24nb4592

## Monitoring of the small ice patch Juvfonne, southern Norway

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In this talk I present measurements carried out since 2010 on Juvfonne, a small ice patch in southern Norway. Juvfonne has survived for over 7000 years and contains the oldest ice dated in Norway. Since 2010, however, the area has reduced by 40%. I compare the mass balance, front variation and area changes with results of neighbouring glaciers. I also compare the recent development of Juvfonne with the disentegrating and downwasting Breifonn glacier and several ice patches that are about to disappear in Norway.

24nb4593

## Glacier surges in Hornsund (Svalbard) in the late Little Ice Age

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Svalbard is a cluster of surge-type glaciers and the length of their surge cycles may exceed 150 years. Here, we present the evidence of the late Little Ice Age (LIA) surges of Hornsund glaciers, Hansbreen and Werenskioldbreen, based on geomorphological mapping and historical observations from the late 1800s and early 1900s. Their possible surge history has long been debated due to the lack of evidence of the active surge phase in regular observations. However, the landscape of their forefields reveals characteristic features of the surge-type glaciers, including crevasse-squeeze ridges, fluted moraine and large terminal moraine systems. In addition, in the submarine forefield of Hansbreen, we can observe a terminal moraine with a debris-flow lobe and streamlined lineations in the inner part of the fjord. These landforms are fingerprints of a surge event of Hansbreen captured in the photographs from the Austro-Hungarian North Pole Expedition in 1872. The photos documented a surge bulge, extensive crevassing, and the terminus position of the advancing glacier, which had not yet reached the LIA maximum. Photogrammetric photos from the Norwegian expedition in 1918 revealed the quiescent phase of Hansbreen and Werenskioldbreen and the latter must have surged sometime before 1918. The photos documented more evidence of the late LIA surges, including looped moraines and cross-cutting healed crevasses reaching high up the glaciers. Our study supports the idea that the maximal LIA extents of Svalbard glaciers reflected the combination of climatic conditions and internal glaciological factors. This work was funded by the National Science Centre of Poland (grant no. 2021/41/N/ST10/02070).

24nb4594

## Fog forcing of surface energy balance from measurements on Arctic glaciers

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Fog forcing of surface energy balance from measurements on Arctic glaciers

24nb4596

## Micro-meteorological impact of glacier retreat and proglacial lake temperature in western Norway

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Glaciers are retreating worldwide, yet, little is known about the influence of these changes on local weather and climate in glacial landscapes. Changes in glacier extent and proglacial lakes alter thermally forced wind systems and cold air pools in glacier-lake-valley systems that may be of similar or greater importance for future microclimate than direct effects of global warming. To study the impact of these changes, we combine the first set of high-density spatiotemporal observations of a glacier-lake-valley system at Nigardsbreen in western Norway with high-resolution numerical simulations. The sensitivity of meteorological conditions to the representation of glacier retreat and proglacial lakes is tested using glacier outlines from 2006 and 2019 as well as varying lake surface temperatures. The model represents the evolution of glacier flow and cold air pools well when thermal forcing dominates over large-scale forcing. During a persistent down-glacier flow regime, the glacier-valley circulation is sensitive to lake temperature and glacier extent, with strong impacts on wind speed, convection in the valley, and interaction with mountain waves. However, when the large-scale forcing dominates and the down-glacier flow is weak and shallower, impacts on atmospheric circulation are smaller, especially those related to lake temperature. This high sensitivity to meteorological conditions is related to whether the wind regime promotes thermal coupling between the glacier and the lake. The findings of this study highlight the need for accurate representation of glacier extent and proglacial lakes when evaluating local effects of past and future climate change in glacierized regions.

24nb4598

## Icelandic snow cover changes and impacts under the warming climate

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This project seeks to address the pressing need to comprehensively assess recent snow cover changes in Iceland, especially in a watershed scale, to understand their underlying causes, and elucidate the far-reaching impacts on both the natural environment and the people who call this island nation home. Through systematic research and analysis, we aim to contribute to the knowledge base required for informed decision-making and the formulation of adaptive strategies to mitigate the effects of changing snow cover.

24nb4599

## Investigation of temperature inversion and lapse rates on Beerenberg, Jan Mayen

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This project investigates temperature inversion and lapse rates on the flanks of the glacier-covered volcano, Beerenberg (2277 m a.s.l.), on the remote island of Jan Mayen. The high humidity often leads to cloud formation, nonlinear lapse rates, and temperature inversion. However, little is known about the spatial and temporal variability and the inversion characteristics. A network of temperature, humidity and pressure loggers have been mounted on bamboo poles at 1 m and 2 m heights at varying altitudes at the wind-exposed, west-facing Kerckhoffbreen and the southeast-facing Sørbreen in the leeside. This data will be analysed together with data from a HOBO weather station installed at the front of Sørbreen, and a weather station and radio sonde data from the Norwegian Meteorological Institute station in Olonkinbyen, c. 20 km away from the foot of Beerenberg. The main objective of this study is to determine whether the characteristics and vertical variations of surface air temperatures differ significantly between the wind-exposed western flank of Beerenberg (at Kerckhoffbreen) and the leeside southeastern flank (at Sørbreen).

24nb4600

## AirIPR: An operational airborne ice-penetrating radar system

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We present a new helicopter-based ice-penetrating radar (AirIPR) that was first tested in 2021 and 2022 field seasons in the Saint -Elias Mountain in Western Canada. We will talk about the instrument carrying system and the reasons behind choices made to come up with the current design. We also describe the AirIPR system and its field tests and operational surveys carried out throughout the 2023 and 2024 field seasons. We will present field data obtained in various climatic zones and show that the system is capable of routinely reaching to around 600m depth in temperate ice conditions as found on the ablation zones of typical glaciers in the Canadian's western cordillera.

24nb4601

## Subglacial ice ocean interaction using a conservative high-order finite element method

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In this talk, we present a practical approach to modeling complex ocean dynamics, using a continuous finite element method applied to the non-hydrostatic Boussinesq approximation of the Navier-Stokes equations. This approach is well-suited for applications such as coastal ocean dynamics and ice-ocean interactions. We introduce a modification to the gravity force term that improves energy conservation in numerical simulations without requiring a strictly divergence-free condition. This enhancement allows for more accurate energy estimates, covering both kinetic and potential energy. Additionally, we propose a new symmetric viscosity operator, specifically designed for modeling turbulence in stratified flow, ensuring conservation of angular momentum while dissipating kinetic energy. The viscosity coefficients are determined using a residual-based method, making the method high-order accurate. We demonstrate the effectiveness of this approach through numerical tests, including a simulation of ocean circulation and basal melting beneath the ice tongue of the Ryder Glacier and the adjacent Sherard Osborn fjord. Our method, implemented on a fully unstructured mesh, shows better resolution of turbulent flow features and reduced artificial diffusion when compared to traditional ocean models.

24nb4602

## New glacier bed and thickness maps for Svalbard and the Canadian Arctic

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New glacier bed and thickness maps for Svalbard and the Canadian Arctic

24nb4603

## Improved numerical stabilisation of full-Stokes grounding line problems

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The grounding line marks the boundary between grounded and floating ice, and is a critical region for ice-sheet stability and sea-level projections. The complex ice-flow at the grounding line, where the stress regime moves from vertical shear to horizontal extension over a relatively short distance, is prone to numerical instability in transient full-Stokes simulations. Furthermore, boundary conditions change at the grounding line, switching from a friction law in grounded ice to an ocean pressure force at the ice-ocean interface. Grounding-line full-Stokes problems have been successfully stabilised by the 'sea spring' stabilisation scheme in Elmer/Ice[1] which mimicks an implicit time-stepping scheme by predicting the surface elevation and corresponding ocean pressure in the next time step. We extend on this stabilisation approach by introducing the Free-Surface Stabilisation Approximation (FSSA) to the ice-ocean interface. FSSA has been proven successful in allowing larger stable time steps in grounded problems with an evolving ice-atmosphere interface[2]. This stabilisation approach incorporates a boundary condition term into the weak-form of the Stokes equations representing the predicted stress adjustment between the current and next time step. Using a synthetic MISMIP set up[3], we investigate the application of FSSA to the ice-ocean interface.

[1] G. Durand et al., Marine ice sheet dynamics: Hysteresis and neutral equilibrium. Journal of Geophysical Research, doi: 10.1029/2008JF001170, 2009.

[2] A. Löfgren, J. Ahlkrona, and C. Helanow. Increasing stable time-step sizes of the free-surface problem arising in ice-sheet simulations. Journal of Computational Physics: X, doi: 10.1016/j.jcpx.2022.100114, 2022.

[3] F. Pattyn et al., Results of the Marine Ice Sheet Model Intercomparison Project, MISMIP. The Cryosphere, doi: 10.5194/tc-6-573-2012, 2012.

24nb4604

## Numerical stability of full-Stokes models inferred from linear Stokes eigenvalue analysis

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Accurately modeling the dynamics of glaciers and ice sheets is crucial for assessing their contributions to future sea-level rise. The full-Stokes model, coupled to the free-surface equation, offers the most accurate description of their evolution but is computationally expensive. Stabilization methods can increase stable time-step sizes to speed up simulations; however, standard approaches typically only stabilize the free-surface equation, overlooking the problem's coupled nature. An alternative approach is the so-called free-surface stabilization approach (FSSA) which seeks to approximate a fully implicit time-stepping scheme by adjusting the Stokes velocities based on the evolving free surface. This approach has shown the potential to increase stable time-step sizes by an order of magnitude. Theoretical understanding of the stabilization remains, nonetheless, limited. This talk aims to bridge that gap by analyzing the relationship between the largest stable time-step size, the domain aspect-ratio, and the eigenmodes derived from a linearization of the problem. Results show that the FSSA pushes eigenvalues toward zero as the time-step size increases, yielding an unconditionally stable scheme, although the full nonlinear problem remains conditionally stable. Furthermore, it is demonstrated that the largest stable time-step size scales quadratically for coarse meshes and small aspect ratios, implying stability consideration might be important for large-scale ice-sheet simulations.

24nb4605

## Modelling of ice-surface depressions formed by emptying of small water bodies at the base of a glacier

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Depressions often form on the surface of glaciers when water bodies at the base are emptied. These water bodies may be formed by localized geothermal heat flux or may be conduits or ponded water that form in the subglacial paths of jökulhlaups emptied at the end of the flood. The water body at the base may be expected to be smaller than the horizontal extent of the surface depression due to flow of the surrounding ice towards the depression for typical ice thicknesses of several hundred metres. We investigated the relationship between the size of a water body at the base and the dimensions of the surface depression formed by the collapse of the basal cavity with Elmer/Ice finite-element modelling for a visco-elastic ice rheology. For small water bodies in comparison with the ice thickness, the surface depression has a minimum horizontal extent close to the ice thickness and its shape is relatively independent of the detailed shape of basal cavities with the same total volume. For water bodies with horizontal extent close to the ice thickness or larger, the surface depression is wider than the size of the water body by approximately half to one ice thickness. The subglacial water pressure in a basal cavity of a size on the order of the ice thickness emptying over a time period on the order of a day is reduced by several bars or tens of bars (several tens or hundred of metres lowering of the piezometric surface) from the ice overburden during the outflow of the water because of stresses induced by the flow of the ice towards the cavity. For such a water body, the elastic deformation of the ice increases the lowering of the piezometric surface in the cavity by a few metres but has little effect on the final shape of the surface depression. The results of the model simulations are compared with two examples of lidar measurements of ice surface depressions in W-Vatnajökull and Mýrdalsjökull.

**24nb4606**

## Dynamics of the Flatbreen glacier lake in Fjærland, Western Norway: Insights from field observations and hydrological modelling

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Dynamics of the Flatbreen glacier lake in Fjærland, Western Norway: Insights from field observations and hydrological modelling

24nb4607

## Icelandic glacier climate disequilibrium and committed ice loss

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Glaciers in Iceland are important contributors to meltwater runoff for hydropower production. Most of the hydropower infrastructure is in the central highlands, relying on water resources temporarily stored as snow and ice in glaciers. Understanding and quantifying changes due to climate change on water resources are important for both operational control and planning of energy infrastructure on shorter timescales. We model the evolution of the largest six glaciers in Iceland up to 2100 using present-day climate conditions (2000–19), assuming no future climate change, deriving the committed volume and area loss for the period. A present-day (2020) steady-state was inferred using the Instructed Glacier Model, utilizing a combination of satellite remote-sensing data and observations, within a GPU enabled optimisation/data assimilation framework. In turn, this permits three-dimensional glacier evolution accounting for the coupling between ice dynamics, surface mass balance, and mass conservation. We make use of the assimilated present-day state to run the model forward until 2100 with the climatic surface elevation change of 2000–19 to infer committed mass loss over the period. Taking advantage of high-performance GPU computing, mass balance sensitivity tests were done to demonstrate mass and area loss variability within the current day climatology, providing committed volume and area loss scenarios, as well as runs extending 2100 to estimate the equilibrium state for Icelandic glaciers under the current climate. For Langjökull, Hofsjökull, Mýrdalsjökull and Eyjafjallajökull, the resulting committed ice loss exceeds a fifth of the present-day ice volume by 2100 (~20% area loss), while Vatnajökull shows less relative loss, ranging from 7–15% for both area and volume. Under the current climate, Eyjafjallajökull will reach a future equilibrium state in 140 years, while the other glaciers will reach future equilibrium in 200–300 years. Langjökull, however, is expected to reach steady state in 400 years, with over 40% relative volume loss.

24nb4608

## Reconstructing the Greenland Ice Sheet during the last two deglaciations

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Reconstructing the Greenland Ice Sheet during the last two deglaciations

24nb4609

## Investigating ice geometry and retreat patterns of outlet glaciers from Folgefonna ice cap, western Norway

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Large-scale glacier and glacio-hydrological models often lack the resolution and accuracy needed for regional and local applications. This can be partly attributed to the scarcity of ice thickness observations, particularly for outlet or valley glaciers. Ground-based subsurface topography mapping of steep outlet glaciers presents significant challenges due to accessibility issues. However, methodological advancements in helicopter-borne Ground Penetrating Radar (GPR) applications facilitate data collection over rugged and complex surfaces which are not accessible on ground. In this study, we focus on the analysis and implementation of helicopter-borne GPR measurements collected in April 2024 from the outlet glaciers of the Folgefonna ice cap. We here present first results of subglacial topography and ice-thickness interpretations of selected outlet glaciers for which previous ice thickness measurements have been sparse. When integrated with remotely sensed surface-topography, these results enable comprehensive reconstruction of current and near-past glacier geometry. Given the presence of hydropower plants downstream of many outlet glaciers and their popularity as tourist destinations, understanding retreat behaviour and potential future changes in drainage routing is highly relevant to estimate societal impacts in the future. In addition to reconstructing the glacier geometry we therefore aim to calibrate glacier retreat models with our data, to be able to provide reliable assessments of retreat behaviour and potential changes to drainage routing of the outlet glaciers.

**24nb4610**

## Nutrient availability from weathered glacial sediments

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This study aims to assess glacial flour (fine-grained debris) as a nutrient source. Weathered glacial debris may be a source of nutrients in subglacial environments, that can also be exported to downstream aquatic environments, such as freshwater lakes, rivers and fjords by outflowing glacial waters. We set up year-long incubation experiments using glacial sediments, collected from a glacial outlet close to Ilulissat, Greenland, at close to in situ temperatures to assess changes in nutrient concentrations of both sediment pore waters and overlying water. Complimentary nutrient extractions were conducted to quantify the concentrations of nutrients held on the sediment surface. Here, we present our initial results of the low-temperature incubations and their implications for glacial sediment as a potential source of Si, N and P for subglacial environments.

24nb4611

## The structural glaciological evolution of rapidly receding temperate Piedmont glaciers and the implications for debris entrainment and landform development at Svínafellsjökull, southeast Iceland

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Recent research on ice cap piedmont lobes has highlighted variations on ice flow patterns, related to the interaction between topographic controls and glacier structure as glaciers respond to climatic changes, and in Iceland become more susceptible to recession onto overdeepenings. This research provides a detailed understanding of the structural glaciological evolution and the implications for debris entrainment and landform development at Svínafellsjökull, Southeast Iceland. The structure of Svínafellsjökull has been impacted in recent years by a warming climate and this has initiated passive retreat of the glacier. Since then, the glacier has undergone accelerated recession and pronounced thinning over an overdeepening. This research investigates the structural glaciological response, both spatially and temporally, to this recession and accompanying thinning of the terminal zone. This structural evolution within the marginal area of Svínafellsjökull in turn influences the debris entrainment and transport pathways at play. A transport process model for Svínafellsjökull and Falljökull has been proposed incorporating debris-rich glacial ice formation processes, debris transport pathways, and their glaciological controls. Changes in the structural configuration of the lower reaches of Svínafellsjökull, especially the development of radial crevasses, have impacted upon the landform record preserved within the foreland of the glacier. Geomorphological mapping of the foreland is presented and facilitates the development of more robust palaeoglaciological models/interpretations of the landform and sedimentary record of Quaternary glacier-climate relations. Overall, this research highlights the importance of examining multiple aspects of a glacial landsystem to achieve a full understanding of the process-from relationships which are shaping the landscape.

24nb4612

## Demystifying the darkening of the Greenland Ice Sheet through remote sensing

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The Greenland Ice Sheet is rapidly melting in response to climate change. The darkening of the ice sheet, characterized by a decrease in surface ice albedo, accelerates melt and contributes significantly to global sea level rise. Various factors contribute to the ice sheet darkening, including snowmelt, meltwater content, and light-absorbing particulates like glacier ice algae and mineral dust. Our study investigates the interactions between different darkening processes and the accumulation of various light-absorbing particulates. We combined in situ AWS albedo observations, multispectral and hyperspectral imagery, and surface mass balance models to investigate the influence of different darkening processes on albedo variations, dark ice distribution, and the subsequent impact on melt.

24nb4613

## Unravelling microbial bloom dynamics on glacier surfaces by high-resolution mass spectrometry

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Surface microbial communities on the Greenland Ice Sheet are critical in modulating glacier surface melt by directly affecting surface albedo through extensive algal blooms. With the predicted further warming climate, the potential for longer melt seasons and increased absorption of solar radiation will further promote the expansion of such blooms. However, the factors that control bloom density and distribution, such as microbially produced compounds involved in signalling or defence, are not well characterised. Identifying intracellular metabolic changes under environmental stress can provide deeper insights into the algal bloom regulation and cell-to-cell communication. The composition of the endometabolome is complex and depends on factors such as the composition of the microbial community and changing physicochemical parameters (e.g., variations in light conditions and changes in the freeze-thaw cycle of glacier surfaces). We investigated the stress response of supraglacial microbial communities that thrive under various physico-chemical conditions and identified factors controlling microbial blooms. We used high-resolution mass spectrometry (HRMS) to identify intracellular microbial secondary metabolites with ecological functions that modulate bloom dynamics. Our results contribute to an expanding database of supraglacial microbial secondary metabolites and provide insights into the chemical diversity of glacier ecosystems in oligotrophic extreme environments.

24nb4614

## Updated inventory of ice-front positions along the King Frederick VI Coast, SE Greenland

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Updated Inventory of Ice-front positions along the King Frederick VI Coast, SE Greenland

24nb4616

## Mapping the 'Little Ice Age' extent of Folgefonna, western Norway: implications for reconstructing and inventorying plateau icefield-type glaciers

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Mapping the 'Little Ice Age' Extent of Folgefonna, Western Norway: Implications for Reconstructing and Inventorying Plateau Icefield-Type Glaciers

24nb4617

## Glacial geomorphology and dynamics of palaeo-ice streams in northeast Iceland

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Ice streams within the Iceland Ice Sheet (IIS) have previously been proposed, but limited studies existed on their geomorphology. The aim of this study is to advance the understanding of the geomorphological imprint, configuration, and dynamics of palaeo-ice streams and their development during and following the Last Glacial Maximum by mapping glacial landforms and analyze their internal architecture. The research focuses on streamlined subglacial bedforms (SSBs; drumlins and megascale glacial lineations), crevasse-squeeze ridges (CSRs), and ribbed moraines; however, glaciofluvial and ice-marginal landforms, as well as hummocky terrain were also mapped. The distribution and orientation of SSBs reveal four flow-sets of cross-cutting palaeo-ice streams that shifted in time and space, along with ice divides. During the maximum glaciation, ice flow was towards the north, unconstrained by the topography, but became confined to the fjords and valleys as the ice sheet thinned. The CSRs and ribbed moraines indicate ice-stream shutdown following glacier readvances during the Late Glacial. The variance in landform morphology and distribution is used to reconstruct the configuration and dynamics of the ice streams. The results provide new insight into the dynamics of the IIS and palaeo-ice streams within it and are essential for constraining numerical modelling experiments of the ice sheet's evolution. This research has implications for our understanding of modern and palaeo-ice sheet behaviour during deglaciation and under warming climate, and paves the way for further studies and reconstructions of palaeo-ice streams in Iceland.

24nb4618

## How well does the snow service SeNorge describe snow volumes upstream Swedish hydropower dams?

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text

24nb4619

## Updates from the perennial firn aquifer on Lomonosovfonna, Svalbard

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text

24nb4620

## New insights into the development of slowly rising jökulhlaups from the Grímsvötn subglacial lake, Iceland, deduced from ICEYE SAR images and in-situ observations

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We present a study on two jökulhlaups from the subglacial lake Grímsvötn, beneath Vatnajökull ice cap, SE-Iceland. In the first, spanning the period 14 November–10 December 2021, ~0.92 $km^3$ of water was released, reaching peak discharge from the lake of ~3500 $m^3$/s from the lake on 4 December. In the latter, taking place 4-22 October, 2022, the corresponding numbers were ~0.16 $km^3$ and ~500 $m^3$/s. Both jökulhlaups were captured by ICEYE X-band radar satellites, with daily repeated SAR images, allowing construction of 3D ice motion above the ~50-km long subglacial flood route, using InSAR and amplitude offset-tracking results. During both jökulhlaups, the outflow from the lake, derived from the lake level (with GNSS), was monitored, as well as the development of the flood near the glacier margin in the river Gígjukvísl. During the 2021 jökulhlaup, the ice motion above the flood path, deduced from the satellite data, was validated with data from a GNSS station operated ~30 km from the glacier margin. Surface elevation changes above the lake before, during and in between the jökulhaups were derived from Pléiades optical stereo images. These datasets reveal new insights into the development of jökulhlaups from Grímsvötn, presented in the talk.

24nb4621

## Monitoring glacier topography from space: past successes, novel observations using SWOT and perspectives from 4D-Earth

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Observing changes in glacial topography is important because glaciers are excellent climate indicators, and their melting contributes to rising sea levels, water resources in arid regions and can trigger glacier hazards. The first global and comprehensive estimate of terrestrial glacier volume loss, for the period 2000-2019, has been made possible thanks to the opening of the ASTER/TERRA satellite's stereo pair database. This satellite will definitively run out of fuel in 2027 and will not be replaced. Modern optical sensors provide stereo images of higher resolution and precision, but mainly for the polar regions or specific targets, and with no free, systematic or global acquisitions. Radar satellites such as the German Aerospace Center's TanDEM-X (or Harmony in the future) deliver highly-resolved elevations, but the data are ambiguous due to signal penetration into snow and ice and lack of easily interpreted visible images. In this presentation, we will illustrate past, present and near-future efforts to continue glacier monitoring from space. We will show how the swath observations from SWOT are promising, not only for glaciology but also for other applications in geosciences, such as the measurement of the elevation difference produced by volcanic activity. Finally, we will present 4D-Earth, a satellite mission proposed to the French Space Agency to ensure frequent monitoring of the Earth surface.

24nb4622

## Spatio-temporal mass changes of the Mýrdalsjökull icecap (Iceland) since 2010: insights from high-resolution statistical modelling.

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Changes in glacial loading of Mýrdalsjökull icecap impact the dynamic behavior of the subglacial volcano Katla. Here, we are quantifying the glacial changes since 2010 with a daily resolution. This will improve the understanding of Katla's response to both, long-term and seasonal changes. We employ a linear regression to predict elevation changes from parameters extracted from the weather reanalysis CARRA and surface velocity data. A comparably rich data collection of digital elevation models from spaceborne stereo images (Pleiades, ArcticDEM) is used as training data.

24nb4623

## Sólheimajökull data compilation and exploration of future mass balance questions

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Sólheimajökull Data Compilation and Exploration of Future Mass Balance Questions

24nb4624

## Svalbard update

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TBD

**24nb4625**

## Enhancing sub-ice geology in East Antarctica with Self-Organizing maps based on gravity, magnetic and radar data

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Sub-ice geology significantly influences the dynamics and future evolution of the Antarctic Ice Sheet, but largely inaccessible for direct sampling. Here, we present an approach, where we use a Self-Organizing Map (SOM) to describe sub-glacial properties. Based on attributes derived from gravity, magnetics and radar data from the NASA Operation Ice Bridge dataset in East Antarctica, we train a Self-Organizing Map (SOM). The attributes are selected to represent at sub-glacial conditions and in our analysis, we study the trade-offs between these data sets helping to identify for which properties these are most sensitive. The trained SOM identifies the outlines of the main geological structures beneath the ice and supplements models based on inverse and forward modelling. In contrast to such often regional interpretations, the SOM captures small-scale structures at the ice bed, as we illustrate with case examples, and highlights areas with inconsistencies in existing geological interpretations. The SOM can furthermore be used as input for inverse modelling of the physical properties of the sub-glacial geology in Antarctica.

24nb4626

## Explosive volcanic history of Snæfellsjökull, west Iceland: geochemistry, chronology and tephra distribution

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Tephrochronology is critically limited by our understanding of volcanic history. Iceland´s Holocene explosive volcanic history is predominantly derived from investigations of soil sections and written archives, following the Settlement c. 877 CE. Unsurprisingly, historically active volcanic provinces are most often the target of these tephrochronological investigations (e.g. Hekla, Katla, Bárðarbunga-Veiðivötn and Grímsvötn). Despite the risk of large explosive eruptions, some volcanic provinces – like Snæfellsjökull have received less attention. While the glaciated central volcano has no described historical eruptions, mapping from the late 1960s and early 1980s suggests there have been three explosive eruptions (producing acidic tephra) known from the Holocene era: Sn-1 ~1.8 ka BP, Sn-2 ~4.4 ka BP and Sn-3 ~8-10 ka BP. It is assumed that tephra from at least two of these eruptions has been identified in European stratigraphic archives. Furthermore, other (crypto-) tephra horizons in Europe exhibit similar geochemical properties to the Snæfellsjökull province, albeit different age estimates than Sn-1, 2 or 3. The tephrochronological potential from Snæfellsjökull is limited by our lack of fundamental knowledge on the volcanic history and the potential range in tephra geochemistry from the stratovolcano. As a step towards addressing this knowledge gap, we present a record of tephra stratigraphy from lake Laugarvatn, near Snæfellsnesjökull, and review all Snæfellsjökull-like tephra deposits to improve understanding of Snæfellsjökull's post-glacial explosive volcanic activity affecting both regional and distal environments.

24nb4627

## Glacier mass changes in Svalbard

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The most recent inventory of Svalbard glaciers shows an area of 33 775 $km^2$ covering 57% of the total land area of the archipelago. The area has decreased by an average of 80 $km^2$ $a^{-1}$ over the past ~30 years, representing a reduction of 7%. Mass balance monitoring was started by the Norwegian Polar Institute in 1967 at two small glaciers in Kongsfjorden, North-West Spitsbergen. These have been extended to larger glaciers in the same region since 1986 and since 1988 Hansbreen in South Spitsbergen has been monitored. The mass balance time series are among the longest continuous data series from the Arctic. However, they cover only a small fraction (~2%) of the total glaciated area. On all glaciers, summer ablation is more variable than winter accumulation, thus summer temperatures provide most of the control on the net balance. The larger glaciers are in general less negative, since their accumulation areas are both higher and larger than the smaller glaciers. The hypsometry is important for the response to climate changes. The bulk of the glacier area is close to the equilibrium line altitude and thus the Svalbard glaciers are very sensitive to small temperature changes. The mass balance data show an increasing negative trend during the last ten years. Geodetic mass balance has been obtained by analysing older maps from the 1930s and more recent satellite data after 2000. This shows that most glacier regions in Svalbard have experienced low-elevation thinning combined with high-elevation balance or thickening. The general thinning rate has increased over the last decades. The largest ice losses have occurred in the west and south, while northeastern Spitsbergen and the Austfonna ice cap have been more stable. The most recent surface mass balance estimate for Svalbard glaciers is $-7 \pm 2.1$ Gt $a^{-1}$ (2000–19) or $-0.21 \pm 0.06$ m w eq $a^{-1}$. The only available estimate of current frontal ablation from Svalbard in the period 2000–06 amounts to nearly 7 Gt $a^{-1}$, hence, frontal ablation is roughly equivalent to the mass loss by climatic mass balance in the same period. Many glaciers are of surge-type and surges may alter the are/altitude distribution and for calving glaciers give a temporary increased mass loss.

24nb4628

## Global glacier casuality list and other outreach projects in Iceland

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Since the year 2000, global warming has led to the disappearance of thousands of glaciers across the world. At first, many of these glaciers were small. But now larger glaciers melting, many with vital cultural, economic and environmental importance to human communities. The Global Glacier Casualty List (GGCL) exists to remember their names and tell their stories and is a dynamic platform to visualize data about recently disappeared and soon-to-disappear glaciers. At the rate of climate warming, all glaciers are endangered. But to date there is no comprehensive list of all the glaciers that have disappeared. The GGCL project was founded in 2024 through a collaboration between Rice University, the University of Iceland, the Icelandic Meteorological Office, the Iceland Glaciological Society, the World Glacier Monitoring Service and UNESCO. The project supports the UN's designation of 2025 as the International Year of Glaciers' Preservation and the first World Glacier Day, which will be held on March 21, 2025. Through the project Extreme Ice Survey Iceland, a series of photography platforms have been installed in Iceland to enable citizen scientists to record how the country's glaciers are changing. The new initiative by the Iceland Glaciological Society invites the public to document changes by taking photographs of glaciers from predetermined locations and uploading them to build a photographic record preserved for future generations. The project is backed by environmental photographer James Balog who has spent a distinguished career documenting the decline of glaciers worldwide. In the last few years, historical glacier photographs of the Iceland Glaciological Society have been scanned and registered. This historical archive is being used to create repeat photographic pairs, documenting glacier change since the 1930s. Together, these initiatives will create ground to delineate past, present and future glacier changes.

24nb4629

## Post glacial relative sea level changes in west Iceland

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The thin, dynamic crust of Iceland is particularly sensitive to the loading and unloading of land by glaciers and ice sheets. Determining the pattern and rate of postglacial sea level change in Iceland is critical for constraining models of deglaciation, ice sheet behaviour, and palaeoclimate. Despite decades of work, relative sea level (RSL) histories remain poorly resolved due to patchy coverage, poorly constrained sea level index points, and chronological uncertainties. The objective of this master's project is to develop an open-access database of sea level index points and emergence curves for west Iceland. Existing data will be compiled, quality assessed and integrated into a standardized database. The RSL database is supplemented with new geochronological (tephra and radiocarbon) data from submerged coastal peatlands located in west Iceland, specifically the classic site of Seltjörn, Grótta (-4.2 m beneath hightide; Þorarinsson 1956). These findings contribute to our understanding of the deglaciation of the Icelandic Ice Sheet and the Early Holocene sea level low-stand.

Þorarinsson, S. 1956: Morinn i Seltjörn [English summary: The submerged peat in Seltjörn]. Náttúrufrædingurinn 26, 179-193.

24nb4630

## Tracking glacier surge evolution using interferometric SAR coherence — examples from Svalbard

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We present a practically simple methodology for tracking glacier surge evolution and onset using interferometric Synthetic Aperture Radar (InSAR) coherence. Detecting surges early and monitoring their build-up is interesting for a multitude of scientific and safety-related aspects. We show that InSAR coherence maps allow the detection of surge-related instability on Svalbard many years before being detectable by, for instance, feature tracking or crevasse detection. Furthermore, we present derived data for two types of surges; downstream- and upstream-propagating, with interestingly consistent surge propagation and post-surge relaxation rates. The method works well on Svalbard glaciers, and the data and core principle suggest a global applicability.

24nb4631

## Glacier surge as a trigger for the fastest delta growth in the Arctic

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The widespread retreat of Svalbard glaciers has been frequently interrupted by short-lived surge advances. In the case of marine-terminating glaciers this is often expressed in the remodelling of coastal zones. We analyzed the coastal zone changes in front of the recently surging Recherchebreen. The glacier advanced ca 1200 m since 2018 and suddenly stopped in June 2020 followed by the rapid formation of a delta system in front of its subglacial meltwater outlet. The delta advanced by ca 450 m with probably the fastest progradation rate ever detected in the Arctic region (ca 7 m/day). The synchroneity of the final slow-down of the glacier with the delta building indicates that this event records the release of stored water and sediments from beneath the glacier, and thus provides direct evidence of drainage reorganisation at the termination of a surge. Such behaviour is likely common among Svalbard surging glaciers, but it only rarely leaves any direct geomorphic evidence.

24nb4633

## Over 200 years of glacier change and ice-dammed lake outburst floods at Nedre Demmevatnet, Rembesdalskåka Glacier, Norway

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Glaciological and environmental factors governing the timing and mechanisms of ice-dammed glacier lake outburst floods (GLOFs) remain poorly understood mainly due to the lack of in-situ data and the complexity of the drainage mechanisms. In this study, we present a reconstruction and analysis of over 200 years of glacier change and 28 GLOF events at a glacier-dammed lake in Norway, Nedre Demmevatnet. Since 1736, Nedre Demmevatnet has resulted in several floods with devastating downstream impacts on the valley below the glacier, particularly in 1893, 1937, and 1938. Following these events, two tunnels were constructed to lower lake levels continuously, effectively preventing outbursts for 38 years from 1899 to 1937 and for 76 years from 1938 until their reactivation in 2014, with GLOFs now occurring almost annually. Throughout these periods, the glacier has also undergone major changes, including advances in the 1930s and 1990s, retreats from 1890 until the 1930s and rapid 21st century decline. The central question is whether a link exists between glacier retreat, advance, and the timing of outburst occurrences, as well as what insights can be drawn from the documented switch between rapid subglacial tunnel drainage (within 3 hours) and slower supraglacial overspill (over several weeks). The study compiles historical records, data, coupled with the reconstruction of digital elevation models from archival aerial imagery and Arctic DEM data to document glacier change. Documented examples of each drainage mechanism will also be examined using the reconstructed topographical data. This will allow us to reconstruct and describe fluctuations in glacier and lake volumes over time. Additionally, we will test historic descriptions of ice-dam outburst mechanisms such as overspill, ice uplift, and subglacial ice tunnels, and attempt to explain the relationship between glacier change and outburst mechanisms. Finally, Nedre Demmevatnet offers a rare dataset of varying outburst mechanisms, glacier change, and human interference from 1736 to 2024. By analyzing this extensive dataset, we aim to better understand the possible links between glacier dynamics and outburst flood mechanisms, as well as their timing and magnitude.

24nb4634

## Reflections on early Nordic contribution to glaciology and climate studies

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Nordic understanding of glaciers, their dynamic nature, outburst floods and the relationship of glaciers to cold climates is apparent from ancient documents going back over 800 years, e.g. the Danish Saxo (ca 1200 AD) and the Norwegian *Kings Mirror* (13th century). In the late 17th century, the Icelandic Vídalín proposed the frost expansion theory of glacier motion and in 1794, Icelander Sveinn Pálsson described glaciers flowing as viscous material under their own weight. In the 19th c several Nordic geoscientists explored the evidence for the Ice Age, some of them visiting Iceland. Modern Nordic glaciology began in the 20th century with the Swedish-Norwegian-Icelandic expeditions led by Hans Ahlmann who studied glaciers around the North Atlantic. He and his collaborators introduced systematic mass balance measurements, described conditions for the existence of glaciers, and reported warming in the Arctic which they explained as triggered by changes in atmospheric and ocean circulation. Faithful to the empirical approaches of early 19th century geoscientists, they reported observations but did not advance theories for clarifying changes in climate. These early pioneers advocated more observations and believed these were the key to explaining the processes causing glacier retreat and observed warming in the Arctic. However, a theoretical basis for understanding the interaction of glaciers with climate needed input from physics and chemistry and this began to emerge in the late 19th century. Here again, Nordic input was significant – from the discussions in the Stockholm Physical Society around 1900 (of Högbom, Arrhenius and Ekholm) to Bolin's and Eriksson's (1959) final explanation of the buffering of the oceans against absorbing atmospheric $CO^2$. The disciplines of the geosciences have thus passed through several phases. The pre-1800 explorers were trying to understand and devise a framework for describing the present environment. Geology's fundamental axiom, that the present Earth is key to understanding the past (Lyell), became accepted in the 19th century. The 20th century scientists emphasized the significance of the physical laws of nature for a more mechanistic understanding. The greatest challenge facing glaciologists of the 21st century will certainly be the overwhelmingly fast, multifaceted and imminent changes of the Earth's surface and

24nb4635

## Ice thickness and bed topography of Jostedalsbreen ice cap in Norway

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We present an extensive dataset of ice thickness measurements from Jostedalsbreen ice cap, mainland Europe's largest glacier. The dataset consists of more than 351 000 point values of ice thickness distributed along ~1100 km profile segments that cover most of the ice cap. Ice thickness was measured during field campaigns in 2018, 2021, 2022, and 2023 using various ground-penetrating radar (GPR) systems with frequencies ranging between 2.5 and 500 MHz. The large majority of ice thickness observations were collected in spring using either snowmobiles (90 %) or a helicopter-based radar system (8 %), while summer measurements were carried out on foot (2 %). To ensure accessibility and ease of use, metadata were attributed following the GlaThiDa dataset (GlaThiDa Consortium, 2020) and follows the FAIR (Findable, Accessible, Interoperable, and Reusable) guiding principles. Our findings show that glacier ice of more than 400 m thickness is found in the upper regions of large outlet glaciers, with a maximum ice thickness of ~630 m in the Tunsbergdalsbreen outlet glacier accumulation area. Thin ice of less than 50 m covers narrow regions joining the central part of Jostedalsbreen with its northern and southern parts, making the ice cap vulnerable to break-up with future climate warming. Using the point values of ice thickness as input to an ice thickness model, we compute 10 m grids of ice thickness and bed topography that cover the entire ice cap. From these distributed datasets we find that Jostedalsbreen has a mean ice thickness of 154 m ±22 m and a present (~2020) ice volume of 70.6 ±10.2 km3. Locations of depressions in the map of bed topography are used to delimitate the locations of potential future lakes, consequently providing a glimpse of the landscape if the entire Jostedalsbreen melts away. Together, the comprehensive ice thickness point values and ice cap-wide grids serve as a baseline for future climate change impact studies at Jostedalsbreen. All data are available for download at https://doi.org/10.58059/yhwr-rx55 (Gillespie et al., 2024).

24nb4636

## Controls of ice-surface structures during the 1991 surge of Skeiðarárjökull, Iceland, on the post-surge glacial landsystem

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Investigations of surge-type glaciers are important for understanding glacier dynamics and proving analogues to modern and palaeo-ice streams. However, the link between surge-related surface structures to a post-surge glacier landsystem is poorly understood. This thesis focuses on surge-phase structural glaciology and post-surge geomorphology of the western limits of Skeiðarárjökull in relation to its 1991 surge. The 1991 surge of Skeiðarárjökull was described as a two-stage surge, from March–July and September–November. This second stage of the surge significantly impacted its western margin, with an advance of 1 km, resulting in extensive crevassing that is often seen in surge events. Crevasse mapping of 3–4 km upglacier from the 1991 ice-margin reveals extensive longitudinal and splay crevassing in several domains of orientation; arcuate transverse or en-échelon crevassing have been identified near the ice margin as well. Post-surge mapping of the western forefield based on a 2012 DEM and LiDAR intensity dataset, reveals a highly reworked landsystem that may be a result of the geomorphological impact of the surge, jökulhlaups, and/or overdeepening in the forefield. Given that much of the forefield of the glacier has been impacted by a large jökulhlaup in 1996, the western forefield remains relatively undisturbed in comparsion. Common features in this forefield include an end moraine, dead-ice / hummocky moraine, flutings, drumlins, eskers, and crevasse-squeeze ridges. These are all features that are described within surging glacier landsystems. The mapping indicates that late-phase surface structures display a variety of orientation, heavily exhibited with longitudinal crevassing. The domination of longitudinal crevassing on the surface is associated with the longitudinal compression that occurs from the passage of the surge bulge. However, there does not appear to be a link between the orientation of crevasses and post-surge morphology. This lack of relation is likely due to poor preservation of landforms that could suggest such a link (e.g. crevasse-squeeze ridges), caused by the high prevalence of dead-ice terrain that may have overridden these features.

24nb4638

## Continuous tremor associated with recent jökulhlaups from the Katla caldera in Iceland

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Large outburst floods, jökulhlaups, commonly occur from the glacier-covered parts of the volcanic zones of Iceland. The most common source areas are the calderas of the volcanoes Grímsvötn and Katla, but floods from the Skaftár ice cauldrons in Vatnajökull are also quite frequent. The source of the flood water in most cases is geothermal melting at the base of the glacier or subglacial eruptive activity of the volcanoes. In a few cases floods are known to have triggered volcanic eruptions, e.g., the Grímsvötn eruptions of 1922, 1934, and 2004. The floods are often accompanied by continuous earth tremor picked up by seismograph stations in the area around the glaciers. The tremor provides one of the important methods to monitor the floods in real time. In a recent study of continuous tremor associated with the Grímsvötn volcano we identified three processes as sources of different types of tremor: Water flood tremor, geothermal tremor, and eruption tremor. The water flood tremor has relatively high frequency (2–9 Hz) and short distance range, rarely more than 50 km. Geothermal tremor has a narrower frequency band (2–6 Hz) but also a short distance range. It appears to be caused by flash boiling of the geothermal system of the volcano. Eruption tremor begins simultaneously with eruptions of the volcano. It has distinctly lower frequency than the other types of tremor (0.5–4 Hz) and a much wider distance range than the other types of tremor. Recent floods from the Katla caldera have also been accompanied by seismic tremor. The large floods of 2011 and July 2024 caused severe damage to the main road across the Mýrdalssandur outwash plain. They were accompanied by low-freqency tremor that was recorded on seismic stations over a large part of the country. Considering the frequency band and the wide range of this tremor it resembles the eruption tremor of the Grímsvötn volcano. A smaller jökulhlaup from Katla in September 2024, on the other hand, was accompanied by high-frequency tremor recorded on the closest seismograph only.

24nb4639

## Preliminary results of the Early Holocene deglaciation of eastern Iceland from cosmogenic 36Cl exposure ages and tephrochronology

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The Iceland Ice Sheet (IIS) is thought to have extended to the shelf break around Iceland at the Last Glacial Maximum and then collapsed and retreated to a position inside the present-day coast during the Bølling-Allerød. Following the Younger Dryas (YD; 12.9–11.7 ka BP) and Preboreal (Pb; 11.5–11.2 ka BP) readvances to coastal areas, the IIS retreated inland and deposited a number of end moraines of unknown age. Several records suggest that remnants of the IIS were smaller than present glaciers by ~9 ka BP. However, the rate of retreat from the YD and Pb positions to the interior highlands remains unresolved. The tracks of palaeo-ice streams have recently been revealed in NE-Iceland, with one of them extending from the highland interior north of the present Vatnajökull to the coast in Vopnafjörður. Several end moraines are preserved along the center flow line of this former ice stream, indicating periodic stillstands or readvances that punctuated its overall retreat. In this project, roughly 30 samples were collected for cosmogenic 36Cl surface exposure dating of glacially scoured bedrock and end moraines along a ~120 km long transect from the coast in Vopnafjörður to near the northern margin of Vatnajökull. Preliminary results reveal decreasing exposure ages upice along the center flow line of the ice stream and a rapid deglaciation of the IIS during the early Holocene. Two exposure ages from the coast in Vopnafjörður reveal mid-Younger Dryas ages of 12.2–12.3 ka, provisional age from Bustarfell (25 km upice) gives 12.2 ka BP, four samples from the Skessugarður bouldery end moraine (66 km upice) cluster tightly at 11.1 ka BP, and the Fiskidalur moraine (83 km upice) dates to 10.5 ka BP. Pending dates from three moraines further inland (c. 90, 106, and 120 km upice), along with analyses of tephra marker horizons, will complete the transect and shed light on the rates and timing of the final deglaciation. These efforts will provide a unique dataset of the final deglaciation of the IIS with important implications for our understanding of the rates and pattern of IIS decay and serves as a critical constraint for palaeoglaciological modelling of the IIS.

**24nb4640**

## Hofsjökull ice cap, central Iceland: a decade of snow radar measurements in support of mass balance studies

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Hofsjökull is an 800 km$^2$ ice cap in central Iceland, lying between elevations of 650 m and 1790 m. Area changes of the ice cap since the LIA maximum in ~1890 are well documented and mass balance measurements have been carried out since 1988. Meltwater from Hofsjökull forms an important part of glacial runoff utilized in several hydropower plants on the rivers Þjórsá and Blanda in S-and N-Iceland. Mass balance has been measured with the glaciological method at 25–35 fixed points on the ice cap since 1989. During spring expeditions, snow cores are drilled through the winter layer at these points. Density measurements on the cores allow determination of the winter balance and stake readings during the spring and autumn yield data on summer balance. Since 2015, the acquisition of continuous profiles of winter snow thickness with a GPR-system has formed part of the spring measurements. The IceMap system used consists of a 500 MHz transmitter, a GPR Sensor and a GPS receiver, all built into a single unit which is placed in a toboggan towed by a ski-doo. The radargrams display a clear reflection from the glacier ice surface beneath the winter snow layer in the ablation zone of the ice cap. Reflections in the accumulation zone can be more ambiguous due to meltlayers that are commonly observed below or above the layer inferred to represent the summer surface. Comparison with summer surface determination on snow cores helps in the selection of the correct reflector, which can then be traced between coring locations. The density-dependent EM-velocity is calibrated each year using travel times and snow depth data from the snow cores. The reproducibility of radar depths is excellent; two profiles measured over the same 2 km distance typically yield average snow depths differing by 1-2%. At 32 crossover points on the ice cap the average difference in snow depth determined from the two profiles was 1.2%, but differences up to 10% were observed. The presentation will give an overview of the mass balance of Hofsjökull 1988–2024, with emphasis on results obtained in the last 2 years. Results from new snow radar data collected in 2023 and 2024 will be compared with results from earlier campaigns. The snow radar data are being used to improve coverage of winter balance measurements in the ice-flow basins where mass-balance data are collected and to correct for bias in stake measurements.

24nb4641

## Geomorphic effects of steep volcanic relief on glacigenic deposition and mass balance

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The recession and thinning of glaciers is resulting in icefield fragmentation, with glacier disconnections often occurring in areas of steep topography. The disconnections affect mass balance and other characteristics of regenerated glaciers below as well as icefields or dome glaciers above the line of separation. On examples from Icelandic and Antarctic Peninsula glaciers, overlying specific volcanic landforms mostly formed by subglacial effusive eruptions, we investigate what effects the steep precipices exert on glacier morphology, deposition and mass balance in these climatically two distinct regions. The last aspect is especially relevant in the current acceleration of glacier thinning and increases of equilibrium line altitude. Using remotely sensed data from uncrewed aerial vehicles and satellite observations, we focus on characterising of the glacier flow acceleration towards the edges of volcanic mesas or plateau icefields, evident in crevasse patterns or glacial meltwater drainage network. The detailed description of glacigenic landforms in the recently deglaciated areas may help constrain the changes that have led to the present status.

24nb4642

## Seismic signals associated with subglacial geothermal activity, and jökulhlaups from the Skaftár cauldrons in western Vatnajökull, Iceland

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The Skaftár cauldrons, a pair of glacial surface depressions on the Vatnajökull glacier, NW of Grímsvötn, signify subglacial lakes caused by geothermal heat sources within the underlying bedrock, which cause the lakes to grow in volume and produce fast-rising jökulhlaups at the glacier outlet, 35-40 km away, every 1-5 years. As with Grímsvötn, the first phase which spans subglacial flood propagation and cauldron deepening, is dominated by low amplitude, low frequency, highly repetitive events, possibly relating to hydrofracturing and stick-slip motion of the glacier at the bedrock, as the water propagates subglacially. The second phase, once most of the water has drained from the cauldrons, exhibits regional tremor. Probabilistic location methods reveal that this tremor is co-located with the cauldrons. Sustained tremor (0.2–4 Hz), persisting for 1.5–3 days, is interpreted as enhanced geothermal boiling or non-eruptive magma migration due to rapid depressurization of the subglacial hydrothermal system. Spasmodic, high amplitude tremor bursts (0.5–8 Hz, culminating at 0.5–4 Hz) with durations of 10s of minutes occur during the second phase of each jökulhlaup. The tremor bursts have a strong relationship with increased electrical conductivity in the flood water and have been interpreted controversially as confined hydrothermal explosions, magma migrating at a shallow crustal level or even subglacial eruptions. However, a registered hydrothermal explosion (0.5–4 Hz) in 2013, associated with a sudden drainage from an ice-dammed lake within the caldera of the Kverkfjöll volcanic system at the northern margin of Vatnajökull, had markedly lower amplitudes and shorter durations than the Skaftár tremor bursts.

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## Towards a spatio-temporal perennial firn aquifer distribution throughout Svalbard

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Firn aquifers are regions of firn where surface meltwater fills available firn pore space and is retained without fully refreezing. They can delay runoff and water input to subglacial channels, or the aquifer water can be carried to the glacier bed through hydrofracturing. Liquid water storage in firn is a substantial energy reservoir, impacting the thermal regime of the ice. Thus, the presence or absence of a firn aquifer may be a large factor for the dynamics of the glacier. Decreasing firn cold content and higher melt rates may lead to an expansion of firn aquifers, but decreasing firn pore space and shrinking firn areas may lead to an opposite effect. There are a few reported observations of firn aquifers in Svalbard. Nevertheless, there is a considerable knowledge gap in understanding how wide-spread they are in Svalbard glaciers and how they change under a warming climate. Here, we present a set of newly collected ground-penetrating radar data from Holtedahlfonna and Austfonna, Svalbard, and discuss the required steps to obtain a regional distribution of firn aquifer extent and evolution throughout the archipelago.

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## How stable are the ice divides in the northern Greenland ice sheet?

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The mass loss from the Greenland ice sheet since year 2000 is faster than projected, mainly driven by surface melting. While the interior of the Greenland ice sheet has remained relatively stable, the mass loss from the ice sheet margins have spread to the north and since 2007 propagated into interior North Greenland. We present here an assessment of the interior stability in central North Greenland using GPS data, remote sensing data, climate model output, ice core data and ice flow modelling. We compile GPS survey data from interior ice core sites in North Greenland at GRIP (1992-1996), NorthGRIP (1996–2001), NEEM (2007–15), and EastGRIP (2015–22), and compare with surface mass balance estimates and remote sensing data to assess changes over the last decades. While the surface elevation has remained relatively stable at the northern ice divide sites, an inferred northward migration of the ice divide in Northwest Greenland observed in 2007–15 coincided with the onset of thinning along the ice margin in the Baffin Bay area. Preliminary results suggest that the surface elevation near the summit of the Greenland ice sheet observed in 1992–96 lowered slightly over the last 40 years, during a period of widespread thinning along the western margin. These interior elevation changes can be due to local changes in surface mass balance or be an interior dynamical response to mass loss at the margins, thus suggesting that the central ice divides are responding to the increased mass loss along the margins.

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## New monthly maps of accumulation over the Greenland Ice Sheet

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The Greenland Ice Sheet has become the single largest contributor to present day sea-level rise, with mass loss driven by changes in Surface Mass Balance (SMB). Snow accumulation, as the largest component of SMB, is critical to monitor as Arctic warming continues at an accelerated rate. In-situ observations are inherently sparse, with coarse, inconsistent temporal resolutions, presenting challenges for model validation. Here, we present a novel method to calibrate regional climate model precipitation output with in-situ SMB records from the SUMup dataset, primarily containing radar, ice-core, and stake measurements. We provide monthly bias-adjusted accumulation maps for HIRHAM5 regional climate model output between 1960-2022, highlighting misrepresented regions and possible causes. Model output data is decomposed into Empirical Orthogonal Functions (EOFs), reflecting different modes of spatial variability, and Principal Components (PCs), capturing temporal fluctuations relating to various climate indices. A set of coefficients to scale each EOF and PC are determined based on SUMup data using least-squares optimisation. Coefficient values indicate if there are particular climate mechanisms which may be systematically misrepresented by the model. For example, we find that the third PC, correlating with the winter Greenland Blocking Index and anti-correlating with the Autumn Atlantic Oscillation, is scaled down significantly. Overall, the method shows that HIRHAM5 underestimates accumulation by an average of 9.5%. The south-eastern regions show the greatest underrepresentation, consistent with previous studies, with accumulation underestimated by up to 40% around the southeast ice margin.

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## How to measure accumulation on the Greenland Ice Sheet?

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The Arctic climate is currently undergoing rapid change, causing a sustained, uninterrupted mass loss from the Greenland Ice Sheet over the last 28 years. The Danish-Greenlandic governmental monitoring programmes Greenland Climate Network (GC-Net) and Programme for Monitoring of the Greenland Ice Sheet (PROMICE) aims to assess the mass balance, combining remote sensing, modelling and in-situ observations. The largest component of the ice sheet mass balance is the accumulation of snow, which is notoriously hard to represent correctly in models, but also hard to observe from satellites. Consistent, automated in situ measurements of accumulation are thus crucial to validate and calibrate regional climate models and satellite products, but are challenging to retrieve in the extremely remote and harsh environment of the ice sheet. Here we present our current efforts to address this problem, using everything from plywood to Cosmic Ray Neutron Sensing, focusing on the technical and practical challenges.

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## Using in-situ observation of atmospheric water vapor isotopes to benchmark isotope-enabled General Circulation Models and improve ice core paleoclimate reconstruction

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Water vapor is an important component of the global hydrological cycle and an important greenhouse gas. Yet our current knowledge of atmospheric processes responsible of clouds development, moistening/drying of the troposphere remains imprecise and leads to a large spread in the projections of future temperatures. Specifically, a better understanding of the mechanisms controlling the marine boundary layer humidity has been identified as an important step for reducing the spread in the climate sensitivity uncertainty. Complex interactions between the ocean surface, the marine boundary layer and the free troposphere are involved in the moistening of the marine boundary layer and in turn the development of clouds. Due to their strong influence on the radiative balance, and because the climate sensitivity differences are related to different model representations of clouds these uncertainties have a large impact on climate predictions. Here we present in situ observations in the Atlantic with potential for revealing hidden moistening processes of the marine boundary layer. The instruments deployed in the Atlantic allowed for a high frequency sampling of water vapour and their isotopic composition. The isotopic composition of water vapour is sensitive to the different sources of the vapour and to the different processes that affected the air parcel upstream. This means that the water vapour isotopic composition contains a wealth of additional information on the moistening processes, which are normally hidden when just looking at the humidity variability. The measurements done in the frame of a RANNIS project provide an unprecedented record of water vapour isotope measurements in the North Atlantic Ocean. From this data record a conceptual model was developed capable of reproducing the variability observed in our measurements. The results highlight the importance of the interactions between the first layer of the atmosphere and the free troposphere on the humidity budget of the first layer. The sensitivity of isotopes to these exchanges makes them a powerful tool to evaluate the accuracy of climate model in simulating these important exchanges. We also better identified the control on isotopes at the surface, such as the development of the marine boundary layer or the characteristic of the free troposphere. These are important findings as water isotopes records, in ice cores for example, are used to infer the properties of past climates.

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## Glacial isostatic adjustment modelling of Iceland: moving into the 2020s

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Iceland is subject to current ice mass changes, and undergoes Glacial Isostatic Adjustment (GIA) with uplift rates up to 35 mm/yr. A proper GIA model allows to estimate and remove the time-dependent GIA signal when studying other deformation processes, such as magma movements and tectonic deformation. Moreover, the GIA-induced stress changes may affect magma production rates, storage stability and intrusion vs eruption likelihoods. We use a 3D Finite Element model, developed using COMSOL Multiphysics, assuming a flat incompressible Earth in the governing equations, but allowing for material compressibility in the Earth rheology, and neglecting selfgravitation. Previous GIA studies in Iceland have been based on estimates of the integrated mass loss of Vatnajökull, between 1890-2004 or shorter, and on rough estimates for the other glaciers. For Vatnajökull, we now merge data from two time frames: between 1890-2010, we use an ice-history based on the integrated values of the mass-balance with a few years to several tens of years resolution; between 2010-2023, we use a laterally varying ice history based on observational data at an annual and kilometer scale. For all the other glaciers, we use integrated values for their mass balance following each 1890-2023 ice-history. The new glacier data, compared to the last used in present day GIA studies, show a lower estimate of the mass loss of the Icelandic glaciers, amounting to 34%. Our Earth model consists of an elastic plate overlying a viscoelastic mantle. The rheological parameters vary only with depth. GNSS and InSAR observations, which span several time periods from 1993 and on, are well fitted by the models. For this simple Earth model, we find the optimal elastic thickness to be 35 km, and the optimal viscosity ranging between 2-4 x 1018 Pa s. While the elastic thickness is consistent with previous studies, the optimal viscosity is lower, following the reduced estimates of the Icelandic glacier mass-loss since 1890 used herein. This work is expected to pave the way for a more accurate analysis of the GIA time dependency and GIA-induced horizontal displacement.

24nb4649

## Modeling holocene glacial isostatic adjustment in Iceland using composite asthenosphere viscosity: comparisons with linear rheology and implications for glacially induced asthenosphere melting

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The usage of higher-order dislocation-included composite rheology flow laws is quickly emerging in studies of Glacial Isostatic Adjustment, in agreement with longstanding evidence from other subfields that the upper mantle is controlled by a stress-dependent composite (linear + nonlinear) rheology. With improvements in computing ability and geodetic data coverage, the longstanding simplification of linear Maxwell viscoelastic asthenosphere rheology is becoming less justifiable. No high-order rheology Earth parameter search focused on Iceland has been performed up to this point based on geodetic data, despite the anomalously soft linear estimates for Icelandic Asthenosphere viscosity (~1E19 Pa·s) produced in the past. The goal of this body of work is to evaluate the necessity of stress-dependent rheology in future 3D Icelandic GIA modeling efforts. We find composite rheological models can fit the data as well as linear rheological models, with neither rheology having a statistically significant better fit than the other. The second phase of the work evaluates the impact of non-linear rheology on GIA induced depressurization and partial melting of the mantle. It is the first study of GIA induced melting to use nonlinear rheology and the second to use a realistic melt parameterization and melting region. It is also the first independent finite-element modeling attempt at modeling glacially-induced melting in the early Holocene. Predictions of pressure changes produced by the models display wide spatial and temporal variation based on the contribution of dislocation flow and magnitude of deglaciation. Nonlinear rheology leads to noticeably front-loaded melting (i.e., melting at the beginning of deglaciation) and increases melting (6-35%) in predicted total mantle melting from 1890-2020 over linear rheology. For a full deglaciation (with the early Holocene deglaciation in Iceland as the test case), composite nonlinear models predict the opposite trend of reducing total melt generation by 4-10%. Further work implementing nonlinear rheology into future detailed modeling of melt production is therefore recommended, especially when simulating significant glaciations.

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## Rapid earth uplift in southeast Greenland driven by deglaciation above the Iceland plume track

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Around the periphery of the Greenland ice sheet, Global Navigation Satellite System (GNSS) stations record uplift that reflects Earth's response to past and recent unloading of ice mass. On the southeast coast, near the Kangerlussuaq glacier, GNSS stations show unusually rapid ground uplift exceeding 12 mm/yr. Current models of glacial isostatic adjustment (GIA), which employ a layered Earth structure, cannot explain this rapid uplift. We find that 3D models that incorporate a "track" of weakened earth structure, consistent with the passage of Greenland over the Iceland plume, can predict the rapid uplift of southeast Greenland. This uplift is dominated by a viscous response that is amplified by the low viscosities of the hot plume track. Recent mass loss, occurring during the last millennium and especially within the past few decades, drives most of the uplift. Rapid uplift also occurred in this area following deglaciation at the end of the last ice age, but this uplift happened thousands of years ago and was recorded by geologic indicators of rapid sea level drop at the start of the Holocene. Regions of weakened mantle positioned below marine terminating glaciers may be especially important, because rapid uplift following ice mass loss can affect the future stability of entire ice catchment areas upstream. Such regions will become increasingly important in the near future as deglaciation accelerates.

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## Generating distributed surface mass balance fields with a Bayesian Hierarchical Model

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Generating distributed surface mass balance fields with a Bayesian Hierarchical Model

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## Photos and folk: citizen science repeat photography

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Historical photographs can be a valuable resource for repeat photography providing detail of glacier and landscape changes over time. Today photography is more widespread than ever among both experts and the public who visit glaciers. We consider how the photographic record taken today can be made more useful for future comparisons, and how photography and repeat photography for glacier monitoring can be made open and accessible for public contributions. We present two new citizen science projects of Jöklarannsóknafélag Íslands/Iceland Glaciological Society (JÖRFÍ) – Jöklasýn/Extreme Ice Survey Iceland (EISI) and RePhoto – that invite the public to engage with glacier monitoring through repeat photography from fixed locations, and the accurate geolocation of historical images. This work builds upon an expanding archive of historical photographs including the recently scanned collection of JÖRFÍ which is now publicly available. While the projects are in early stages (both launched in 2024) engagement so far demonstrates the potential of citizen science to involve the public in the understanding of glacier changes in a participatory way.

24nb4653

## Jökulhlaups in Iceland: recent floods, and risk assessment


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A jökulhlaup is a flood caused by the sudden emptying of a water body that is formed by a glacier. The water bodies can be supraglacial lakes, proglacial lakes, or subglacial lakes. Jökulhlaups are an important part of the hydrology of Iceland's glaciers. These floods range over orders of magnitude in size and may have a maximum discharge on the order of hundred thousand cubic meters per second and a maximum flood volume on the order of cubic kilometers in the largest events. In Iceland, jökulhlaups are most often caused by an interaction between glaciers and geothermal and/or volcanic activity. These floods are one of the main natural hazards related to glaciers in Iceland. Jökulhlaups may endanger people and livestock and there has been an increased risk to people in recent years due to increased tourist activity in exposed areas. Jökulhlaups can damage different infrastructure such as roads, communication lines, farmland, hydropower plants and power supply systems. There are around 1–3 hazardous floods per decade causing damage. The hazard and the risk caused by jökulhlaups needs to be assessed and quantified for land-use planning and risk reduction. In Iceland, such assessment is already completed for selected areas, but other locations are still being worked on. A risk assessment for several different scenarios of jökulhlaups released to west and south from the subglacial Bárðarbunga volcano is one of the projects that is being worked on. Initial results of the project will be presented, but these jökulhlaups could severely affect Iceland's hydropower production. The most recent jökulhlaup that caused damage happened in July this summer, 2024. The flood was released from the Mýrdalsjökull ice cap and breached the main ring road around Iceland (road 1) east of the bridge over the river Skálm. This caused transportation problems for two days during the height of the tourist season. We will present the initial results on quantification and hydraulic modelling of this flood.