Book of abstracts

Liss M. Andreassen <lma@nve.no>
Section for Glaciers, Ice and Snow, NVE
Contribution type: R

Changes of Jostedalsbreen - Norway's largest ice cap

Abstract: The Jostedalsbreen ice cap is mainland Europe's largest ice cap accounting for 20 % (458 km2 in 2019) of the total glacier area of mainland Norway. Here we present an overview of changes from LIA to present day using geodetic surveys, repeated inventories and in situ measurements. The work is a contribution to the JOSTICE project (2020-2025) that aims to assess the present and future changes in mass balance, runoff, ice volume and local climate of Jostedalsbreen.

Luc Beraud <luc.beraud@univ-grenoble-alpes.fr>
Institut des Géosciences de l'Environnement
Contribution type: R

Glacier-wide seasonal and annual geodetic mass balances from Pléiades stereo images of the Glacier d'Argentière, French Alps.

Abstract: We assess the ability of sub-meter stereoscopic satellite images to retrieve annual and seasonal mass balances over the Glacier d'Argentière, in the French Alps. We use a seven-year time series of 12 DEMs derived from the Pléiades optical satellites to estimate five annual and four winter geodetic glacier-wide mass balances. We find good agreement between the mass balance values estimated using the geodetic method and those of in-situ glaciological measurements: mean values via the geodetic method are -0.66 m w.e. (annual) and 1.47 m w.e. (winter), respectively; mean absolute discrepancies are 0.25 m w.e. (annual) and 0.36 m w.e. (winter). We investigated the interest of degree-day mass balance adjustment between geodetic and glaciological mass balances, without improvement. Our study identified three main limitations of our methodology: (i) the intrinsic DEM precision; (ii) the lack of control over the satellite acquisition dates; and (iii) the density assumption.

Marta Chiarle <marta.chiarle@irpi.cnr.it>
CNR-IRPI
Contribution type: R

The 2022 Marmolada Glacier failure in the framework of historical glacier instability in the Italian Alps

Abstract: On July 3, 2022, on a hot and sunny day, about 60.000 m3 of ice suddenly detached from the Marmolada Glacier (Dolomites), generating a rapid flow of ice, water and debris, which hit several climbers. The event, which is the most tragic event ever documented in the Italian Alps, had a remarkable media coverage and suddenly raised the attention of the citizens and of authorities in charge of risk management towards glacier hazards; as never before, there has been a perception of emerging risks related to ongoing climate and cryosphere changes. We present a study on the main glacier failures that have been documented in the Italian Alps in the last 90 years, which allows to provide a preliminary picture of their spatio-temporal distribution and to draw some considerations on the impact of climate change on their occurrence.

Samuel Cook <samuel.cook@unil.ch>
University of Lausanne (UNIL)
Contribution type: R

Alpine ice thickness estimation using deep-learning-driven emulation of Stokes

Abstract: Mountain glaciers are a major source of sea-level rise and an important freshwater resource in many regions. However, to date, only 2% of the world's glaciers have any thickness data, creating a large and policy-relevant scientific gap. The recent development of a global-scale ice-velocity dataset, however, provides an opportunity to fill this gap. This can be done by inverting an ice-dynamics model to solve for the ice thickness. For accurate thickness results, this needs to be a full-Stokes model, but such a model is too computationally cumbersome to apply globally, and simpler methods based on the shallow ice approximation are too inaccurate. As a solution to this problem, we present results from a deep-learning-driven inversion model that emulates the performance of full-Stokes models at a thousandth of the computational cost. With a view to a large-scale application to all the world's 200,000 glaciers, we present initial thickness-inversion results for the European Alps.

Federico Covi <federico.covi@gmail.com>
University of Oslo
Contribution type: R

Spatio-Temporal Variations of Blue Slush and Water Flow in the Percolation Zone of Greenland: the Role of Local Topography

Abstract: The presence of thick ice layers in firn (so-called ice slabs) has the potential to increase the contribution to sea-level rise of the Greenland ice sheet. These impermeable ice layers prevent water percolation in the firn, leading to more efficient runoff by favoring lateral movement of water on top of the ice slabs. Here we use optical images from the Sentinel-2 satellites to track the seasonal and interannual evolution of snow fully saturated with water to the surface (blue slush) in southwest Greenland. Furthermore, we use a high resolution digital elevation model to assess the role of local topography on the formation of ice slabs and on lateral movement of water. We find that blue slush can reach elevations up to 1900 m a.s.l. in years with above average melt with maxima in August. Blue slush appears preferentially in areas where the surface slope approaches 0°, which is also where the ice slabs are thicker. The propagation of blue slush to lower elevation following local topography indicates water movement on top of the impermeable layer. Thus, we suggest that the process of formation of thick ice slabs is a self-sustaining positive feedback system.

Davide Fugazza <davide.fugazza@unimi.it>
University of Milan, Italy
Contribution type: R

Documenting the demise of Forni Glacier from repeat UAV surveys 2014-2022

Abstract: UAVs have become an increasingly important tool to understand height and volume variations of glaciers. However, most studies are based on a few years of data. Here, we compare DEMs from six UAV surveys of Forni Glacier (Ortles-Cevedale, Italy) acquired between 2014 and 2022. Various drone platforms/cameras were used for the surveys, and before 2020 a limited number of GCPs was set up, with negative impacts on DEM accuracy. In 2022, we employed a Phantom 4 RTK with GCPs and carried out post-processing of the UAV GNSS tracks; thus, we were able to obtain a 3D accuracy better than 5 cm. All previous DEMs were coregistered to the 2022 DEM using the point-to-plane variant of the ICP algorithm, by selecting stable areas outside the glacier for the coregistration procedure. Based on the coregistered DEM stack, we are therefore able to provide a high-resolution timeline documenting height changes of Forni Glacier, whose tongue is showing high downwasting and areas prone to collapse.

Adrien Gilbert <adrien.gilbert@univ-grenoble-alpes.fr>
IGE (Grenobe)
Contribution type: R

Inferring the Basal Friction Law from long term observations of Glacier Length, Thickness and Velocity changes on an Alpine Glacier

Abstract: Glacier and Ice sheet basal sliding remain a large source of uncertainty when simulating the long term evolution of ice masses. In particular, ice-flow response to changes in driving stress strongly depends on the value of the exponent m in non-linear friction laws (e.g. Weertman's law) which is poorly constrained by observations. Here, we perform a natural scale friction experiment on the Argentière Glacier (French Alps) by taking advantage of particularly well-resolved observations of glacier surface mass balance, geometry and basal sliding over long time scale. We combine three different independent methods based on (i) surface velocities inversion, (ii) transient length change modeling and (iii) direct local sliding measurement to infer value of m = 3.3 ± 0.2. We suggest this value should be used in general for hard-bedded glaciers and ice sheets modeling in opposition to linear laws that are likely inaccurate.

Noel Gourmelen <noel.gourmelen@ed.ac.uk>
University of Edinburgh
Contribution type: R

Global glacier mass balance and mass balance partitioning from radar altimetry

Abstract: We generate for the first time a high spatial and temporal record of ice loss across glaciers globally from CryoSat-2 swath interferometric radar altimetry, demonstrating that radar altimetry can now be used alongside GRACE and DEM differencing for global glacier mass balance assessments. Between 2010 and 2020, glaciers lost a total of 272 ± 11 Gt yr−1 of ice, equivalent to a loss of 2% of their total volume during the 10-year study period. All years observed experienced ice loss, however there is considerable variation in the rates of loss from year to year. Between 2010 and 2020, glaciers have contributed 0.75 ± 0.03 mm yr−1 to SLR, equivalent to the loss of both ice sheets combined over the same period, and equivalent to about 25% of global sea-level budget. We then partitioned mass change into surface mass balance and change in ice discharge. Between 2010 and 2020, surface mass balance was responsible for 90% of the global glacier mass loss. In Patagonia and in the Barents and Kara sea regions, increasing ice discharge played a significant role on, and sometimes dominated, the mass budget.

Oskar Herrmann <oskar.herrmann@fau.de>
Friedrich-Alexander Universität Erlangen-Nürnberg
Contribution type: R

Out-of-the-box application of deeplearning for calving front detection.

Abstract: Glacier calving is an essential process of the ablation of marine-terminating glaciers. With the increasing number of satellite images, the calving process is observable with a higher temporal resolution. The usage of Synthetic Aperture Radar (SAR) permits observation that is independent of season and cloud coverage. This work presents a method that automatically delineates the calving front on SAR imagery using a neural network. nnU-Net is a framework that simplifies the training of the neural network U-Net, widely used for segmentation tasks. We train the network on an already published dataset of SAR and the manually delineated calving front position and image segments (ocean, glacier, rock and radar shadow). We show that simultaneous training of glacier calving front detection and image segmentation increases the accuracy of the individual tasks. This method is called Multi-Task Learning (MTL). We evaluate and compare different approaches of MTL. In the end, we examine the influence of season, satellite and glacier on the accuracy of the calving front delineation.

Mylène Jacquemart <jacquemart@vaw.baug.ethz.ch>
WSL
Contribution type: R

Playing It Cool: A global englacial temperature database (glenglat)

Abstract: Ice temperature is an important characteristic of any glacier, but ice temperature measurements are logistically complex, expensive, and laborious to collect. In order to alleviate the growing need for a better understanding of glacier thermal regimes and their changes, we have compiled a database of englacial temperature measurements from published literature and submitted datasets. Data from around 70 studies, comprising almost 300 temperature profiles collected on nearly 90 different glaciers distributed across all continents have been assembled into a structured database. Here, we present this database as a community resource, elaborate on the data content and structure, solicit additional and future data contributions, and provide a first analysis of global ice temperature distributions.

Livia Jakob <livia@earthwave.co.uk>
Earthwave
Contribution type: R

GlaMBIE – An intercomparison exercise of regional and global glacier mass changes

Abstract: Retreating and thinning glaciers are icons of climate change and impact the local hazard situation, regional runoff as well as global sea level. Towards IPCC SROCC and AR6, there have been considerable improvements with respect to the availability of geodetic datasets. This opens new opportunities for regional evaluations of results from different methods as well as for truly global assessments of glacier mass changes and related contributions to sea-level rise. At the same time, the glacier research and monitoring community is facing new challenges related to the spread of different results as well as new questions with regard to best practises for data processing chains and for related uncertainty assessments. In this presentation, we introduce the Glacier Mass Balance Intercomparison Exercise (GlaMBIE) project of the European Space Agency, which is building on existing activities and the network of the International Association of Cryospheric Sciences (IACS) working group on Regional Assessments of Glacier Mass Change (RAGMAC) to tackle these challenges in a community effort. We will present our approach to develop a common framework for regional-scale glacier mass-change estimates towards a new data-driven consensus estimate of regional and global mass changes from glaciological, DEM-differencing, altimetric, and gravimetric methods.

Guillaume Jouvet <guillaume.jouvet@unil.ch>
University of Lausanne (UNIL)
Contribution type: R

Overview and capabilities of IGM, a glacier evolution model boosted by deep-learning

Abstract: Deep-learning emulators permit to reduce dramatically the computational times for solving physical models. Trained from a state-of-the-art high-order ice flow model, the Instructed Glacier Model (IGM, https://github.com/jouvetg/igm) is an easy-to-use python code that can simulate the 3D evolution of glaciers several orders of magnitude faster than the instructor model with minor loss of accuracy. Switching to Graphics Processing Unit (GPU) permits additional significant speed-ups, especially when modeling large-scale glacier networks and/or high spatial resolutions. Taking advantage of GPUs, IGM can also track a massive amount of particles moving within the ice flow, opening new perspectives for modeling debris transportation of any size (e.g., erratic boulders). Here I give an overview of IGM, illustrate its potential to simulate past and future glacier evolution in the Alps together with particle tracking applications, and present ongoing model developments.

Nina Kirchner <nina.kirchner@natgeo.su.se>
Stockholm University/Tarfala Research Station
Contribution type: R

Tarfala Research Station (TRS): Current Activities

Abstract: TRS is Stockholm University's centre for glaciological and alpine research and is situated in the Tarfala valley at 1135 m a.s.l. east of Kebnekaise. TRS is Sweden's only research station in a high alpine arctic environment surrounded by glaciers. An important component of the research conducted at TRS is the glacier mass balance program for Storglaciären, Mårmaglaciär, Rabots glacier and Riukojetna. TRS is also responsible for measuring the annual height of Kebnekaise's southern peak, which determines the highest point in Sweden and thus generates great public interest. Over the years TRS has broadened its scope of research with active projects now going beyond glaciology and geomorphology focusing on ecosystems, biodiversity, hydrology, meteorology, climatology, archaeology and cultural geography to name but a few. Here, a few examples from TRS will be presented.

Magnus Magnusson <magnus@igsoc.org>
IGS
Contribution type: R

IGS summary

Abstract: -

Christoph Mayer <christoph.mayer@badw.de>
Bavarian Academy of Sciences and Humanities
Contribution type: R

Snow, clouds and sun, the ingredients for extreme mass balance events

Abstract: Since the beginning of the new millennium, glaciers in the Alps experienced two extremely negative mass balance years. The event of 2022 even topped the already very high melt rates in 2003, reaching far into hitherto existing accumulation basins. We investigate the similarities and differences between the two years, especially with regard to forcing parameters, melt water production and the role of the snow and firn reservoir at Vernagtferner in the Ötztal Alps. It appears that the glacier today mostly lost its controlling influence on discharge, while at the same time the firn coverage reduced to a minimum. The mass balance gradient shows a similar shape between the two years, even though the slope is considerably steeper in 2022, indicating that especially the higher regions are contributing above average to the total melt.

Samuel Nussbaumer <samuel.nussbaumer@geo.uzh.ch>
University of Zürich (UZH)
Contribution type: R

Long-term response of the mountain cryosphere to climate change – a comparative perspective of the Andes of central Chile and the European Alps

Abstract: Over the last two decades the importance of the Andean cryosphere, particularly as water resource, has been recognized in both the scientific literature and the public sphere. However, in contrast to the European Alps, lack of field studies and limited knowledge regarding long-term cryosphere evolution has precluded basic knowledge for water-resource management and planning. Using detailed glacial geomorphological mapping and new geochronologic and geophysical data we unravel the ice evolution in four basins in the Andes of central Chile, a region that has been experiencing accelerated warming and a dramatic drought spell. The findings from our analysis suggest glacier advances during the pre-last glacial period and the Last Glacial Maximum (~26–18 kyr ago), between 9–12 kyr ago, ~2700 yr cal. BP, ~850 yr cal. BP, and by the 13th to 16th centuries and early to mid-19th century. Since then, a gradual pattern of distinct moraine ridges denotes a rather active and gradual ice demise. We discuss ages and their paleoclimate implications and we conclude with an interhemispheric comparison of glacier chronologies from the Andes and the European Alps.

Atsumu Ohmura <atsumu.ohmura@env.ethz.ch>
Institute for Atmospheric and Climate Science, E.T.H.Z.
Contribution type: R

Alpine Glaciers in Changing Climate-especially on the role of longwave downwelling radiation

Abstract: To understand the causal process of the on-going climate warming, a crucial information was missing. It is about the possible change in the longwave atmospheric downwelling radiation (hereafter IR), which is the energy source for the warming at the Earth's surface. To investigate if indeed IR is changing, and if changing, how fast, the World Climate Research Programme (WCRP) launched a project, Baseline Surface Radiation Network (BSRN) in 1992. Since then, thirty years' precision radiometry was carried out at about fifty sites covering strategically important regions of the world. The Alps is well covered with this network. The analysis of IR in and around the Alps indicates an unmistakable increase of IR. Further, the IR increase appears faster at higher altitudes where glaciers and permafrost are located. The changing speed of observed IR is faster than most model predictions. These observational facts pause a critical question for the future of the cryosphere in the Alps. The results of the IR analysis and their effect on the cryosphere will be quantitatively discussed.

Aleksandra Osika <1aleksandra.osika@gmail.com>
University of Silesia in Katowice
Contribution type: R

Fluctuations of glaciers in Svalbard from radiocarbon dating and numerical modeling

Abstract: The ongoing climate warming leads to rapid retreat of glaciers in the Arctic, including Svalbard. Analyzing the warmer phases of the Holocene may shed new light on their future evolution. The aim of our study is to reconstruct the fluctuations of land- and marine-terminating glaciers in Hornsund (Svalbard) combining geochronological analyses with ice flow modeling. Radiocarbon dating of marine shells, organic sediments and subfossil soils suggests that glaciers in the first half of the Holocene and in the Medieval Warm Period were smaller than present. The periods of cooling and subsequent advances occurred c. 2 ka cal. BP and during the Little Ice Age. In turn, a time-dependent 2-D ice flow model was used for analysis of the geometric and climatic controls on the extent and dynamics of Hansbreen (tidewater) and Werenskioldbreen (land-based). Our study confirms their high sensitivity to even minor increase of the ELA, which contributed to retreat of Hansbreen onto land and rapid colonization of a new fjord branch since the Early Holocene.

Akash Patil <Akash.Patil@badw.de>
BAdW Munich & FAU Erlangen
Contribution type: R

Improved volume-to-mass conversion of Alpine Glacier by new density scenarios

Abstract: Abstract: The mass balance of glaciers indicates the effect of regional climate and also provides information on glacier hydrology. Glacier mass balance can be estimated by converting differences in glacier volume to mass using various geodetic and remote sensing methods. However, this requires an assumption about the bulk density. Our study focuses on investigating the volume-to-mass conversion of glaciers by considering the new density scenarios and geodetic and geophysical techniques, motivated by Huss [2013] as a reference study. With continuous UpGPR (Upward looking Ground Penetrating Radar) data, we are analyzing the evolution of the snow and firn and the density distribution over the depth within the snowpack at a glacier accumulation site. Preliminary understanding suggests that UpGPR gives a clear picture of the evolution of snow and firn layers and considerably supports the density distribution evolution within the snowpack. However, it needs further improvements in different data analysis techniques, mainly during the melt season, to provide a realistic transformation of the firn layer during the summer period. We demonstrate the potential of the non-destructive methods of density investigations. This study forms the basis to develop the monitoring of the spatiotemporal variation of firn distribution and density with changes in glacier surface mass balance and dynamics under different climate conditions.

Livia Piermattei <livia.piermattei@wsl.ch>
WSL
Contribution type: R

Glacier elevation changes from spaceborne optical data using single and multi-DEM approaches

Abstract: Livia Piermattei1,2, Désirée Treichler2, Ruitang Yang2, Luc Girod2, Robert McNabb3, Andreas Kääb2 1 Department of Land Change Science, Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf, Switzerland 2 Department of Geosciences, University of Oslo, Oslo, Norway 3 School of Geography and Environmental Sciences, Ulster University, Coleraine, UK This work is part of the Regional Assessments of Glacier Mass Change (RAGMAC) inter-comparison experiment, which aims to compare estimates of glacier elevation changes from spaceborne optical and radar data using the geodetic method. Here we present the results of one participant group. We compared two approaches to derive glacier elevation changes on a single glacier (i.e. Hintereisferner, Austria) and an ice cap (i.e. Vestisen, Norway) using ASTER DEM. The first approach - referred to as the single DEM approach - consists of calculating elevation differences using selected DEMs close to the validation period and with sufficient glacier coverage. The validation period is defined by the acquisition period of the airborne surveys, which are used as validation data. The second approach - referred to as the multi-temporal DEM approach - is based on the extrapolation of elevation values using the provided ASTER DEM time series. Our approach consists of using the co-registered ASTER DEMs time series to derive the median elevation within fixed elevation bands (e.g. bins of 100 m), interpolate the median elevation data points over time using a RANSAC linear interpolation, and extrapolate the elevation information for each band that corresponds to the validation period. We then derived the area-weighted mean to calculate elevation changes over the entire glacier. This approach is different from other multi-temporal approaches, which commonly assess the elevation evolution of individual pixels (or a window filter) and then aggregate the so-derived trends in a second step. We validate our spaceborne results with airborne data and discuss the pros and cons of our two approaches. We also discuss the challenges related to ASTER DEM for calculating glacier elevation change, including issues related to the co-registration, void filling, and annual and seasonal corrections.

Fanny Brun / RAGMAC WG1 <fanny.brun@univ-grenoble-alpes.fr>
RAGMAC WG1
Contribution type: R

Observing glacier elevation changes from spaceborne optical and radar sensors – lessons learned from an intercomparison experiment using ASTER and TanDEM-X data

Abstract: Spaceborne sensors have made it possible to quantify spatially distributed glacier elevation changes on a regional and global scale. However, the results show a wide spread with differences often beyond error bars. Here, we present the results of a community-based inter-comparison experiment using spaceborne optical and radar sensors to assess elevations changes for selected individual glaciers and regional glacier samples. Validations with airborne data show that the median of the spaceborne ensemble is biased of a few decimeters per year (standard deviation of about half a meter per year). Thereby, we find no sensor or processing strategy to perform significantly better for all experiment sites. 45% of the individual experiment runs are significantly different from the validation results, hinting towards underestimated error bars. On a regional scale, we find that the co-registration of DEMs is the most relevant processing step for an accurate assessment of elevation change.

Johannes Reinthaler <johannes.reinthaler@geo.uzh.ch>
University of Zürich (UZH)
Contribution type: R

Reconstructing the Little Ice Age glacier surface

Abstract: To reconstruct the glacier surface at the Little Ice Age maximum, recent studies interpolated the elevation from the values along the former outline. However, no detailed comparison of the methods, their input data requirements or uncertainty analysis of the related surface reconstruction method has been presented so far. In this study, we quantify the performance of different surface interpolation methods when replicating modern glacier surfaces from a recent DEM. This was tested with the Arctic DEM for a sample of 85 glaciers in southern Novaya Zemlya. First results indicate, that the Natural neighbour as well as the Topo to Raster tool, are the most promising interpolation methods. We also developed a method for LIA surface reconstruction, complementing outline elevation data with centre point elevations derived from elevation changes on the side of the glacier. This allowed us to generate a more realistic representation of the former glacier surface by accounting for concave or convex surfaces. The calculated volume change rate for the glacier sample in Novaya Zemlya is -0.14 m a-1, six times lower than the change in the last 20 years (Hugonnet et al. 2021).

Niklas Richter <niklas.richter@uibk.ac.at>
University of Innsbruck
Contribution type: R

Improving understanding of regional drivers of glacier surface energy balance

Abstract: Most regional glacier mass change studies do not quantify the atmospheric drivers of glacier melt, nor their spatial variability. Surface energy and mass balance (SEB and MB) models that address this shortcoming are typically applied at only a few glaciers where observations can address model dependence on both (i) reliable atmospheric forcing data and (ii) calibrated model parameters. Here we evaluate the possibility of extending SEB/MB simulations from local to regional scale by introducing a semi-automated model parameter calibration of the open-source COSIPY model coupled with remotely derived transient snowline altitudes and geodetic MB using Bayesian inference on a few selected reference glaciers in High Mountain Asia from 2010 to 2020. We seek to compare the calibrated results to existing studies and measurements to evaluate both the feasibility of the applied framework and the posterior parameter space and assess the uncertainty in light of parameter equifinality.

Juan Pedro Roldan Blasco <juan-pedro.roldan-blasco@univ-grenoble-alpes.fr>
IGE (Grenobe)
Contribution type: R

Deformation, creep enhancement and sliding in a temperate alpine glacier

Abstract: We present an inclinometry study carried out from late 2019 to late 2020 at the ablation zone of Glacier d'Argentière, a temperate glacier in the French Alps. We reconstruct the deformation rates, the resulting deformation velocity, and the basal velocity. We infer the rheological parameters by comparing our observations with a three-dimensional full-Stokes model of the glacier. The yearly-averaged deformation rates profile has limited sensitivity to the flow law exponent and instead mainly reflects an increase in the creep factor with depth which can be due to depth-increasing interstitial water content. We further show that internal ice deformation exhibits seasonal variability. At longer timescales, surface velocity variability is due to changes in deformation, while shorter velocity variability is due to changes in basal velocity. Higher deformation during summer suggests increased ice-bed coupling resulting from the development of a drainage channel in the central part of the glacier.

Hugo Rousseau <hugo.rousseau@geo.uzh.ch>
University of Zürich (UZH)
Contribution type: R

Modelling discontinuties in ice flow using a Material Point Method

Abstract: Understanding glaciers evolution is of major concern to evaluate their contribution to the sea level rise in the context of global warming. Among the various processes involved in the glacier dynamics, fractures like the calving of ice at the front of marine terminating glacier and crevasse formation affect the stress state, potentially modifying the glacier's velocity. Crevasses also impact the melting rate. The fractures alter the roughness of the ground, increasing the amount of absorbed radiation (Pfeffer and Bretherton, 1987), and open new networks in which the meltwater is likely to penetrate deeper toward the glacier bed (van der Veen, 1998; Stevens et al., 2015; Poinar et al., 2017). As a consequence, the modelling of ice discontinuities in glacier has become a great challenge over the years. One of the most common models is the Linear Elastic Fracture Mechanics (van der Veen, 1998a) which states that a crevasse propagates downward if the longitudinal stress reaches a critical value given by the fracture toughness. This model can be coupled with a damage variable advected along the flow to model the softening of ice happening upward on the glacier (Krug et al. 2014). However, such methods fail to predict large crevasses and require additional closures into the governing equations that need to be calibrated and solved. In this work we propose to model such discontinuities as inelastic deformation, using a continuum damage Material Point Method (Gaume et al. 2021): we solve the classical governing equations for ice flow in a Eulerian-Lagrangian framework and we use a strain softening Drucker-Prager constitutive model to simulate plasticity. Thanks to the Lagrangian part of the model, the fractures appear explicitly where the plastic deformation is high enough. The behaviour of a glacier flowing over a step is investigated. Crevasses appear when the glacier flows over the step and a pattern with regular spacing between the fractures emerges. We propose a parametric study to determine which parameters affect the length of these patterns and potential non-dimensional numbers driving the patterns are identified.

Martin Rückamp <martin.rueckamp@badw.de>
Bavarian Academy of Science and Humanities
Contribution type: R

Modelling the future evolution of an alpine debris-covered glacier

Abstract: Debris-covered glaciers react differently to external forcings than clean-surface glaciers. The debris layer impacts the glacier mass balance by either enhancing the surface melt or protecting the underlying ice. We couple the full-Stokes equation with debris transport but extend the model setup to three-dimensional complex geometries. The framework is implemented using the Ice-Sheet and Sea-level System Model (ISSM) and applied to an idealized alpine glacier geometry. To test the sensitivity of future projections on the debris layer, simulations are forced with high-resolution regional climate model (RCM) data from the EURO-CORDEX ensemble.

Lilian Schuster <lilian.schuster@uibk.ac.at>
Department of Atmospheric and Cryospheric Sciences, University of Innsbruck
Contribution type: R

Glacier projections sensitivity to temperature-index model and climate downscaling parameter calibration choices

Abstract: A recent large-scale glacier model intercomparison revealed a strong influence of model design choice on glacier projections. We look at specific model choices by examining various temperature-index models and calibration options. With the Open Global Glacier Model (OGGM) framework, we compare performance and projections dependence to choices in the surface-type dependent degree-day factors, temporal climate resolutions (daily, monthly), and downscaling strategies (temperature lapse rates, temperature and precipitation bias correction). We focus on 88 glaciers with in-situ observations to assess the added value of higher-resolved mass balance observations. The future glacier state and climate compared to the calibration period decide how specific temperature-index model options will influence the projections. More data for calibration results in smaller projected glacier volumes, although individual glaciers' responses vary. Small differences in model choices have even larger impacts on simulated glacier runoff.

Christian Sommer <chris.sommer@fau.de>
Friedrich-Alexander-Universität Erlangen-Nürnberg
Contribution type: R

Constraining regional glacier reconstructions using past ice thickness of deglaciating areas – a case study in the European Alps

Abstract: Accurate knowledge on regional glacier thickness is essential in order to assess future melt-water runoff. Yet, in-situ thickness observations are limited to a small number of glaciers worldwide. A remedy is found by estimating past ice thickness of deglacierized areas at the glacier margins from remote sensing data such as glacier inventories and DEMs. However, it is known that an uneven spatial distribution of thickness observations can result in a significant bias in the estimate of the total ice volume. Here, we show an approach to overcome this generic limitation of so-called "retreat" thickness observations by applying an empirical relationship based on the estimated ice viscosity from different samples of in-situ and "retreat" thickness observations. Combining different glacier change observations from the European Alps, topography-based correction factors of the ice viscosity are derived and applied to Alpine glaciers to reconstruct the regional ice thickness distribution exclusively from remote sensing data.

Franziska Temme <franziska.temme@fau.de>
Friedrich-Alexander-Universität Erlangen-Nürnberg
Contribution type: R

Modelling Surface Mass Balance in the Furious Fifties: Monte Sarmiento Massif, Tierra del Fuego, Chile

Abstract: Elevated mass loss rates of the Patagonian Icefields make them a global hotspot for glacier retreat. Turning southwards, we encounter a similar picture for the glaciers in the Cordillera Darwin in Tierra del Fuego. The difficult accessibility and the harsh climatic conditions in that area result in scarce observational data on atmospheric conditions and glacier mass balance. This study investigates strategies for calibration of surface mass balance models in the Monte Sarmiento Massif, western Tierra del Fuego, with the goal to achieve realistic simulations of the regional surface mass balance. We apply three calibration strategies ranging from a local single-glacier calibration to a regional calibration with the inclusion of a snowdrift parametrization. Furthermore, we apply four models of different complexity. This way, we examine the model transferability in space, the benefit of regional mass change observations and the advantage of increasing the complexity level regarding included processes. During regular field surveys of Schiaparelli Glacier since 2013, ablation stake, thickness and weather station data was acquired. Satellite remote sensing provides additional information on flow velocities and elevation changes for the entire study site. Performance of simulated surface mass balance is validated against geodetic mass changes and stake observations of surface melting. Results show that transferring mass balance models in space is a challenge, and common practices can produce distinctly biased estimates. Model performance can be significantly improved by the use of remotely sensed regional observations. Furthermore, we show that snowdrift does play an important role for the surface mass balance in the Cordillera Darwin, where strong and consistent winds prevail. The massif-wide average annual surface mass balance between 2000 and 2022 falls between -0.25 and -0.07 m w.e./yr, depending on the applied model. The surface mass balance in the Monte Sarmiento Massif is primarily controlled by surface melting and snowfall.

Anuar Togaibekov <anuar.togaibekov@univ-grenoble-alpes.fr>
University of Grenoble Alpes
Contribution type: R

Rain-induced transient variations in glacier dynamics characterized by a continuous and dense GPS network at the Glacier d'Argentière

Abstract: The motion of glaciers with a temperate base is highly variable in time and space, mainly as a result of glacier basal sliding being strongly modulated by subglacial hydrology. Although transient friction laws have recently been established in order to predict short-term sliding velocity changes in response to water input changes, yet little observations enable fully constraining these laws. Here we investigate short-term changes in glacier dynamics induced by transient rainwater input on the Glacier d'Argentière (French Alps) using up to 13 permanent GPS stations. We observe strong surface acceleration events materialized by maximum downglacier velocities on the order of 2 to 3 times background velocities and associated with significant glacier surface uplift of 0.03 m to 0.1 m. We demonstrate that uplift strikingly coincides with water discharge. In contrast, horizontal speed-up occurs over a timescale shorter than discharge and uplift changes, with a maximum occurring concomitantly with maximum water pressure but prior to maximum discharge or uplift. Our findings suggest that transient acceleration and uplift of the glacier are not necessarily modulated by the same mechanism. We also observe that the horizontal speed-ups propagate downglacier at migrating speeds of 0.04 m s-1 to 0.13 m s-1, suggesting an underlying migration of subglacial water flows through the inefficient, distributed system. We demonstrate that the temporal relationship between water discharge, water pressure, and three-dimensional glacier motions are complex and cannot be directly interpreted by changes in the subglacial water pressure through cavity formation and water storage.

Saurabh Vijay <saurabh.vijay@ce.iitr.ac.in>
IIT Roorkee, India
Contribution type: R

New initiatives to resolve lesser known glacier and glacial lakes change in the Indian Himalayas

Abstract: Title for the Talk: New initiatives to resolve lesser known glacier and glacial lakes changes in the Indian Himalayas Title of the poster: New collaborative work by early career Indian glaciologists

Michael Zemp <michael.zemp@geo.uzh.ch>
University of Zürich (UZH)
Contribution type: R

Temporal interpolation of glaciological mass-balance observations

Abstract: Observations of glacier mass balance using the glaciological method has been the backbone of internationally coordinated glacier monitoring since the mid-20th century. Annual mass-balance estimates have been used to understand glacier reactions to climate change and to assess regional to global glacier mass changes as well as related contributions to runoff and sea-level rise. Thereby, the use of annual mass-balance observations comes with some limitations. As such, the comparability of annual results is hampered by differences in survey periods and in mass-balance amplitudes between glaciers, regions, and hemispheres. Numerical modelling of glacier mass-balance can well address these issues but requires computational resources and knowledge, and comes at the cost of availability and dependency of meteorological data. In this work, I present a simple approach to temporally interpolate glaciological mass balance using seasonal observations and sine wave functions. The approach allows to interpolate seasonal and annual balances at monthly to daily resolutions and it can deal with observational gaps as well as with different durations of winter and summer periods. The results from selected glaciers with long-term observation series are used to illustrate the potential of the sine wave approach to visualize differences in glacier mass-balance amplitudes, to homogenize differences in survey periods, to compare results from northern and southern hemispheres, and to compare glaciological results to monthly time series from spaceborne gravimetry. Finally, the interpolated balances from the sine wave approach are compared to results from numerical modelling to discuss strengths and limitations of both methods.

Etienne Berthier <etienne.berthier@legos.obs-mip.fr>
CNRS-LEGOS
Contribution type: S

How summer 2022 affected Mont-Blanc glaciers. Observations from Pléiades and Pléiades Neo satellite stereo-images.

Abstract: We used Pléiades and Pléiades Neo satellite stereo images acquired in summer 2021 and 2022 to generate digital elevation models and quantify the elevation changes in the Mont-Blanc area during this unusual glaciological year. The one-year thinning measured from satellite data is compared to GNSS measurements at 8 transverse profiles. We show that the thinning was massive and extended up to the highest altitudes.

Roger J. Braithwaite <r.braithwaite@manchester.ac.uk>
University of Manchester, UK
Contribution type: S

Record high glacier melting in in the Alps Summer 2022 but summer temperatures were not as high as in 2003

Abstract: The WGMS (World Glacier Monitoring Service) has reported very high glacier melting in the Alps for 2021/2 while summer temperatures in and around the Alps were somewhat lower than in 2003, the warmest summer recorded so far. The exceptionally negative annual balances in 2021/2 might be due to reduced winter balance the previous winter, or to higher net radiation absorption in the summer. These are probably both under investigation by glaciologists now, while we revisit the extrapolation of temperature variations to glacier altitudes and we re-assess the temperature sensitivity of glacier melt. We confirm that temperature variations in summer 2022 were broadly similar at different stations in and around the Alps, and at different altitudes, and were generally lower than in 2003. Exceptionally high melting for 2021/2 could have arisen with temperatures lower than in summer 2003 if temperature-sensitivity of melt were a little higher than previously known. The ultimate causes of any change in sensitivity must be changes in mass and energy balance.

Aaron Cremona <cremona@vaw.baug.ethz.ch>
VAW - ETH Zürich & WSL
Contribution type: S

Extraordinary melt rates for the Swiss glaciers in summer 2022: more than half of the average summer mass loss in only 25 days

Abstract: The extreme summer of 2022 resulted in record mass losses of the Swiss glaciers, hence reaching a level that was only expected in the decades to come. In this study, we analyze the implications that such extraordinary heat waves have on ice melt and related water runoff from glaciers. To do so, a novel approach based on computer-vision techniques was developed for automatically determining daily mass balance variations at the local scale. The approach is based on an automated recognition of color-taped ablation stakes from camera images. Daily melt rates were automatically retrieved at six sites on three different glaciers and were compared to average values over the last decade to detect and assess extreme melt events. The result indicates 23 days with extreme melt and a strong correspondence between these events and heat waves. The Swiss-wide glacier mass loss during the 25 days of heat waves is estimated as 1.27±0.10 Gt, corresponding to 35% of the overall glacier mass loss for 2022. Compared to the 2010-2020 average, the heat waves in 2022 caused a glacier mass change that corresponds to 56% of the expected overall mass change during summer, demonstrating the relevance of heat waves for seasonal melt.

Nicolas Eckert <nicolas.eckert@inrae.fr>
IGE, INRAE / Grenoble Alpes University
Contribution type: S

Extreme value analysis of the 2022 crazy summer: insight from the Sarennes series

Abstract: The 2022 “crazy summer” led to record-braking glacier mass balance values. Formally, such values should be analyses in the framework of extreme value statistics, but devoted methods remain seldom used in the glaciological community. As one of the longest continuous annual and seasonal mass balance measurement series worldwide, Sarennes glacier series can be used to i) develop methods and tools to analyse abnormally large glacier mass balance values, ii) evaluate to which extent 2022 was an outlier. Here, we present first analyses highlighting i) the return period of 2022 values for accumulation, melt and annual balance and the related uncertainty, ii) how return periods and related uncertainty evolve with the sample size, iii) how results are affected if the discussible stationarity assumption is relaxed, and iv) how more robust estimates could be obtained by borrowing strength from a sample of glaciers from the same area. For the latter, we first use data from other French glaciers, to be later expanded using a wider sample.

Andrea Fischer <andrea.fischer@uibk.ac.at>
IGF/ÖAW
Contribution type: S

Monitoring extreme melt on glaciers and rock glaciers: How to be prepared

Abstract: The extreme melt of 2022 had effects on the ice coring activities, rock glaciers and our measurement networks. What will we have to prepare to cope with such events in the future?

Isabelle Gärtner-Roer <isabelle.roer@geo.uzh.ch>
University of Zürich (UZH)
Contribution type: S

Surprising rockglacier velocities in the summer of 2022

Abstract: Long-term observations of horizontal velocities of rockglaciers are considered a reliable measure to determine the influence of temperature warming on permafrost conditions. Related spatio-temporal patterns of accelerating and decelerating landforms have been described for many sites in the European Alps. The data collection is performed using repeated aerial images, annual terrestrial surveys, continuous GNSS, and is combined with continuous logging of ground (surface) temperatures. During the extraordinary summer of 2022, an increase in horizontal velocities was expected, but the results from rockglaciers in the Engadine and the Valais did not meet these expectations. The given observations provide new insights into subsurface processes.

Marco Giardino <marco.giardino@unito.it>
University of Torino
Contribution type: S

Decade ablation and 2022 sudden collapses within the Miage debris-covered glacier (Mon Blanc)

Abstract: The aerial photogrammetric survey of the Miage Glacier (Mont Blanc) in August 2022 made it possible to develop a DTM for comparison with that produced using LIDAR in 2008. Over the area investigated (4.6 km2) the glacier lost an average of 23 m thickness for a total volume of 110 million m3: in 14 years, a reserve of fresh water equal to 100 billion liters has been lost. Equally impressive are the effects detected on the ground in the scorching summer of 2022. The Miage, a loosely sloping glacier covered in debris, is collapsing due to melt waters. Funnel-shaped concentric annular shapes have appeared on the surface as well as some sudden sinkings. These forms have been related to the sudden emptying of the Miage lake, the activation of endoglacial paths and the breakthrough of the frontal moraine that occurred on the night of 07/11/2022.

Lea Hartl <lea.hartl@oeaw.ac.at>
Austrian Academy of Sciences
Contribution type: S

Summer 2022 at Jamtalferner, AT

Abstract: Jamtalferner in the Austrian Silvretta lost about 6% of its volume during the summer of 2022. With a specific mass balance of -3.6 m w.e., 2022 was by far the most negative mass balance season in the 33 year time series of direct glaciological measurements. In the lower sections of the glacier, 2022 was comparable to previous, very negative mass balance years (2003, 2018). Mass loss at the highest stakes, located in what is no longer the accumulation zone, exceeded previous values by over 1 m w.e. and is completely unprecedented in the time series. 2022 summer fieldwork posed some new challenges, from unusually wet river crossings to stake positions that are no longer viable due to loss of glacier area. Jamtalferner has lost all of its firn and will continue to disintegrate in the coming years. In situ monitoring strategies will have to be adapted to fully capture the process of deglaciation. We look forward to discussing these issues with the community.

Kay Helfricht <kay.helfricht@oeaw.ac.at>
University of Innsbruck
Contribution type: S

The 2022 suspended sediment transport in glacier fed streams

Abstract: Tirolean glaciers had record mass losses by a number of approximately three times higher than average, and suspended sediment yields of the glacial streams appeared to be higher by a comparable number in 2022.

Matthias Huss <huss@vaw.baug.ethz.ch>
ETH Zürich / WSL
Contribution type: S

How it feels to witness the disappearance of a glacier

Abstract: Glacier monitoring in Switzerland has a tradition of more than a century. The last years have impressively demonstrated that the loss of long-term monitoring series is inevitable. Only during the extreme summer of 2022, the measurements of seasonal mass balance needed to be abandoned on three small Swiss glaciers due to (almost) complete wastage of the remaining ice. What does that process do to glaciologists, and how can we prepare to its imminent repetition expected for the coming years? This presentation will give both personal and scientific insights into witnessing the disappearance of glaciers and propose strategies for the future.

Enrico Mattea <enrico.mattea@unifr.ch>
University of Fribourg
Contribution type: S

Colle Gnifetti: giving the firn a wash

Abstract: The cold, dry firn of Colle Gnifetti (4450 m a.s.l., Monte Rosa range) has been a leading site for ice core research during 50 years. In summer 2022, major infiltration of meltwater led to temperate conditions in the firn over at least 2 m depth, persisting for more than one month – far exceeding subsurface temperatures of previous summers and contaminating at least 2-3 annual layers of the ice core record. Remarkably, air temperatures in 2022 did not surpass previous heatwaves at the site. Results from a physical energy-balance and firn model attribute the exceptional meltwater infiltration to simultaneous poor refreezing during warm nights, and consistently strong insolation at daytime. These were possibly compounded by reduced latent heat losses due to high atmospheric moisture. Such conditions pose an urgent threat to the viability of ice core drilling at Colle Gnifetti.

Bastien Ruols <bastien.ruols@unil.ch>
University of Lausanne (UNIL)
Contribution type: S

Impressions from the field : our journey to Otemma.

Abstract: For Swiss standards, the Otemma glacier is rather wild and remote. It lays at the end of a long and narrow valley that can be reached from the Val de Bagnes in the Canton of Valais. For the last three summers, a field camp has been installed near the Otemma floodplain for researchers from the University of Lausanne and collaborating partner institutions. In 2022, our team spent a week at the camp with the objective of recording a large, high-density, 3D ground-penetrating radar dataset near the tongue of the Otemma glacier using a newly developed drone-based instrument. This short unpretentious video aims to briefly present the field-site, the camp, and the data collection using pictures, drone's footages, and narratives.

Marit van Tiel <vantiel@vaw.baug.ethz.ch>
ETH Zürich / WSL
Contribution type: S

The downstream travel of the extreme glacier melt in 2022

Abstract: Summer 2022 broke numerous glaciological, hydrological and climatological records in Europe. Dry and warm conditions led to extreme low-water levels and problems with water supply. The hot summer in combination with little snow in winter was disastrous for the Swiss glaciers; they never lost as much volume in the century long observational record. At the same time, this massive glacier melt meant an alleviation of the downstream hydrological drought situation. Glacier contributions to streamflow during hot and dry periods, as well as their changes due to glacier retreat are, however, poorly quantified. In this study, we characterize the glacio-hydrometeorological extremeness of the hydrological year 2022 in Switzerland and compare it with other exceptional years in the past. Observational streamflow records from about 80 stations along glacier-fed rivers were analyzed, together with (i) temporally downscaled and spatially extrapolated glacier mass balance observations, as well as (ii) temperature and precipitation information.

Lander Van Tricht <lander.van.tricht@vub.be>
Vrije Universiteit Brussel
Contribution type: S

Regional-scale vs glacier-scale models: a comparison in the Tien Shan

Abstract: Glaciers in the Tien Shan mountains supply meltwater for irrigation, industry and drinking to the arid lowlands of among others Kyrgyzstan and Kazakhstan. When snowmelt is depleted and precipitation is absent, the proportion of meltwater from ice masses to river discharge can reach more than 50% (typically in July). Therefore, it is crucial to understand how ice masses in the Tien Shan are reacting to climate change and how they will evolve in the future. For individual glaciers, detailed 3D ice flow models can be calibrated and applied. For regional studies, and because necessary detailed input data is largely lacking, flowline models that rely on various parametrisations, such as GloGEMflow, are used to model glaciers. However, only a limited number of in-depth studies have been performed to assess the accuracy and applicability of such large-scale models. In this study, we compare the glacier evolution for six well-studied ice masses as modelled with (i) a 3D ice flow model and (ii) the large-scale GloGEMflow model. Our analysis suggests that differences in ice volume obtained by 2100 from the 3D HO-model and GloGEMflow are generally limited and that these can mainly be explained by the calibration data.

Annelies Voordendag <annelies.voordendag@uibk.ac.at>
University of Innsbruck
Contribution type: S

The glacier loss day as indicator for extreme glacier melt in 2022

Abstract: The glacier loss day (GLD) is the day in the hydrological year when the mass of a glacier is equal to the start of the hydrological year. Near-daily glacier-wide observations of glacier surface elevation changes over three years at Hintereisferner (Austrian Alps) are used to approximate the mass change. The GLD of the extreme hydrological year 2021/22 is reached on 24 June, whereas the GLD is reached on 9 (10) August in 2019/20 (2020/21). Nevertheless, the surface elevation change rate is similar for the three years. Thus, as soon as the ablation season starts, the GLD and the glacier surface elevation change and mass balance at the end of the season can be estimated. The GLD is an indicator of glacier imbalance with changing climate and offers a predictive measure for water availability studies in glacierized catchments.

Dominik Amschwand <dominik.amschwand@unifr.ch>
University of Fribourg
Contribution type: P

The 2020-2022 surface energy balance of rock glacier Murtèl: the role of rain and snow.

Abstract: The debris mantle of rock glacier Murtèl (Engadine, eastern Swiss Alps) stores, converts and transfers heat and moisture in its vast pore space between the atmosphere and the underlying permafrost core. Few microclimatological studies attempted to simultaneously parametrize air circulation, conduction, longwave radiation and phase changes, since few comprehensive subsurface hygro-thermal measurements beyond ground temperatures exist in blocky mountain permafrost. Here, we present data-driven estimates of the surface energy fluxes derived from our large sensor network that we installed above ground as well as in in natural cavities. The two hydrological years 2020/21-2021/22 with their starkly different weather conditions provide insight into the summertime turbulent flux partitioning (sensible vs. latent flux) and wintertime debris mantle-atmosphere coupling controlled by the snow cover.

Molly Arndt <mjarndt@middlebury.edu>
Middlebury College
Contribution type: P

Using OGGM to determine the future of glacier runoff in La Paz, Bolivia

Abstract: Glacier retreat is threatening the livelihoods of communities that depend on glacial runoff. One of the most important methods in determining glacial contribution to water resources is the use of glacier simulations, which predict the glacier's behavior through time–on the scale of years to decades–given climate and geographical inputs. Current glacier simulators are reliant on climate models to predict meltwater runoff rates, and disagreement in precipitation trends among climate models results in uncertainty in these runoff predictions. This uncertainty is particularly apparent, and important, as these glacier simulators attempt to model glaciers decades into the future. In this undergraduate thesis, I investigate how sensitive glaciers in Bolivia's Cordillera Real are to a range of predicted precipitation trends, and what the implications are for glacial runoff to La Paz and El Alto, Bolivia. To do this, I simulate glacial runoff using the Open Global Glacier Model (OGGM) using a variation of climate model inputs to determine glacier runoff change between 2020 and 2100. I will discuss the ongoing process and hypotheses of this developing project with the hope of conversing and receiving feedback from fellow AGM attendees.

Jorge Berkhoff <jorge.andres.berkhoff@fau.de>
Universitat Erlangen-Nuremberg
Contribution type: P

Thermal Regime of Glacial Lakes in the Exploradores Valley, Norther Patagonia Icefields, Chile.

Abstract: Glacial lakes have grown in Patagonia during the last 20 years due to the decrease of the glacier area. These glacial lakes affect the dynamics of the glaciers and can precondition producing flash floods in the rivers that are in contact with the glacier and the glacial lakes. Because of these problems, it is of vital importance to study how glacial lakes interact with the glacier system. In this research, we integrate glaciological and hydrological information to explain the evolution of glacial lakes to mass changes in the Exploradores glacier located in the Northern Patagonian Icefield, Chile. We studied this glacier and 4 glacial lakes, of which 3 are in direct contact with the glacier and one corresponds to a proglacial lake in the period 2019-2020. For this study, we used a set of ground data obtained from water-level sensors installed in these 4 glacial lakes and meteorological data obtained from a weather station on the glacier. Further data comprises high-resolution imagery acquired with a unmanned aerial vehicles (UAV) as well as a digital elevation model (DEM). On this basis, we retrace the geomorphological evolution of the new glacial lakes, calculate the geodetic mass balance and calculate the velocity of the glacier derived from Sentinel 2 images using remote sensing techniques. Our analysis indicates that the glacier has a mass loss of -14.2 (m.e.w) due to melting, obtained from the traditional energy balance calculation. The melting of the glacier contributes directly to the water level of the glacial lakes. In addition, we found a seasonality in the thermal regime of these lakes. On the other hand, the remote sensing analysis indicates that the glacier has a specific mass balance of -0.4 meters calculated by the geodetic method. Frontal ablation is an important factor in the overvall mass budget a low velocity rate at the front of the Explorers glacier (<1 meter) due to the detrital cover that is located on the glacier. The height variations and low ice velocity help the areal growth and the formation of new glacial lakes. This study helps us to better understand the relationship between glacier mass loss and its relationship with the water level of the lakes that are on the glacier. It further allows us to understand the formation and evolution of glacial lakes through glaciological and geomorphological analysis.

Jordi Bolibar <j.bolibar@uu.nl>
Utrecht University
Contribution type: P

Functional Inversion of Glacier Rheology from Ice Velocities using ODINN.jl

Abstract: Inversion methods play an important role in glacier models, both to calibrate and estimate parameters of interest (e.g. Glen's coefficients). However, inversions are usually made for each glacier individually, without using any global information, i.e. without deriving general laws governing the spatiotemporal variability of those parameters. The reason behind this limitation is twofold: the statistical challenge of making constrained inferences with multiple glaciers, and the computational limitation of processing massive glacier datasets. Machine learning powered with differential programming is a tool that can address both limitations. We introduce a statistical framework for functional inversion of physical processes governing global-scale glacier changes. We apply this framework to invert a prescribed function describing the spatial variability of Glen's coefficient (A). Instead of estimating a single parameter per glacier, we learn the parameters of a regressor (i.e. a neural network) that encodes information related to each glacier (i.e. long-term air temperature) to the parameter of interest. The inversion is done by embedding a neural network inside the Shallow Ice Approximation PDE - resulting in a Universal Differential Equation - with the goal of minimizing the error on the simulated ice surface velocities. We previously had shown that this hybrid model training is possible thanks to the use of differential programming, enabling differentiation of a PDE, a numerical solver and a neural network simultaneously. In this work we upscale this approach to include larger datasets and with the goal of learning real empirical laws from observations. This framework is built inside ODINN.jl, an open-source package in the Julia programming language for global glacier evolution modelling using Universal Differential Equations. ODINN exploits the latest generation of ice surface velocities and geodetic mass balance remote sensing products, as well as many preprocessing tools from the Open Global Glacier Model (OGGM).

Stefanie Börsig <sboersig@student.ethz.ch>
ETH Zürich
Contribution type: P

R-channel laboratory experiments: data evaluation and numerical simulations

Abstract: Englacial and subglacial drainage substantially controls glacier dynamics. However, because of the inaccessible glacier bed, few actual measurements exist and empirical relations in current models are either adopted from other research fields or based on theoretical arguments. This study focuses on the channelized drainage system and determines the flow properties of R- channels: we evaluate a set of laboratory experiments and complementary computational fluid dynamics simulations of their final geometries. These experiments make use of channels with water flow in ice blocks and represent pressurized englacial R-channels. Simulation and measurements only partially agree on pressure gradients and the resulting hydraulic friction factor. However, the results are within the published range of variability.

Dagmar Brombierstäudl <brombierstaeudl@uni-heidelberg.de>
South Asia Institute, Heidelberg University
Contribution type: P

Aufeis in the Upper Indus Basin – Compilation of an inventory based on satellite imagery

Abstract: Dagmar Brombierstäudl, Susanne Schmidt, Marcus Nüsser Department of Geography, South Asia Institute, Heidelberg University Aufeis is a common phenomenon in cold regions of the Northern Hemisphere that develops during winter by successive water overflow and freezing on ice-covered surfaces. Most studies on aufeis occurrence and its hydrological importance focus on regions in North America and Siberia, while research in High Mountain Asia is still in an early phase. In order to address this lack of knowledge, an inventory of aufeis fields in the entire Upper Indus Basin (UIB) and surrounding endorheic basins was compiled. Delineation is based on recent Landsat and Sentinel-2 imagery for the period 2008–2021 by using semi-automatic and machine learning approaches. In total, over 3700 aufeis fields covering an area of about 300 km² have been detected. Their distribution is characterized by an increase in number and size towards the Tibetan Plateau and a distinct elevational range from 4000 to 5500 m a.s.l. Water overflow mainly occurs between January and March and is highly variable on the intra- and inter-annual scale. Potential water sources feeding aufeis are often located close or within wetland areas, suggesting close hydrological interactions. This inventory fills an important research gap and will help in further comprehensive cryosphere studies in the UIB and beyond.

Fanny Brun <fanny.brun@univ-grenoble-alpes.fr>
IGE (Grenobe)
Contribution type: P

Investigating the recent changes of South Col Glacier (Everest region)

Abstract: The South Col Glacier is an iconic small body of ice and snow (approx. 0.2 km2), located on the southern ridge of Mt. Everest. A recent study proposed that South Col Glacier is rapidly losing mass. This seems in contradiction with our comparison of two digital elevation models derived from aerial photographs taken in 1984 and a stereo Pléiades satellite acquisition from 2017, from which we measure a mean elevation change of 0.01 +:- 0.07 m a-1. To reconcile these results we investigate wind erosion and surface energy and mass balance, and find that melt is unlikely a dominant process, contrary to previous findings.

Pascal Buri <pascal.buri@wsl.ch>
WSL
Contribution type: P

On the importance of vapor fluxes for the water balance of a high elevation Himalayan catchment

Abstract: Future projections of water availability in and from catchments in High Mountain Asia (HMA) remain uncertain. Mechanistic modeling approaches incorporating cryospheric, hydrological and vegetation processes in high spatial, temporal and physical detail have never been applied for high-elevation catchments of HMA. We use a land surface model at high spatial and temporal resolution to simulate the coupled dynamics of energy, water and vegetation for the upper Langtang catchment (Nepal). We compare our model outputs against a large set of observations to gain insight into the partitioning of the catchment water balance at the subseasonal scale and across elevation bands. We find that the depletion of the cryospheric water budget is dominated by snow melt, but at high elevations is primarily dictated by sublimation. Snow sublimation is the dominant vapor flux (49%) at the catchment scale, accounting for the equivalent of 11% of snowfall, 17% of snowmelt and 75% of ice melt, respectively. We conclude that simulations should consider snow sublimation and other vapor fluxes explicitly, as otherwise water balance estimates can be ill-quantified.

Bo Cao <caobo@lzu.edu.cn>
Lanzhou University, China
Contribution type: P

Dynamic interactions between glacier and proglacial lake: a case study at a rapidly expanding proglacial lake in High Mountain Asia

Abstract: Most glaciers and glacial lakes in High Mountain Asia have experienced rapid variations throughout changes in the climate. To explain the relationship between proglacial lakes and glacier dynamics, we present a detailed investigation of the changes in the surface elevation, velocity, and frontal ablation of the Jiongpu Co glacier and the corresponding expansion of its proglacial lake in the Yigong Zangbu Basin on the Tibetan Plateau. The Jiongpu Co proglacial lake expanded by 820 % (from 0.6 ± 0.1 km2 to 5.3 ± 0.3 km2) with accelerate expanding rate since 1967. Compared with land-terminating glaciers, the Jiongpu Co glacier shows rapid shrinkage and mass loss with accelerated in velocity, especially since 2010. The fraction of frontal ablation in total mass loss of Jiongpu Co glacier was increasing significant with the proglacial lake expanding over time. All evidence shows the existence of a positive feedback between the glacier and its proglacial lake. It is considered that the existence of this proglacial lake influences the spatial change pattern of the glacier, and the expansion of the lake amplifies the changes associated with the glacier's evolution.

Nicole Clerx <nicole.clerx@unifr.ch>
University of Fribourg
Contribution type: P

Modelling lateral meltwater flow atop the Greenland Ice Sheet's near-surface ice slabs

Abstract: The Greenland ice sheet is losing mass. Thereby, surface runoff of meltwater plays an important role. In recent years surface runoff has increasingly occurred from higher elevations, thereby expanding the area of mass loss: between 1985 and 2020, the visible runoff area expanded by around 29%. Meltwater percolation and refreezing has caused the formation of thick, near-surface ice layers, also called ice slabs. Field experiments carried out in the accumulation zone around 1750 m a.s.l. in the SW of the Greenland ice sheet show that meltwater generated over ice slabs is generally forced to flow laterally: initially through a near-surface slush matrix and then forming streams and rivers. It remains unclear, however, how much of the meltwater contributes to runoff, and which percentage refreezes and contributes to ice slab formation or expansion. Here we present a conceptual quasi 2D-model of runoff that simulates lateral meltwater flow on top of an ice slab using measured firn hydrological properties. We adapted a linear-reservoir runoff routing model to calculate (i) the distance meltwater can travel within one melt season, and (ii) when meltwater breakthrough at the snow surface (i.e. slush formation) occurs.

Armin Dachauer <armin.dachauer@geo.uzh.ch>
University of Zürich (UZH)
Contribution type: P

Anomalous mass gain of a tidewater outlet glacier with rapidly thinning ice sheet margin in Greenland

Abstract: In response to the general warming ocean-termination outlet glaciers of the Greenland ice sheet are generally thinning and retreating rapidly. However, the glacier system of Qajuuttap Sermia (also known as Eqalorutsit Kangilliit Sermiat), at the southwestern basin of the greenland ice sheet, shows a strongly contrasting and highly heterogenous dynamical behaviour. Detailed analysis of elevation changes (AeroDEM, GIMP, ArcticDEM) between the years 1985 and 2021 shows slight but significant advance and thickening over at least the last 35 years, whereas its neighboring ocean- and land-terminating glaciers and more interestingly its three direct northwestern tributaries all show rapid thinning. The data indicates that effects of fjord geometry alone cannot explain this anomaly and we therefore further investigate potential reasons using operational continuous time series of solid ice flux (PROMICE) and surface mass balance (RACMO, MAR).

Harry Zekollari <zharry@ethz.ch>
ETH Zürich
Contribution type: P

How do various types of mass balance observations affect modelled future glacier evolution?

Abstract: Until recently, the mass balance component of large-scale glacier evolution projections was typically calibrated to match regional mass balance estimates. However, with glacier-specific mass balances becoming available at global scales (Hugonnet et al., 2021), the question arises how these new observations impact future glacier projections. In this contribution, we model the future global glacier evolution with the OGGM and GloGEM models under CMIP6 scenarios. We compare the modelled future glacier evolution when calibrating the mass balance model to glacier-specific mass balances (new approach) vs. regional mass balances (old approach). In our analysis, we particularly focus on how the differences in mass balance data affect glacier evolution at various spatial scales: ranging from the global scale, through the regional scale, to the glacier-specific scale.

Martina Di Rita <martina.di-rita@leica-geosystems.com>
Leica
Contribution type: P

High-resolution High-accuracy Orthophoto Map of Forni Glacier tongue from UAV photogrammetry

Abstract: This work presents the high-resolution high-accuracy orthophoto map of Forni Glacier, in the Ortles-Cevedale massif, Italian Alps. It represents the status of the glacier tongue in mid-August 2022 when aerial surveys were carried out with a DJI Phantom 4 Real Time Kinematic (RTK) UAV. Accuracy requirements of the final deliverables were ensured by combining Post Processed Kinematic (PPK) approach and Structure from Motion (SfM) integrated with bundle block adjustment, and also using targets 15 as Ground Control Points (GCPs) and 8 as Check Points (CPs), to guarantee redundancy and being able to evaluate the overall geolocation accuracy and precision. The whole processing pipeline was carried out in Leica Infinity and an overall 3D geolocation accuracy of the image block of 6.0 cm was achieved. A 3.0 cm orthomosaic was generated and it will be made available for analysis of the current status of the glacier, and to be used as a reference for further and diverse studies on the area.

Theresa Dobler <theresa.dobler@hm.edu>
University of Applied Sciences Munich
Contribution type: P

Crevasse dynamics of Vernagtferner, Ötztal Alps

Abstract: Once a crevasse is formed, it moves, opens or closes according to the existing velocity fields of the surrounding ice. A detailed monitoring of the ice flow and the changes of the surface geometry around crevasses can help to understand the mechanics behind. We used UAV (unmanned aerial vehicle) to obtain high resolution imagery and DEMs (digital elevation models). This data collection, combined with stake measurements, can provide the basis to investigate crevasse formation and development. For this purpose, different crevasses on Vernagtferner in the Ötztal Alps were observed and compared over the summer season. The poster presents first results and gives an outlook on our future work.

Jessica Droujko <droujko@ifu.baug.ethz.ch>
ETH Zürich
Contribution type: P

Low-cost sensor network for suspended sediment monitoring: a proof-of-concept study on the Spöl river, Switzerland

Abstract: Monitoring of suspended sediment (SS) in rivers is expensive and most monitoring setups are restricted to few single site measurements. We propose a low-cost SS network to better understand the spatial heterogeneity of fine sediment transport in rivers. Such a network can be used to monitor sediment in glacier networks, small streams and deltas, and to investigate the effect on environmental variables such as the survival of fry fish and the prevention of riverbed clogging. We have developed, calibrated, and tested, such a low-cost sensor. We applied the sensor on the Spöl river, a tributary of the Inn river, to monitor the effect of hydropeaking on fine sediment transport. These sensors were deployed at two locations on the Spöl and two locations on the Inn during an experimental flood. The collected data revealed sediment concentration pulsing as the discharge steadily increased throughout the day. The highest concentration of sediment appeared with the onset of the flood and again with the peak discharge. Our findings reveal stage-concentration hysteresis loops in the clockwise and counter-clockwise directions. This study shows that obtaining high spatial- and temporal-resolution SS data is possible with a low-cost network.

Ines Dussaillant <ninedussa@gmail.com>
University of Zürich (UZH)
Contribution type: P

An annual mass balance estimate for each of the world's glaciers based on observations.

Abstract: The geodetic method has become a popular tool to measure glacier elevation changes over large glacierized regions with high accuracy for multiannual/decadal time periods. In contrast, the glaciological method provides annually to seasonally resolved information on glacier evolution, but only for a small sample of the world glaciers (less than 1%). Various methods have been proposed to bridge the gap on spatio-temporal coverage of glacier change observations and provide annually resolved glacier mass balances using the geodetic sample as calibration. Thanks to a new globally near-complete (96% of the world glaciers) dataset of geodetic mass balance observations, this goal has become feasible at the global scale. Inspired by previous methodological frameworks, we developed a new approach to combine the glacier distribution from the globally complete Randolph Glacier Inventory with the mass balance and elevation change observations from the Fluctuation of Glaciers database of the World Glacier Monitoring Service (WGMS). Our results provide a global assessment of annual glacier mass change and related uncertainties for every individual glacier during the 1976 – 2021 period. The glacier-specific time series can then be integrated into an annually resolved global gridded glacier change product at any user-requested spatial resolution, useful for comparison with gravity-based products, calibration or validation of glacier mass balance models operating at a global scale and to improve calculations of the glacier contribution to regional hydrology and global sea-level rise. We will also show preliminary results of an experimental assessment of a monthly global gridded glacier mass change product.

Taisiya Dymova <tasinidze@gmail.com>
Institute of Water Problems, Russian Academy of Sciences
Contribution type: P

Future evolution of the debris cover on the glaciers in the Northern Caucasus.

Abstract: Debris-cover representation is rarely included into regional or global glacier models although it can reduce melt by insulating glacier ice in case it is sufficiently thick. Implicit representation of debris cover by simple calibration of mass-balance model parameters is not physically correct since the debris-cover geometry evolves through time while the mass-balance parameters do not. This study assesses the evolution of debris-cover thickness and area throughout the 21st century under different SSP scenarios. We also explore the interplay between debris-cover geometry change and its effects on glacier mass balance, ice velocity, ice thinning, changes in glacier area, volume, and position of the glacier fronts. We use the GloGEMflow glacier model and introduce a new debris-cover evolution module. The model is calibrated using newly mapped debris cover outlines and ice-thickness data from Rounce et al. (2021). The debris evolution is simulated with a steady deposit model adapted from Verhaegen et al. (2020) and Anderson & Anderson (2016), where debris input onto glacier surface is generated from a fixed point on the flow line. We compare glacier evolution including evolution of debris cover for the explicit and implicit debris-cover formulation for five SSP scenarios from CMIP6. The debris-cover evolution patterns differ significantly between the Terek and the Kuban basins, which include most of the glaciers of the Northern Caucasus. In the Kuban basin, glaciers are positioned generally at lower elevations, retreat rapidly and lose ice at the debris-covered glacier tongues. On the contrary, the supraglacial debris of the Terek basin glaciers may under certain climate scenarios expand and play an increasingly-important role in glacier evolution with time. However, under warming-scenario SSP5-8.5, the ice loss by 2100 overwhelms the debris-cover effects in both regions. The maximum difference in glacier length, area and volume depending on the explicit or implicit mode of debris-cover modeling occurs before 2100, but by the end of the century it is eliminated due to the retreat of debris-bearing parts of the glaciers or due to the elevation-stabilization effect. Overall, explicitly accounting for debris cover in the projections only has a minor effect on the projected regional mass loss, but improves the representation of processes on the intra-glacier scale. This study was carried out under Governmental Order to Water Problems Institute, Russian Academy of Sciences, subject no. FMWZ- 2022-0001, and was funded by the RSF grant number 22-17-00133.

Olaf Eisen <oeisen@awi.de>
Alfred-Wegener-Institut
Contribution type: P

Greenland ice stream dynamics: short-lived and agile?

Abstract: Reliable knowledge of ice discharge dynamics for the Greenland ice sheet via its ice streams is essential if we are to understand its stability under future climate scenarios as well as their dynamics in the past. Currently active ice streams in Greenland have been well mapped using remote-sensing data while past ice-stream paths in what are now deglaciated regions can be reconstructed from the landforms they left behind. However, little is known about possible former and now defunct ice streams in areas still covered by ice. Here we use radio-echo sounding data to decipher the regional ice-flow history of the northeastern Greenland ice sheet on the basis of its internal stratigraphy. By creating a three-dimensional reconstruction of time-equivalent horizons, we map folds deep below the surface that we then attribute to the deformation caused by now-extinct ice streams. We propose that locally this ancient ice-flow regime was much more focused and reached much farther inland than today's and was deactivated when the main drainage system was reconfigured and relocated southwards. The insight that major ice streams in Greenland might start, shift or abruptly disappear will affect future approaches to understanding and modelling the response of Earth's ice sheets to global warming.

Yongmei Gong <yongmei.gong@ntnu.no>
Norwegian University of Science and Technology
Contribution type: P

Glacier impacts On The Hydrological systems in Europe and Central Asia (GOTHECA)

Abstract: Mountain ranges, described as 'the world's water towers', store massive amounts of fresh water in the form of snowpack and glacial ice and sustain environmental and human water demands downstream. Under global warm shrinking glaciers and related hazards affect hydropower production and tourism in Europe. While in Central Asian, changing snow- and glacier-melt patterns have direct impacts on seasonal freshwater supply and runoff regimes, leading to increasing stresses in ecosystems and economies. Both regions are also prone to increasingly frequent flash floods and Glacial Lake Outburst Floods (GLOFs). The GOTEHCA project develops a comprehensive risk assessment scheme for a timely application of increasingly accurate predictions of freshwater availability and GLOFs in glacierized regions to local mitigation and adaptation strategies. Its pilot study focuses on the drivers and societal impacts of freshwater discharge from glacial systems in NOrway and the Chinese Karakoram (GOTHECA NOCK) It reaches its aim through a circular process involving numerical modeling, field observations and assessments of community resilience. The selection enables a holistic view of the interplays between climate, cryosphere, hydrology, and society through the prism of contrasts and similarities.

Audrey Goutard <audrey.goutard@univ-grenoble-alpes.fr>
Institut des Géosciences de l'Environnement (IGE - Grenoble, France)
Contribution type: P

Impact of the snow/rain transition on glacier mass balances over the 21st century : context and early results on the Zongo glacier (Bolivia).

Abstract: A large part of the uncertainty about recent and future glacier mass changes is directly inherited from large uncertainties in the spatio-temporal representation of precipitation. The phase of precipitation is a key concern as it affects the surface albedo and the heat transfer in the snow layers. Accounting for such feedback and physical processes linked to the future rain/snow transition rise requires relying on complex models of surface mass balance (SMB), and major improvements in glacier SMB projections can be achieved by focusing on the accumulation processes and modeling. Using the Crocus model, we simulated the Surface Mass Balance of the Zongo glacier (Cordillera Real in Bolivia) at a local point using meteorological data from the automatic weather station to force the model over the last few years. This model is calibrated and evaluated using available observational data such as temperature, albedo and SMB. A method to identify precipitation events on the glacier was developed and some events were found in order to look in particular at the impact of liquid precipitation on the surface mass balance.

Dominik Gräff <graeffd@uw.edu>
ETH Zürich
Contribution type: P

Distributed Subsea Fiber-Optical Sensing along the Calving Front of a Greenlandic Tidewater Glacier

Abstract: Calving fronts of Greenland's tidewater outlet glaciers are the nexus where atmospheric and oceanic forcings on the cryosphere condense. Dynamic processes acting on these calving fronts not only impact future tidewater glacier evolution but control the stability of the Greenland Ice Sheet. To study these processes, we will install a subsea fiber-optic cable across a Greenlandic fjord on the seafloor and parallel to the calving front of a tidewater outlet glacier. We will use the optical fiber itself as a sensor by measuring tiny changes of strain in the cable over time scales reaching from milli-seconds to years. By doing so, we can utilize the 7km long cable as 1'500 seismometers, 30'000 thermometers and 7'000 strain-meters distributed along the calving front for resolving and quantifying aerial and underwater iceberg calving, warm oceanic water intrusions at the seafloor, meltwater plume activity, underwater ice melt, fjord water stratification and mixing as well as subglacial discharge, sedimentation and frictional resistance at the glacier bed. All together these measurements will create a yet unresolved picture of dynamic processes at calving fronts.

Annika Granebeck <annika.granebeck@su.se>
Stockholm University
Contribution type: P

Life at Tarfala Research Station

Abstract: Tarfala Research Station, TRS is situated in Tarfala valley, Sweden, at 1135 m a.s.l. east of Kebnekaise, among Sweden's highest mountains and several glaciers. Here we investigate Swedish alpine and glacial environment, changes caused by the retreating glaciers and the impact these changes have on ecosystems and people. Scientists come to TRS because the station offers unparalleled possibilities to work in the often hostile Arctic environment under safe and comfortable conditions. As the station manager it is my job to provide a safe work environment for our researchers, and in this talk I will highlight what this entails, including insights from our logistical, safety and operational challenges. The talk will give you a glimpse of life at the station, what our daily routines are like and how is it to spend almost half of the year in such a beautiful, but challenging and remote location, far away from society as well as family and friends.

Alexander Raphael Groos <alexander.groos@fau.de>
Friedrich-Alexander-Universität Erlangen-Nürnberg
Contribution type: P

Mapping supraglacial debris thickness with UAVs

Abstract: Supraglacial debris covers the tongue of many mountain glaciers and can influence their mass balance, geometry and dynamics through the modification of subdebris ice melt rates. While thin debris increases melt compared to a clean-ice surface, thick debris insulates the underlying ice and reduces melting. To better assess the future evolution of debris-covered glaciers, accurate information on the debris thickness distribution is urgently needed. However, debris thickness maps that capture the high spatial variability are still lacking today. Here we present a customised UAV for high-resolution thermal imaging on glaciers and a complete open-source pipeline that enables the generation of surface temperature and debris thickness maps from raw thermal imagery acquired with UAVs. We use thermal imagery and in-situ measurements of debris thickness and debris temperature from the Kanderfirn in the Swiss Alps to illustrate and discuss the uncertainties and potential of the methodology.

Matteo Guidicelli <matteo.guidicelli@unifr.ch>
Uni Fribourg
Contribution type: P

Spatio-temporal reconstruction of continuous snow water equivalent with a combined data assimilation

Abstract:

Florian Hardmeier <florian.hardmeier@geo.uzh.ch>
University of Zürich (UZH)
Contribution type: P

Emergence and development of the proglacial lakes of Witenwasserengletscher, Switzerland

Abstract: As glaciers retreat worldwide, new lakes are forming where overdeepenings in the bedrock are exposed. While such lakes have been widely mapped, their impact on glacier retreat, sediment dynamics and the thermal regime is not well known. We address this gap at the example of Witenwasserengletscher (CH) using aerial imagery since 1959 and a 2021 bathymetric survey. Since 1990, three lakes have emerged with the deepest losing ice-contact in 2009 and forming a delta from mobilized subglacial sediment. Direct contact of the glacier with the lakes has a profound influence on terminus retreat, the thermal regime of the lake and related sediment dynamics. Lake temperatures in ice-contact lakes stay close to 0°C, while the disconnected lake shows temperatures of over 6°C and sediment-rich glacial water perturbs the summertime stratification. Sedimentation shows a high interannual variability which is strongly dependent on the re-routing of glacial streams. We conclude that during deglaciation lake evolution, sediment redistribution and the thermal regime are highly dynamic and may thereby impact pro-glacial streams as an ecosystem habitat.

Martin Hoelzle <martin.hoelzle@unifr.ch>
University of Fribourg
Contribution type: P

New and old long-term permafrost boreholes in the Inner Tien Shan, Kyrgyzstan

Abstract: The cryosphere is currently undergoing remarkable and striking changes worldwide. However, in comparison to snow, glaciers, ice sheets and sea ice, permafrost is much more difficult to detect with remote sensing methods and in situ measurements in permafrost environments are sparse and heterogeneously distributed, especially in remote mountain ranges. Central Asia with its Pamir and Tien Shan Mountain ranges, has vast areas covered by permafrost, but the observational network is very limited. In this region, only a few monitoring programs in Eastern China and Northern Tien Shan near Almaty exist. But also in the Inner Tien Shan, where the Kumtor gold mine is located today, some boreholes were drilled in permafrost in the 1980/90s. In 2022, a new borehole was drilled in the Akshiirak area, and we present the first results of the measurements, which we compare with the old data from the period in the 1980/90s. These measurements show a considerable warming of the ground temperatures. We also compare the structural information from the extracted permafrost core to the results from our geophysical surveys taken in the year 2022. The current results are also furthermore compared to other boreholes in different mountain regions.

Huw Horgan <huw.horgan@vuw.ac.nz>
WSL, VAW – ETH Zürich, Antarctic Research Centre - VUW.
Contribution type: P

Subglacial drainage across Kamb Ice Stream's Grounding Zone, West Antarctica.

Abstract: Kamb Ice Stream in West Antarctica ceased to flow approximately 160 years ago and mass gain in its catchment now offsets a significant portion of the mass loss occurring elsewhere in West Antarctica. The leading hypothesis for why Kamb shut down is changes in subglacial water routing. Here I report on our exploration of the main subglacial drainage channel crossing Kamb's grounding zone and entering the ocean cavity beneath the Ross Ice Shelf. The subglacial channel transitions into a sub ice shelf channel where oceanographic observations detect subglacial discharge. The channel shape and surface change suggest greater discharge rates in the past and sediment coring shows evidence of repeated high-velocity discharge events with different provenance. Together our observations indicate the subglacial hydrologic network beneath Kamb Ice Stream varies temporally, with background flow punctuated by fast flow events, and changes spatially, spanning catchments of variable size.

Mamta K C <mamta.kc@fau.de>
Friedrich-Alexander-Universität Erlangen-Nürnberg
Contribution type: P

A Neural Network Emulator for Full-Stoke Glacier Flow

Abstract: Full-Stokes-based numerical modeling of glacier dynamics is a computationally expensive task. Neural network-based surrogate models are considered an alternative to speed up the computations. Hence, this study uses U-Net architecture as a surrogate to infer glacier average integrated velocities with better accuracy and computational performance. The U-Net was trained using ice thickness and surface slopes as input. The target is the mean vertical velocity. The structural gridded dataset was simulated using Elmer/Ice model and represents glaciers with varied sizes in the French, European Alps. Experiments were also performed with scaling techniques, data augmentation, and hyperparameter tuning to improve the surrogate performance. The best surrogate resulted in 0.027 mean absolute error (~ 6% average relative error) in the test dataset while using the normalization scaling technique, 32 batch size, 0.012 dropout rate, RMSprop optimizer, 0.0007 learning rate, and 2.3M trainable weights.

Arbindra Khadka <arbindra.khadka@univ-grenoble-alpes.fr>
Univerity of Grenoble Alpes
Contribution type: P

Energy and mass balance of Mera glacier and its sensitivity to climate

Abstract: Recent glacier mass changes are very heterogeneous in High Mountain Asia, owing to climatic variability and to the mass balance sensitivity to climate, that may differ from one region to another. Mera glacier in the Everest region is one of the longest field-based monitored and well-studied glaciers of the Central Himalaya. In this study, we examine the sensitivity of Mera glacier mass balance to climate variables using the COupled Snowpack and Ice surface energy and mass balance model (COSIPY), using 4 years (2016-2020) of in-situ meteorological data recorded at different elevations in the ablation and accumulation zones of the glacier. This shows that the net short-wave radiation is the main energy input at the surface, and in turn albedo is a key parameter controlling the glacier mass balance. We produce and analyze 88 distinct climatic scenarios, varying from dry and warm to wet and cold conditions. Dry conditions, primary during the pre-monsoon and secondary during the monsoon, strongly decrease the glacier mass balance, revealing that the annual amount and the seasonal distribution of snowfalls primary drives the glacier-wide mass balance of Mera Glacier.

Dilara Kim <dilara.kim@stud-mail.uni-wuerzburg.de>
University of Würzburg
Contribution type: P

Sub-seasonal snowline dynamics of glaciers in Central Asia from multi-sensor satellite observations, 2000-2021

Abstract: Mass balance models rely on observation-based calibration and validation data, such as transient snowlines (TSLs), a transition between snow and ice-covered surfaces on a glacier at a given point in time. From TSL we calculate the snow-covered area fraction (SCAF), the area on the glacier surface that is snow covered in relation to the total glacier area. Our approach is based on the MODIS time-series, harnessing the advantage of long and close-to-daily observations records. To resolve the issue of MODIS coarse spatial resolution, we retrieved SCAF from multispectral Sentinel-2 and cloud-independent Sentinel-1 SAR imagery using established workflow. The automatic classification and calculation of SCAF is performed using the cloud computing service of the Google Earth Engine, which makes the entire approach easily applicable on a large number of remote glaciers worldwide. The resulting SCAF time series provides unique information on regional and local climatic variations at subseasonal scale.

Johanna Klahold <johanna.klahold@unil.ch>
University of Lausanne (UNIL)
Contribution type: P

Drone-based glacier GPR data acquisition: a summary of the 2022 fieldwork season

Abstract: The Swiss Alps experienced extreme ice loss and record high temperatures during the summer of 2022. At the same time, the 2022 fieldwork season was greatly successful in terms of our acquisition of high-resolution 3D and 4D ground-penetrating radar (GPR) data on Alpine glaciers. With our newly developed drone-based system, we were able to collect an unprecedented quantity of high-density GPR data, amounting to a total of approximately 300 line-km, divided between four glaciers in the Swiss Alps (Otemma glacier, Findelen glacier, Morteratsch glacier, and Rhone glacier). In this contribution, we will briefly summarize these acquisitions and show some of the first data examples.

Marin Kneib <marin.kneib@univ-grenoble-alpes.fr>
IGE (Grenobe)
Contribution type: P

Remote sensing of avalanches on mountain glaciers

Abstract: Avalanches are important contributors to the mass balance of glaciers located in mountain ranges with steep topographies. They result in localized accumulation that is seldom accounted for in glacier models. This is due to the difficulty of quantifying this contribution, let alone the occurrence of avalanches in remote and high-altitude regions. Here, we apply an automated mapping approach developed to map snow avalanches from Sentinel-1 SAR images to characterize the avalanche activity on Argentière Glacier in the Mt. Blanc massif for the period 2020-21. The results highlight the variety in avalanche events, from small and frequent avalanches from steep headwalls to occasional large events originating from hanging glaciers. This study is part of the recently started research project CAIRN (contribution of avalanches to glacier mass balance), which aims at improving the representation of avalanches in large-scale glacier models based on detailed remote sensing and field observations.

Astrid Lambrecht <astrid.lambrecht@keg.badw.de>
Bavarian Academy of Sciences and Humanities, Munich
Contribution type: P

The relation of storage and discharge at Vernagtferner for different mass balance conditions

Abstract: The relation of storage and discharge at Vernagtferner for different mass balance conditions Astrid Lambrecht, Christoph Mayer Bavarian Academy of Sciences and Humanities, Munich Water discharge from mountain glaciers strongly varies on seasonal and multiannual time scales. Different storage units (snow, firn and glacier ice) show different dynamics with respect to meltwater discharge also for longer periods, where e.g. the firn body undergoes considerable variations. In order to investigate the long term evolution of discharge characteristics, we established a numerical setup to simulate the contribution of the different glacier units to the melt water production. Here we present the results of a three-year test run, where we are able to identify the spatial evolution of the storage units and their impact on glacier mass balance.

Lukas Langhamer <Lukas.Langhamer@hu-berlin.de>
Humboldt-Universität zu Berlin
Contribution type: P

Response of short-term fluctuation of ice flow, calving flux and glacier retreat on atmospheric forcing at Cordillera Darwin from 2015-2022

Abstract: At most glaciers in Patagonia melt and calving contribute to mass loss. While glacier melt has a long-term response time, individual calving events can be attributed to single events. We investigate the interplay of ice dynamic changes and atmospheric variability at glacier Schiaparelli (Cordillera Darwin) in the time between 2015 and 2022. Based on georeferenced time-lapse camera images we identify changes of the glacier terminus position. In combination with feature tracking we calculate the ice flow velocity and estimate the calving flux. In addition, remote sensing data (Sentinel-1) enable a spatial view of the ice flow over the whole glacier. Lake level records, discharge measurements and a coupled energy and mass balance model provide insights into glacier's melt water and drainage system. We evaluate downscaled reanalysis data (ERA-5) to identify climate extremes and their underlying synoptic patterns to investigate the ice dynamic response.

Andreas Linsbauer <andreas.linsbauer@geo.uzh.ch>
Department of Geography, University of Zurich
Contribution type: P

The New Swiss Glacier Inventory SGI2016: From a Topographical to a Glaciological Dataset

Abstract: Repeated glacier inventories are key to monitor glacier changes at regional scale. The new Swiss Glacier Inventory 2016 (SGI2016) has been acquired based on sub-meter resolution aerial imagery and digital elevation models, bringing together topographical and glaciological approaches and knowledge. The SGI2016 provides glacier outlines (areas), supraglacial debris cover and ice divides for all Swiss glaciers referring to the years 2013–2018. The SGI2016 maps 1,400 individual glacier entities with a total surface area of 961 ± 22 km², whereof 11% (104 km²) are debris-covered. Interpretation in the context of topographic parameters indicates that glaciers with moderate inclination and low median elevation tend to have highest fractions of supraglacial debris. Glacier-specific area changes since 1973 show the largest relative changes for small and low-elevation glaciers. The analysis further indicates a tendency for glaciers with a high share of supraglacial debris to show larger relative area changes. Between 1973 and 2016, an area change rate of –0.6% a^{-1} is found.

Debasmita Majumder <dmdebasmitamajumder31@gmail.com>
Indian Institute of Technology Bombay
Contribution type: P

Glacial Lakes Inventory for 4 Decades (1975-2021) in the Northern Part of Sikkim State of Indian Himalayan Region

Abstract: Climate change has a significant influence on the world's cryosphere, the most noticeable of which can be seen in the alpine environment where glacier, snow and glacial lakes expansion and losses have a dynamic impact on physical and social environment. The retreat of mountain glaciers gives rise to the creation and development of glacial lakes. Due to this, the threat of Glacial Lake Outburst Floods (GLOF) is evolving and increasing over time, as seen in recent events in the Himalayan region across South Asia. GLOFs are a recurring hazard in the Himalayas, posing significant danger to downstream communities. Hence it is important for these communities to be prepared for the possibility of a GLOF hazard through long-term planning and adaptation strategies. This requires identification of potential GLOF events based on rigorous data analysis. This paper draws from a study of the health of Glacial Lakes in the Northern part of Sikkim state in India using satellite images from 1975 to 2021. In identifying hazardous lakes that may be prone to GLOF events, 453 GLs are been identified over decadal intervals, out of which 10 GLs are analysed for further research in this study.

Evan Miles <evan.miles@wsl.ch>
Swiss Federal Research Institute WSL
Contribution type: P

Mapping debris covered glacier hotspots at the regional scale

Abstract: Ice cliffs and supraglacial ponds are hot spots of melt for debris-covered areas, but are neglected in glacier models as they are difficult to map. Here, we advance a spectral-unmixing method to map ice cliffs and supraglacial ponds using Sentinel-2 multispectral mosaics produced in Google Earth Engine. We evaluate our method against high-resolution quality-controlled cliff distributions derived from Pleiades images, then produce annual distributions across High Mountain Asia for the 2017-2022 period, enabling a robust assessment of the cliff distributions at glacier and regional scales. At the regional-scale, we find that ice cliffs account for 3.3 +/- 0.5 % of debris-covered areas, while supraglacial ponds account for 2%+/-0.1% of debris-covered areas. Our results highlight that cliffs are most prevalent in the middle section of the debris-covered area, whereas ponds are most prevalent in the lowermost sections. We note that although many glaciers are devoid of supraglacial ponds, nearly all debris-covered areas exhibit ice cliffs. Our results enable a first unbiased assessment of the importance of these features at the regional scale.

Marcus Nüsser <marcus.nuesser@uni-heidelberg.de>
Department of Geography, South Asia Institute, Heidelberg University
Contribution type: P

Cryosphere changes and local adaptation strategies: socio-hydrological case studies from the Trans-Himalaya of Ladakh, India

Abstract: The Himalayan region faces massive cryosphere changes, rapid urbanization, and infrastructure development, which increase the vulnerabilities of local communities. The subsequent effects on meltwater-dependent irrigation systems for crop cultivation and risks due to recurring and more frequent cryosphere-related hazards require integrated analyses of local water management and adaptation strategies to cope with predicted water scarcity. An improved understanding of socio-hydrological pathways is necessary to capture regional and local particularities and dynamics, including glacio-fluvial runoff, socioeconomic processes, indigenous environmental knowledge, and external development interventions. We explore the role of water harvesting infrastructures, including implementation of ice reservoirs and construction of improved irrigation networks, and social institutions ranging from village to non-governmental organizations and state-sponsored development programs. The contribution aims to develop a socio-hydrological framework for the fragile Himalayan region that may be used as a basis for more sustainable development pathways.

Boris Ouvry <boris.ouvry@geo.uzh.ch>
University of Zürich (UZH)
Contribution type: P

Development of supraglacial meltwater streams and their influence on the morphology of debris-covered glacier surfaces

Abstract: On debris-covered glacier tongues, supraglacial ponds and ice cliffs are known to enhance mass loss and have been widely mapped, but their formation mechanisms and underlying controls have not been studied in detail. We aim to investigate and analyse the role of supraglacial streams on the morphological development of debris-covered glacier surfaces based on high-resolution DEMs and orthophotos from two debris-covered glaciers of contrasting spatial scales. We perform this using a semi-automated approach that includes meltwater flow routing, the extraction of surface roughness, profiles and extents of supraglacial channel-influenced valleys, as well as the mapping of ice cliffs. On the initially smooth debris-covered surface, locally incised and meandering channels initiate ice cliffs that progressively backwaste, creating a downstream-widening supraglacial valley. This 'mobility area' valley laterally merges and creates quasi-chaotic highly undulated surfaces. We propose a conceptual model that links the downstream morphological development of debris-covered surfaces and explains the genesis of related features such as ice cliffs.

Frank Paul <frank.paul@geo.uzh.ch>
University of Zürich (UZH)
Contribution type: P

Glacier extents in Peru and Bolivia are overestimated In RGIv6 by 25%

Abstract: Despite their importance as a water resource, glacier extents in RGIv6 for the tropical Andes of Peru and Bolivia have large errors, mostly resulting from frequent seasonal snow, cloud cover and shadows of the steep topography. For this study we have remapped all glaciers from 17 Landsat TM scenes acquired in 1998, a year with very good snow conditions. The glaciers were mapped automatically with a red/SWIR band ratio and corrected manually (lakes and missing debris cover), partly using the very high-resolution satellite images available in the ESRI Basemap. The Copernicus DEM GLO-30 provided new drainage divides and topographic information for each glacier. Overall, we mapped 3586 glaciers larger than 0.01 km2 covering an area of 1747 km2. This is 419 km2 or 20% less than the 2166 km2 in RGIv6. As glacier outlines in RGIv6 are from 2000 to 2009 and most area change studies found continuous and strong area decrease over this period, a 'back-calculation' of all glacier areas to the year 1998 with an annual shrinkage rate of 1% gives an area overestimation of 25% for 1998.

Vincent Peyaud <vincent.peyaud@univ-grenoble-alpes.fr>
IGE CNRS/UGA
Contribution type: P

Modeling Mont-Blanc glaciers dynamics

Abstract: Vincent Peyaud 1, Damien Maure 1,2, Fabien Gillet-Chaulet 1, Nicolas Champollion 1, Samuel Cook 3 and Gabriel Collao-Barrios 1 1 Institut des Géosciences de l'environnement (IGE)-Université Grenoble Alpes, 2 Université de liège, 3 University of Lausanne Mountain glaciers retreat due to anthropic climate warming is now well documented [Hugonnet et al. 2021]. They have contributed to around 30% of the last century mean sea-level rise and this rate will be maintained during the XXI century [IPCC, 2021]. However, global glacier models used in future global projections of glacier mass changes are inaccurate to simulate properly ice dynamics at the scale of a mountain range. Thanks to recent surface velocity and thickness datasets, a more complex 3D ice flow model, Elmer/Ice [Gagliardini et al., 2013], has been calibrated to simulate glaciers in the Mont-Blanc mountain range with the surface mass balance coming from OGGM forecasts [Maussion et al., 2019]. Finally, ice volume and extent forecasted by the two models have been compared in order to account for the impact of more realistic modeling of ice dynamics at this scale, and have shown coherent results together with a stronger influence of the ice dynamics in the next decades and for a warm scenario.

Susanne Schmidt <s.schmidt@uni-heidelberg.de>
Universität Heidelberg, Südasien-Institut, Abteilung Geographie
Contribution type: P

Seasonal Variability and Long-term Changes of the Cryosphere in the Trans-Himalaya of Ladakh, India

Abstract: Meltwater supply from different cryosphere sources is essential for irrigated agriculture in the cold-arid Trans-Himalayan region of Ladakh. While the high-altitude glaciers, mostly located above 5200 m a.s.l., and permafrost release meltwater relatively late in the agriculture season, at the time of the sowing period, meltwater of the seasonal snow cover shows high inter-annual variabilities. The uncertainty of regular water supply is a major constraint for livelihood securities in the region. Water scarcity regularly occurs especially after snowless winters. To bridge these critical periods, meltwater from aufeis is used. The aim of this study is to inventory the different cryospheric components and to analyse their seasonal variability and their general dynamics in the context of climate change. Based on different multi-temporal and multi-scale remote sensing data and techniques glacier changes are documented since 1969. The investigation of the seasonal snow cover is based on MODIS data and for the mapping of aufeis fields a time series analysis of Landsat and Sentinel-2 data was conducted.

Mohd Soheb <soheb@uni-heidelberg.de>
South Asia Institute, Heidelberg University
Contribution type: P

Glacier Change and its socio-hydrological dimensions in Ladakh, India

Abstract: The Trans-Himalayan region of Ladakh is prominent for meltwater supply from glaciers which play a vital role in livelihood security. However, glaciers in this region have been undergoing significant stress due to climate change which induces a range of impacts on socioeconomic development paths. Therefore, documenting the changes and understanding their impacts are crucial for successful adaptation and mitigation strategies. This study quantifies glacier changes in four Upper Indus sub-basins and three endorheic basins between 1977–2019 and their implications on the socio-hydrological dynamics. The study is based on a vast data analysis of changes in 2257 glaciers (>0.5 km2) covering ~7923 ±212 km2 equivalent to ~30% of all glaciers and ~89% of the entire glacierised area. Our results show that the area and length of nearly all glaciers (~97%) have decreased over the past 42 years by 6.9% and 12%, respectively. However, heterogeneity in glacier changes was observed across the region; Shayok Basin glaciers experienced the least change (~3.9%), whereas Leh (~23%) and Tsokar Basin (~26%) experienced the greatest deglaciation over the study period. These changes are altering the local and regional hydrological system leading to natural hazards and socio-economic changes.

Ladina Steiner <ladina.steiner@awi.de>
AWI
Contribution type: P

Combined GNSS reflectometry/refractometry for continuous in situ surface mass balance estimation on an Antarctic ice shelf

Abstract: Reliable in-situ surface mass balance estimates are scarce due to limited spatial and temporal data availability. While surface accumulation can be obtained in various ways, conversion to mass requires knowledge of the snow density, which is more difficult to obtain. We develop a methodology for deriving automated and continuous specific surface mass balance time series for fast moving parts of ice sheets and shelves (>10m/a) by an accurate and simultaneous estimation of continuous in-situ snow density, snow water equivalent (SWE), and snow deposition and erosion, averaged over an area of several square metres and independent on weather conditions. A combined Global Navigation Satellite Systems reflectometry and refractometry (GNSS RR) approach is developed. We installed a combined GNSS RR system in November 2021 on the fast moving (~150m/d), high latitude Ekström ice shelf in the vicinity of the Neumayer III station in Antarctica. Continuous snow accumulation reference data is provided by a laser distance sensor at the same test site and manual, monthly density observations. Preliminary results show a high level of agreement with reference observations.

Darrel A. Swift <d.a.swift@sheffield.ac.uk>
University of Sheffield
Contribution type: P

Ice-bed stabilising feedbacks at Findelengletscher, Switzerland, and their significance for drainage system structure and recent (post-2016) terminus retreat

Abstract: Recent retreat of Findelengletscher has been rapid and has included several surface collapse phenomena. We show that rapid retreat has occurred in an area of overdeepening where former ice-surface and bed geometry met the condition for glaciohydraulic supercooling. We further present observations of glacier fluvial sediment evacuation, inferred bed geometry, and observed surface change from 2016-17 that provide insight into terminus hydrology, bed morphology, and the context of collapse feature formation at the start of the period of rapid retreat. We conclude that glacier drainage during retreat was partly englacial, with englacial deposition of fluvial gravels observed in the field in August 2022. We hypothesise that a switch to englacial drainage promoted rapid disintegration of terminus ice that had been located above a 'hydraulic grade line' determined by the elevation of the overdeepening lip, with collapse formation caused by englacial fluvial cavity formation playing an important role.

VIJAYA KUMAR THOTA <vijaya_t@ce.iitr.ac.in>
IIT Roorkee, India
Contribution type: P

Feasibility of using Sentinel-1 data for resolving ice velocity of glaciers in High Mountain Asia

Abstract: Sentinel-1 is a high-resolution C-band Synthetic Aperture Radar (SAR) satellite by the European Space Agency (ESA). First of many to come, Sentinel-1A was launched in 2014, providing uninterrupted data, irrespective of cloud cover, throughout the day and night. Offset-tracking using the intensity or amplitude of Sentinel-1 data has been extensively used to track the glaciers across the world, including the ice sheets of Greenland and Antarctica. To increase the accuracy of the velocity product and to encounter the inefficiencies of offset tracking in slow-moving regions, the phase information of Sentinel-1 by SAR Interferometry (InSAR) has been tested but limited to the polar regions, excluding mountain glaciers in High Mountain Asia. Here we test the feasibility of Sentinel-1 short-term repeat pass (e.g 6-24 days) to resolve seasonal changes in the ice velocities, which is largely unknown, over three different regions in the Indian Himalayas. In addition, we apply conventional intensity based feature tracking algorithm to obtain annual ice velocities and find nearly three times the velocity changes of Zemu Glacier, eastern Himalaya in 2021-22 as compared to 2014-15. Short-term velocity variations indicate 1.5 times velocity increase at Gangotri Glacier (78.11 ± 13.51 m/year and 102.93 ± 5.11 m/year between October 2020/21 and July 2020 - October 2021). Phase based methods applied over the Drangdrung glacier in the Ladakh region show seasonal variation in ice velocity. This needs further investigation why the overall velocity changes interannually and different seasons. This study shows that the InSAR-based methods to resolve largely unknown seasonal ice velocities of mountain glaciers in the Himalayas if the interferometric pairs with the least temporal gaps are available.

Lizz Ultee <eultee@middlebury.edu>
Middlebury College
Contribution type: P

Glacier model dependence of 21st century glacial runoff projections

Abstract: Global climate model projections suggest that many areas will experience drying over the coming century. In glacierized regions, glacial runoff has historically provided some protection from drought. Our recent global-scale analysis has shown that glacial runoff will likely continue buffering drought through the end of this century, even though glaciers are retreating worldwide. However, those results depend on a single glacier model (GloGEM) and its attendant assumptions and simplifications. Here, we describe a new effort to intercompare 21st century runoff projections from different glacier models. We show an example comparison of GloGEM and PyGEM-OGGM output for selected catchments of the Alps. Finally, we discuss implications for water management applications of glacier model output.

Ivan Utkin <iutkin@ethz.ch>
VAW - ETH Zürich
Contribution type: P

Coupled thermo-hydro-mechanical modeling of polythermal glaciers

Abstract: The outbursts of englacial lakes or cavities can have catastrophic consequences. Understanding the mechanisms leading to the formation of these cavities, which often develop in polythermal glaciers, is therefore important for assessing the associated hazards. The presence of liquid water within a temperate region of a glacier significantly alters the mechanical properties of the ice, in particular, the pore water pressure reduces the effective ice viscosity. Furthermore, englacial water transport is strongly coupled with the stress distribution in a glacier. Several models for polythermal glaciers accounting for ice melting and water transport exist in the literature, but the application of such models is still limited in scope. In this work, we present a fully coupled thermo-hydro-mechanical ice flow model. The model consists of the Stokes equations for predicting the stresses and velocities of the ice phase; Darcy's law for the liquid water transport; internal energy balance equations for describing both cold and temperate regions in a unified manner; compaction-based closure relations to predict mechanical bulk deformation of the ice. Using the proposed model, we study numerically the evolution of the liquid water content in a simplified model setup approximating the polythermal Glacier of Tête Rousse.

Marijn van der Meer <vmarijn@ethz.ch>
VAW - ETH Zürich
Contribution type: P

Deep Learning Regional Climate Model Emulators: a 2 comparison of two downscaling approaches over the 3 Antarctic Peninsula

Abstract: Climate models are computer simulations of the Earth's climate system, which include different variables in time and space in various parts of the world. Their complexity is a trade-off between computational costs, pixel resolution, and domain coverage. Climate models are generally defined into two types, dependent on the spatial resolution and domain coverage: global (GCM) and regional climate models (RCM). GCMs cover the entire globe at low resolution, while RCMs, obtained through the dynamical downscaling of a GCM, are local-scale and high-resolution simulations. RCMs offer a more fine-scaled representation of climate systems. However, due to the RCMs' higher spatial resolution, they come with a high computational cost and time. The general problem addressed by this study is the cost-effective translation of RCM-like models to downscale GCMs. We develop a cost-efficient deep learning model, the RCM-emulator, which can be used as a surrogate for the dynamical downscaling of GCMs. We test the model by emulating regional high-resolution surface mass balance over the Antarctic Peninsula. The potential to downscale GCMs to the resolution of RCMs was explored by machine learning in two training scenarios: (1) a perfect and (2) an imperfect model framework. In the perfect model framework, the RCM-emulator's task is to learn only the RCM downscaling function; therefore, it was trained with upscaled RCM features at GCM resolution instead of low-resolution inputs from the GCM. The perfect model RCM-emulator was evaluated both on upscaled RCM and GCM features. On the other hand, in the imperfect model framework, the RCM-emulator was trained with large-scale features from the GCM. The task of the imperfect model emulator was to downscale the GCM while being exposed to RCM-GCM inconsistencies, and it was evaluated on GCM features. The perfect model emulator accurately reproduced the high-resolution surface mass balance truth when evaluated on upscaled RCM features. However, its predictions on GCM data conserved RCM-GCM inconsistencies and led to underestimating the true surface mass balance. The imperfect model emulator predicted, using GCM data, surface mass balance values close to the truth, showing it learned the underlying RCM-GCM inconsistencies and dynamics. Our results suggest that a deep learning RCM-emulator can learn the proper GCM to RCM downscaling function without needing a perfect model framework while working directly with GCM data. machine learning RCM-emulators are limited by their domain and climate model specificity, making it challenging to transfer to new environments. Still, the RCM-emulator presents a significant computational gain compared to running an RCM simulation, with training in under ten minutes and predictions in a few seconds. We conclude that machine learning emulators can be applied to produce fast and fine-scaled predictions of RCM simulations from GCM data. Therefore, they can be an interesting tool for providing low-cost local-scale information on climate variable evolution and dynamics in a changing climate.

Anouk Volery <anouk.volery@unifr.ch>
University of Fribourg
Contribution type: P

Spatio-temporal variability of bare-ice albedo of glaciers in Central Asia and its link to mass balance

Abstract: Albedo modulates the amount of shortwave radiation absorbed at the surface of glaciers. As shortwave radiations provide between 60-90% of the energy available for melt on extratropical glaciers, the variability of albedo strongly governs glaciers' melt rates. The parameter especially plays a critical role during the ablation season, when the ice is exposed and most of the melting takes place. However, the sub-seasonal variability of albedo has been overlooked in glacier modeling so far and is generally understudied. There is thus a necessity to investigate the spatio-temporal behavior and evolution of albedo on glaciers. The present study explores the variations of the bare-ice albedo of Central Asian glaciers during the ablation season - the aim is to assess the sub-seasonal and spatial cycles of the albedo, the evolution of such cycles over the years, and the correlations between albedo values, meteorological parameters, and altitude, as well as their impact on glacier mass balance. The study presents an initial focus on the Abramov Glacier. We generally observe a darkening of the tongue that is more pronounced in the beginning and middle of the ablation season (July-August) than towards the end (September). While the darkening is limited to lower elevations in July, it reaches higher altitude as the season progresses. Years with lowest minimum bare-ice albedo are characterized by greater melt.

Jane Walden <walden@vaw.baug.ethz.ch>
ETH Zürich
Contribution type: P

Investigating the impact of glacier retreat on slope instabilities in southern Alaska

Abstract: Glaciers worldwide are retreating at unprecedented rates as global temperatures rise. One consequence of glacier retreat is the destabilization of paraglacial slopes as the buttressing force changes. Recent work shows clear correlations between glacier retreat and slope destabilization (e.g., Dai et al., 2020, Lacroix et al., 2022) but the processes governing this buttressing are poorly constrained. We investigate eight large paraglacial landslides in southern Alaska, an area undergoing particularly rapid glacier retreat (Hugonnet et al., 2021). Plus, many of the retreating glaciers are leaving behind deep fjords, where landslides entering the water can lead to tsunamis. We reconstruct the slope deformation history using satellite images from the 1980s to present and determine displacement velocities with feature tracking (Bickel et al., 2018). We compare slope deformation rates to ice thinning rates, ice thickness changes, and the proximity of the landslide to the glacier terminus. Using this dataset, we better constrain the buttressing forces and the processes involved, as well as the preconditions that make certain sites prone to failure.

Will Wenban <wwenban1@sheffield.ac.uk>
University of Sheffield
Contribution type: P

The importance of icefalls

Abstract: Icefalls are a common feature of many alpine glaciers, as a sudden step change in the glacier profile, they carry a potential importance over a wide range of scales. From a contemporary perspective, icefalls represent a zone of significant change in ice thickness, velocity and gradient, which all have an impact on ice dynamics. In a warming climate, ablation of the thinner ice within the icefall can lead to exposure of bedrock and a disconnection between the upper glacier and tongue, potentially leading to a rapid mass wastage of the lower tongue as it becomes cut off from ice flow from the accumulation area. In a longer-term landscape dynamics view, icefalls can be seen to frequently coincide with the area of the equilibrium line altitude (ELA), which is often cited as the region of maximum erosion. Past discussions surrounding the influence of glacial erosion on mountain geomorphology and the so-called 'buzz-saw mechanism' have tended to focus largely on cirques as a driving force and feature of importance to maintain some form of equilibrium between uplift and erosion. However, it seems that icefalls may play an important role that has so far been overlooked or insufficiently explored. Questions arise as to whether icefalls could be seen as a static feature formed in place about the long-term average ELA, or potentially a dynamic migratory feature that erodes headward up the valley as a form of knickpoint analogous to a fluvial waterfall. An inventory of icefalls for contemporary glaciers across Switzerland has been compiled to examine their influence on ice dynamics and begin exploring some of these bigger questions surrounding their importance as a driver of change in long-term landscape dynamics.

Rory White <rnwhite1@sheffield.ac.uk>
University of Sheffield
Contribution type: P

Repeated UAV photogrammetry of three collapse features at Oberaargletscher, Switzerland - August 2022.

Abstract: A short study looking at subsidence rates of three large collapse features at Oberaargletscher, investigating potential evolutionary processes. The study uses repeat UAV photogrammetry over a 13-day period in August 2022, in which part of the collapse fell through – revealing a fluvial channel. Results depict high levels of subsidence over center of the collapse in the days prior to the collapse opening - potentially caused by ice slumping due to degeneration below into the fluvial channel. [Supervisor – Dr Darrel Swift, University of Sheffield].