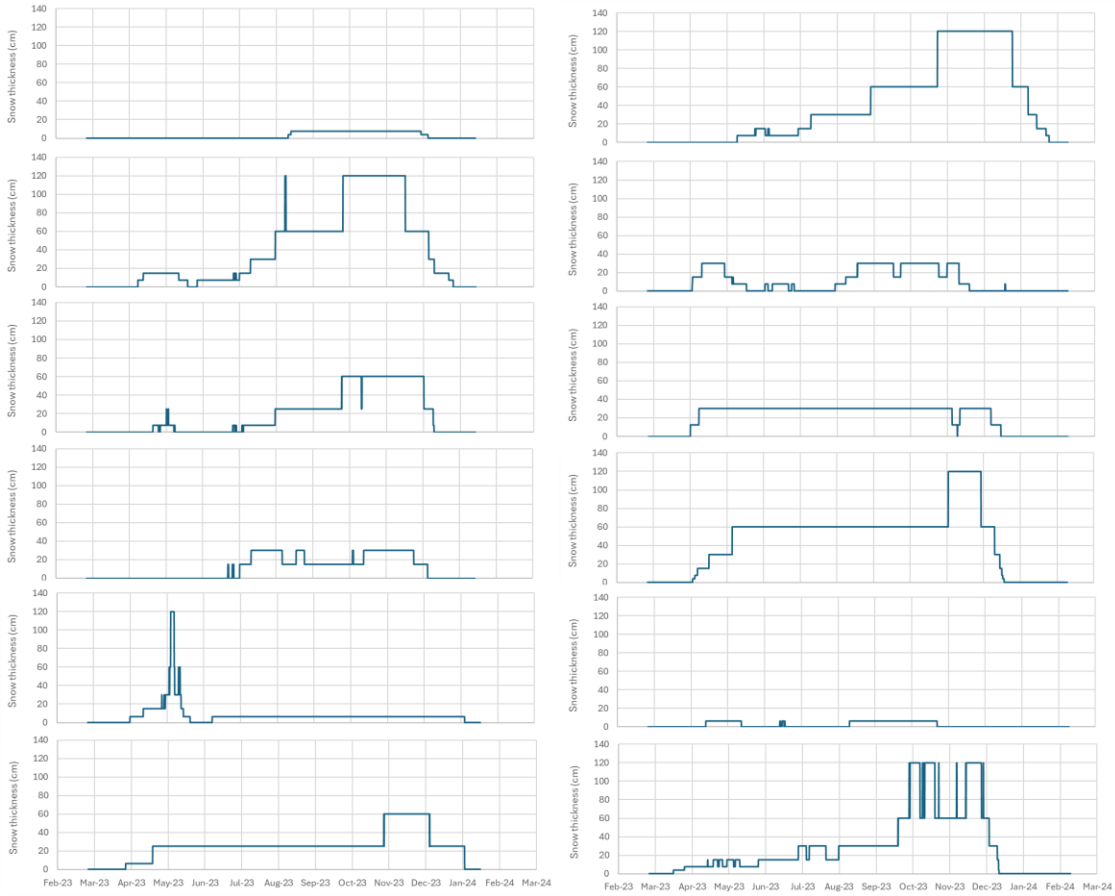

Fig. 1: Example of the snow cover depth evolution in 2023 at 12 monitoring stations of the PERMATHERMAL network in Livingston and Deception Islands.

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Combining Schmidt-hammer, Lichenometry and Cosmogenic Radiation Exposure Methods to understand cirque deglaciation processes in Tröllaskagi (Northern Iceland)

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Abstract.

This study investigates the Lambárdalur, Fremri-Grasárdalur and Nautárdalur glacial cirques in Tröllaskagi (Iceland), focusing on the diversity of landforms and the application of three dating methods: Cosmogenic Radiation Exposure (CRE) ages, Lichenometry and Schmidt Hammer (SHD) rebound values (R-values). The study area includes a range of glacial and periglacial features, such as debris-free glaciers, debris-covered glaciers, rock glaciers, and ice-cored moraines, all of them composed of Tertiary basalt boulders. These landforms reflect the complex glacial dynamics and topographic variation within the cirques.

The primary aim of this research is to assess the correlation between the ages obtained through CRE and Lichenometry and the SHD R-values across different glacial and periglacial environments. Results indicate a strong correlation, with a notable trend: as CRE and Lichen ages increase, the Schmidt Hammer R-values tend to decrease (Fig. 1). This relationship suggests that SH R-values may be a reliable proxy for dating in glacial cirques of northern Iceland, particularly when combined with other techniques.

The chronology of deglaciation in the studied areas reveals significant changes during the Holocene. Deglaciation is generally observed to have occurred 9-10 ka BP, marking the end of the last glacial maximum. However, during the Neoglacial period, glaciers advanced again, as evidenced by the geomorphic features present in the cirques. The types of landforms formed vary significantly depending on the topography of each cirque, underscoring the influence of local conditions on glacial morphology.

In terms of R-values, the highest mean R-values are ~70-72, indicative of the most recent exposed surfaces due to present-day glacial retreat. In contrast, areas deglaciated in the early Holocene showed R-values of 52-54, indicating longer exposure to weathering processes. The external ridges of ice-cored moraines and debris-covered glaciers are related to glacial advances 2 to 4 ka, with R-values between 57 and 64. Values between 65 and 68 are usually associated with LIA landforms. These findings highlight the potential of combining CRE, Lichenometry and Schmidt Hammer methods for a comprehensive understanding of glacial and periglacial geomorphology and landscape evolution.

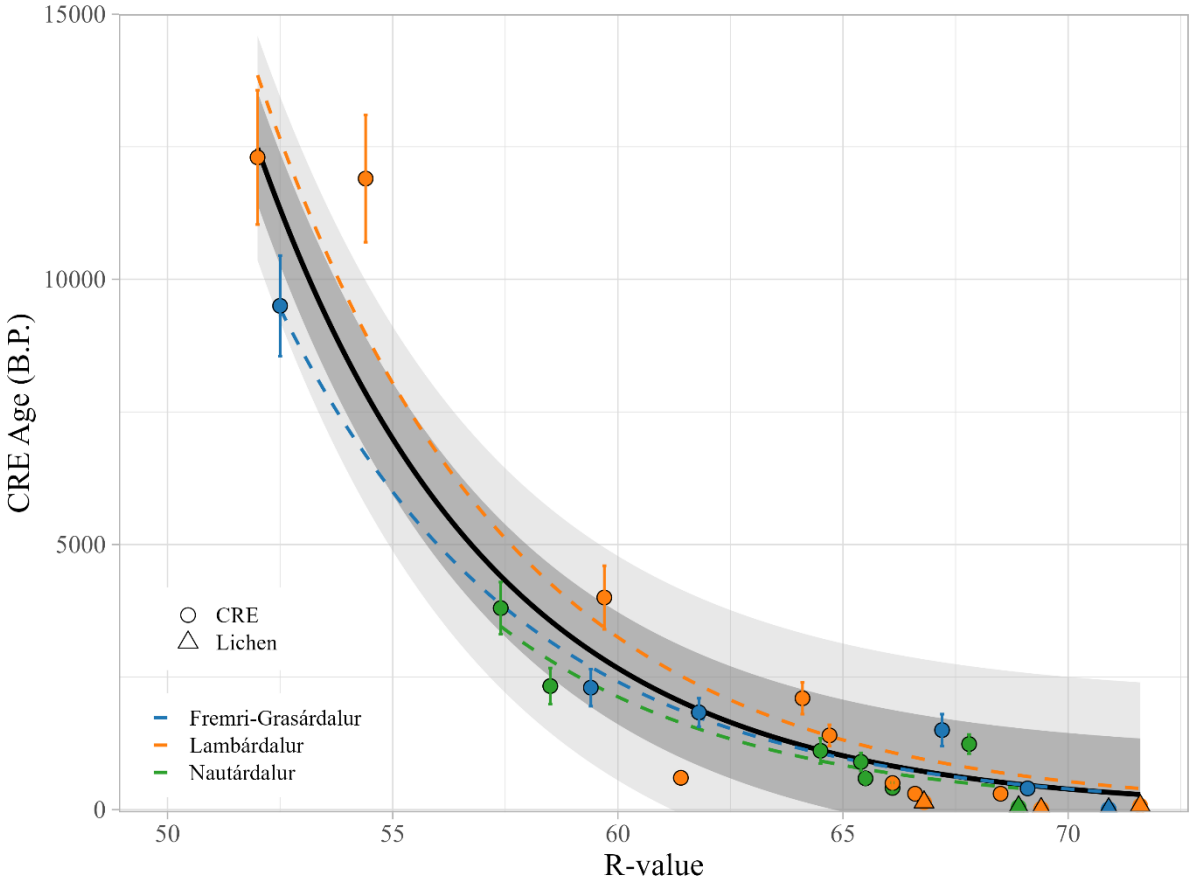

Fig 1. Correlation between CRE ages and SHD R-values for several samples in Fremri-Grasárdalur, Lambárdalur and Nautárdalur cirques.

Keywords: Schmidt-hammer; Cosmogenic Radionuclide; Deglaciation; Glacial geomorphology;

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A methodology for mapping complex landforms derived from the interplay of rock avalanches, slides and glacial processes in Jökuldalur (northeastern Iceland).

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Abstract. Jökuldalur Valley is situated within the Dyrfjöll Mountains, located in the northeast corner of Iceland. The valley originates just below the Dyr Pass (856 m; 65°30'44.70'' N, 13°56'45.85" W), on the eastern slope of the range, nestled between its two highest peaks: Súla (1,136 m) to the north and Stöpull (1,074 m) to the south. The valley flows into Jökuldalur Valley, which ultimately drains into Borgarfjörður near the village of Bakkagerði. The Dyrfjöll Mountains are composed primarily of Tertiary basalt lavas and pyroclastic materials. However, at the Dyr Pass itself, the rock consists of a distinct tephra layer composed of strongly consolidated, black-colored pyroclastic fragments—commonly referred to as black tephra (BT). Jökuldalur Valley displays significant geomorphological complexity. Just below the Dyr Pass is a 200-m-high wall of BT, beneath which lie two small glaciers, each approximately 0.6 km in length. One of these glaciers is currently transitioning into a debris-covered glacier. In front of the glaciers, six series of push moraines are arranged along the central axis of the valley. The four outermost moraines are hummocky in nature, characterized by irregular ridges interspersed with numerous closed depressions. Below the moraine field, at the valley's outlet, lies a large rock avalanche deposit composed of BT macro-blocks—clear evidence of its origin from the Dyr Pass. The avalanche deposit exhibits a distinctive morphology of alternating mounds and enclosed depressions. Additionally, the valley slopes feature several landslides of varying magnitude and zones affected by active solifluction processes.

The objective of this study is to present an accurate map of the complex geomorphology of Jökuldalur Valley. The mapping process combined detailed fieldwork (conducted in August 2023) with photointerpretation of aerial photographs (from August 14, 2003), using a mirror stereoscope. The boundaries of all identified landforms were delineated and drawn on an orthophoto dated July 23, 2017. These features were then digitized and symbolized within a GIS environment (Esri ArcGIS). The final mapping design followed standards established in previous studies [1,2,3]. Furthermore, a 3-m resolution Digital Elevation Model (DEM) was used as the base layer, enhancing the clarity and differentiation of the mapped landforms.

Keywords: Geomorphological mapping, Iceland; rock avalanche; hummocky moraine.

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The scope of glacial advances from the Younger Dryas to the Little Ice Age in the interior of the Tröllaskagi Mountains, northern Iceland

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Abstract.
In this work, we have analyzed the geomorphological setting of three valleys at the Tröllaskagi peninsula, namely: Vatnsdalur; Búferllsdadur and Teigardalur, tributaries of the main valley of Svarfaðardalur, which flows into the Eyjafjörður, near Akureyri. We aim to demonstrate the existence of alpine glaciers in the Tröllaskagi Mountains during the Younger Dryas, previously unknown, and analyses the subsequent evolution up to the present day. A multidisciplinary approach has been used, combining geomorphological mapping, glacial extent mapping over multitemporal imagery (dates 1946, 2000, 2012, 1994, 2019, and 2021), and different absolute/relative dating techniques such as lichenometry (based on *Rhizocarpon geographicum* thalli), Schmidt Hammer (SHD); and cosmic-ray exposure (CRE; 23 ^{36}Cl samples). The results complement the latest available knowledge on the glacial evolution at the Tröllaskagi cirques and the magnitude of the different events. In fact, these small cirques behaved synchronously with the Icelandic Ice Sheet and later central ice caps[1], despite their small size.
CRE and SHD results show that the outermost moraines at Vatnsdalur and Teigardalur cirques were built during the YD, with ages clustered at ~12.9 ka. In both cirques, Preboreal moraines have been found, with ages ranging from 11 to 9 ka, which inform on a lower magnitude event compared to the YD; however, Preboreal glaciers exceeded those limits at some locations. There is no available record of glacial advances between 9 and 5 ka, when glaciers likely disappeared. From 4.2 ka onwards, neoglacial moraines were built in Vatnsdalur and Teigardalur; these formations evidence different magnitude of the glacial advances even within the same cirque. These advances had a slightly lower entity than the Preboreal ones; however, at some locations they are superimposed to its moraines. The most extensive neoglacial advance dates back to 2-1.1 ka. The Little Ice Age (LIA) was the last of the neoglacial advances and always had a more limited scope compared to previous ones. The CRE ages place the LIA maximum at ~14th century. In the Vatnsdalur cirque, some neoglacial moraines evolved to rock glaciers (moraine-derived rock glaciers). In the case of Búferllsdadur, after one of the neoglacial advances, a surge must have taken place, which is usual in these cirques[2]. From this glacial surge, a debris-covered glacier was formed, which overran and deleted the older landforms originated during previous advances. Something similar must have occurred in debris-covered glacier of the central sector of the Vatnsdalur cirque, but to a lesser extent within this large cirque. According to lichenometric data, these glaciers retreated significantly since the end of

the LIA, except for the limited advance of 1970s-1990s cooling period, and some sporadic surges, while the debris-covered glaciers and rock glaciers have remained much more static given their lower climate sensitivity. The results obtained in Vatnsdalur; Búferllsdadur and Teigardalur cirques show a great sensitivity to climate changes, but reinforce the need of considering the interplay of glacial advances and paraglacial processes that may lead to divergent evolution of landforms in a periglacial environment.

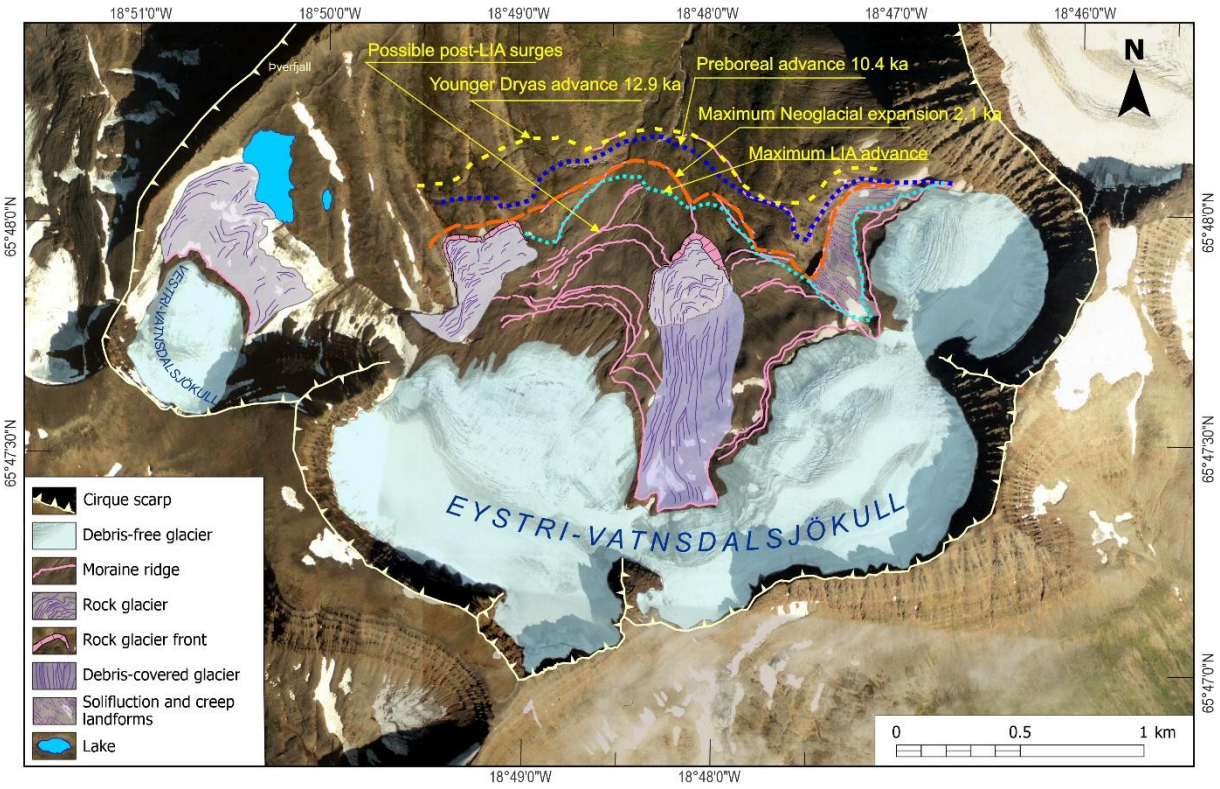

Fig 1. 2019 orthophoto of the Vatnsdalur glacial cirque, delineating the main geomorphological units, and the different phases of glacial expansion according to the CRE ages of 23 samples.

Acknowledgements. This research was framed within the NEOICE project: “Reconstruction of Neoglacial oscillations in Iceland”, ref. PID2020-113798GB-C32, funded by MCIN/AEI/10.13039/501100011033.

Keywords: Tröllaskagi Mountains; Iceland; Younger Dryas, Preboreal, rock glaciers

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Evaluation of the combined use of Sentinel-1 and ICESat-2 data for the detection of elevation changes in Arctic tundra (Tuktoyaktuk Peninsula, Canada)

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Abstract. Sea-level rise coupled with subsidence affects low-lying coastal areas, communities and infrastructures worldwide. In the Arctic, permafrost-thaw subsidence, coastal erosion, and rising sea levels are driving significant land loss rates. Shoreline change studies in the Tuktoyaktuk Peninsula have identified higher retreat rates in low-lying areas. This study utilises field and remote sensing methods to assess land subsidence and permafrost degradation in coastal Arctic tundra areas in the Tuktoyaktuk Peninsula. Sentinel-1 C-band SAR and ICESat-2 LIDAR data may offer advantages when combined. The higher temporal resolution of Sentinel-1 SAR imagery can align with the ultra-high vertical spatial resolution and accuracy of ICESat-2, making for a more robust detection of elevation changes. UAS surveys were conducted in 2023 and 2024 at target low-lying coastal sites along the Tuktoyaktuk Peninsula (Reindeer Point, Toker Point, Tuft Point, and Warren Point). The UAS optical surveys were utilised to derive very high-resolution digital surface models and quantify morphological changes. Sentinel-1-based SBAS D-InSAR analysis for the summers of 2019 to 2024 (from June 1st to October 31st) facilitated the assessment of surface deformations on regional and local scales. ICESat-2 data for the same timespan was extracted and processed. Integrating ICESat-2 crossover estimates of surface-height change validated the InSAR displacement metrics and provided an interannual perspective at selected locations. We analysed the spatial variability of elevation changes in selected locations. Preliminary findings suggest a tendency toward subsidence in several summers, with indications that shoreline retreat hotspots such as Tuktoyaktuk Island, Toker Point, and Warren Point may be particularly affected. Warren Point recorded the highest elevation differences among the UAS surveyed areas between 2023 and 2024, likely due to coastal inundation events that degraded the permafrost, causing thaw subsidence.

Keywords: Permafrost degradation; Thaw subsidence; UAV; Remote Sensing; InSAR.

Debris cone dynamic. La Vueltona (Picos de Europa): 2009-2024

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Abstract. Taluses and debris cones are one of the quickest mechanisms of sediment transference in temperate highlands. The materials originate from walls due to weathering and channels and the processes involved are highly varied. While rockfalls, snow avalanches and debris flows are the primary processes in the debris dynamic, surface processes such creep, rolling, solifluction, physical and chemical weathering, and surface runoff are also present. The dynamics of debris cones and active taluses are currently interpreted in the context of paraglacial settings that support rockfalls, mass displacements, and debris talus changes. The processes involved are nivation, debris flows, solifluction, or gelifluction, plant colonization, trampling by animals, and anthropogenic intervention, such as paths and infrastructure, which all contribute alterations with high spatial and temporal variability.
The study area is the central massif of the Picos de Europa, a massif characterized by an oceanic climate with intense snowfall and precipitation, which surpasses 2500 $mm \cdot y^{-1}$ at the summits. The relief of the Picos de Europa is characterized by its geological structure, karst and glacial morphogenic systems. The high mountain environment is today dominated by nival and periglacial processes.
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ISLANDSINTHEICE – Deglacial history and environmental consequences in west-central Greenland. Ministerio de Ciencia, Innovación y Universidades, Consolidación Investigadora 2023, CNS2023-144040. PI: Dr Marc Oliva. 2024-2026.