NRB23 Abstracts

1. Talks:

Northern landscape in transition; detecting, understanding and predicting environmental change in snow dominated landscapes

Hjalmar Laudon[a]

[a] *Swedish University of Agricultural Sciences, Sweden*

In a time when increasingly rapid rates of climate change and ecosystem transformation are occuring, our ability to understand and predict how, when, where, and why changes happen is essential for adapting and mitigating human behaviors. To detect, understand and predict such changes, long-term field research infrastructures have a fundamentally important role to play. To disentangle how long-term trend in temperature, precipitaition and length of winter are mechnistically connected with declines in groundwater levels, summer runoff rates, and stream water biogeochemistry remains key challenges. Equaly important is to understand how declining trends in tree growth, the accumulation of carbon, and the connection between water flux and greenhouse gas balances are regulated. For northern boreal landscapes, the Krycklan Catchment Study (KCS) has supported such research research efforts by enabling process based research since the site was initiated in 1980. The research infrastructure has expanded over the years to encompass a 6790 ha catchment, currently including 18 gauged streams, 1000 soil lysimeters, 150 groundwater wells, 500 permanent forest inventory plots, and a 150 meter tall tower for measurements of atmospheric gas concentrations and biosphere-atmosphere exchanges of carbon, water, and energy. In addition, the KCS has also been the centre for numerous large scale experiments. This large collection of equipment, experiments and data generation supports a range of multi-, trans-, and interdisciplinary research opportunities. The combination of long-term monitoring, shorter-term research projects, and large-scale experiments, including manipulations of climate and various forest management practices, has contributed much to our understanding of boreal landscape functioning, while also supporting the development of models and guidelines for research, policy, and management.

Water-oriented living lab concept to boost co-operation for healthy waters and sustainable northern hydrological research

Anna-Kaisa Ronkanen[a], Cintia Bertacchi Uvo[a,b], Jari Silander[c]

[a] *Finnish Environment Institute, Marine and freshwater solutions, Finland*

[b] *Water Resources Engineering, Lund University, Sweden*

[c] *Finnish Environment Institute, Quality of information, Finland*

Water-Oriented Living Lab (WOLL) concept has its origins in the 1990s, and since then, the opportunities it presents have been extensively studied and developed. WOLL represents a contemporary approach to conducting research in the 2020s, integrating measurement and observation technologies within research infrastructures, fostering collaborative research, and involving stakeholders and end-users. The underlying premise is to directly test and apply research findings and innovations in real-world environments, ensuring their functionality and practicality in addressing watershed-specific needs. Long-term collaboration is a crucial element in these environments. Thames Estuary (https://thamesestuary.org.uk/) is a well-known example of such an initiative. The implementation of a Water-Oriented Living Lab approach can yield numerous benefits for watershed research. These encompass organizational aspects, stakeholder engagement, financial considerations, and transparency. Additionally, practical application is facilitated, allowing research outcomes and innovations to be directly tested and applied in real-world settings. This ensures the functionality and practicality of developed solutions in addressing watershed-specific needs. The multidisciplinary collaboration inherent in a Living Lab environment enables engineers, environmental scientists, biologists, sociologists, and local communities to collectively devise solutions to complex water-related challenges. Living Lab environments serve as platforms for interaction and knowledge exchange among diverse stakeholders, promoting the dissemination of best practices, mutual learning, and the wider distribution of information within watershed communities. These benefits underscore the potential of Water-Oriented Living Labs to create effective and participatory approaches to water management. Within Europe, the identification of WOLL environments has been undertaken as part of the Water4All project in 2023 (https://www.water4all-partnership.eu/) with the objective of updating the current Water Europe's Atlas of the EU Water-Oriented Living Labs (https://watereurope.eu/wp-content/uploads/2019/07/Atlas-of-the-EU-Water-Oriented-Living-Labs.pdf). WOLL and its maturity are defined by three aspects: Setup, Sustainability and Scalability. Scalability describes Living Lab's spatial coverage and potential to collaborate with other WOLLs whereas sustainability determines its temporal context to long-term development process and collaboration. In Finland, four WOLLs, mostly focused on research infrastructure have been selected as candidates to be part of the new Atlas. Examples of the Finnish selected candidates are the Finnish Marine Research Infrastructure-FINMARI, which is a distributed network of field stations, research vessels, laboratory facilities, ferryboxes, fixed platforms and buoys, and has a high level of maturity. The second example is Pallas Supersite focusing on observation and modelling of ecosystem–atmosphere fluxes and northern hydrological processes with high level of international and national research collaborations.

In-situ high-resolution measurements of stable water isotopes - pushing the boundaries in understanding northern (eco)hydrological processes

Zuosinan Chen[a]; **Pertti Ala-Aho**[a]; **Hannu Marttila**[a]

[a] *University of Oulu, Finland*

High-latitude regions are warming more strongly than the global average, but also see increased annual precipitation and changes in seasonal precipitation. The latter includes warming-induced shifts from snowfall to rainfall, more frequent rain-on-snow events, and less summer rainfall. These do not only directly change the amount and the timing of regional water inputs as snow and rain, but also alter how water goes through and exits the water cycle through the ecosystems, e.g., snowpack formation, sublimation, snowmelt, soil water movement, root water absorption, and tree water uptake. For tracing water movement and the water sources involved, the stable water isotope technique is currently the best tool. Compared to the discrete, time-consuming, and destructive water isotope sampling method, in-situ and high-resolution measurements are essential to better understand (eco)hydrological processes and process-based biophysical mechanisms under changing snowfall and rainfall. Therefore, for the first time in northern environments, we are applying innovative in-situ continuous measurements of stable water isotopes (non-destructive Water Isotope Probes and Picarro L2140-i isotope analyzer) and water fluxes (bi-directional sap flow sensors, soil water content, etc.) along the water movement pathway, i.e., in snow (snowfall - snowpack - snowmelt), rain (rainfall - throughfall), soil (vertical and horizontal), roots, and stems. These measurements are performed in typical boreal forests around the Arctic Circle (Julinia, Oulanka, and Pallas, Finland) that have evolved under high precipitation seasonality.

Ecohydrology at the Pallas research catchment; modeling water ages to explore subarctic water-carbon interactions

Pertti Ala-Aho[a]; J. Welker, K.-R. Mustonen, D. Croghan, H. Bailey, E. Klein, V. Hyöky, J.-P. Nousu, A. Lohila, M. Aurela, H. Marttila.

[a] *University of Oulu, Finland*

Northern headwaters are significant contributors to landscape carbon dynamics. However, detailed understanding of carbon sources and export to streams remains incomplete due to the complex dependence on catchment processes. Technological advancements in monitoring water isotopes and quality offer new opportunities for analyzing the variability in water-C interactions and their linkage with runoff sources. We used a combination of tracer-aided hydrological modeling and high-resolution stream water quality data to explore relationships between different water-C parameters. We used modeling, based on stable water isotope data, to estimate spatio-temporal variability of runoff source areas, and provide a proxy for stream water age. We analyzed the temporal coherence of water-C parameters and simulation outputs, and looked at individual events dynamics water-C interactions under variable antecedent conditions and snow influence.

Our results showed that the simulated runoff generation source areas and water ages can be linked with the in-stream DOC dynamics. Periods of young simulated water ages were associated with high stream DOC concentrations. Higher simulated fraction of runoff originating from peatland led to higher DOC in the stream. The contributing area appeared more important than event size in explaining stream DOC concentration. Our approach combining modeling output and novel datasets allowed us to examine how the runoff generation processes in the catchment integrate to stream carbon response. Our research contributes to a more comprehensive understanding of catchment-scale water-C dynamics in subarctic landscapes.

Water balance and hydrologic controls on water chemistry in the Two-Boat Lake catchment, West Greenland

Ylva Sjöberg[a], Christian Ellekilde Bonde[a], Emma Lindborg[b], Tobias Lindborg[c], Mikkel Toft Hornum[a], Johan Rydberg[d]

[a] *Department of Geoscience and Natural Resource Management, University of Copenhagen, Copenhagen, Denmark*

[b] *Danish Hydrologic Institute, Denmark*

[c] *Blackthorn Science AB, Stockholm, Sweden*

[d] *Department of Ecology and Environmental Science, Umeå University, Umeå, Sweden*

Two-Boat Lake (67°N, 50°W) with its 2 km2 catchment is located near the Greenland Ice Sheet in West Greenland. The catchment is dominated by the lake and there are no permanent streams connecting the lake to the surrounding dwarf-shrub tundra landscape. Hydrological and biogeochemical studies have been carried out in the catchment since 2011, with several hydrological variables monitored continuously for over ten years. The site thereby provides unique data sets for studies of the hydrologic control on water and element fluxes in a landscape with continuous permafrost. The ten-year monitoring series includes groundwater table, ground temperature, on-site meteorology, water isotopes and water chemistry, which we combine with numerical hydrological modeling to investigate the impact of near-surface water flow on element transport. During the snowmelt season, water flow occurs primarily on top of the still frozen soil through a network of intermittent overland flow channels. However, as the active layer thaws, the water-soil interaction progressively increases, as indicated by changes by surface- and groundwater isotopic compositions and chemistry. The results from the numerical hydrological modeling show two things. First, that the water moving through shallow soils during the snowmelt season is young (less than one year), whereas the water entering the lake in late summer is older (up to five years). Second, even if the entire catchment area contributes to the runoff during the snowmelt season, drier areas – which make up a substantial part of the catchment – do not contribute with water to the lake during the summer period. This suggests that the active layer soils in dry areas are not hydrologically connected to the lake, which has implications for the transport of, e.g., water soluble elements supplied via atmospheric deposition.

Controls on Methane Emissions from High-Latitude Fens

Rebecca Serata[a], *Dino Bellugi*[a], *Laurel Larsen*[a], *Eeva-Stiina Tuittila*[b]

[a] *University of California - Berkeley, USA*

[b] *University of Eastern Finland, Finland*

Boreal peatlands are rich carbon stores that participate in a global positive feedback with climate change. Methane emissions from wetlands make up around 30% of the global methane budget. In particular, sub-arctic and high-latitude fens have been experiencing faster warming due to climate change, increasing the risk to their carbon stores. Despite significant research efforts, greater understanding of the processes through which climate change alters methane emissions is needed. In this study, we use state-of-the-art deep-learning and information-theory tools to infer pathways of methane emissions over a range of timescales, drier and wetter years, and evaluate predictability. We demonstrate our approach at two sedge dominated wet minerotrophic fens in the ICOS network; Siikaneva in Finland and Abisko Palsa in Sweden. These two sites exhibit large differences in characteristics across a gradient in average annual temperature, mean annual precipitation, and days with snow cover. For both sites, we find that, once the dominant temperature signal is accounted for, there is strong evidence of vegetation-mediated pathways for emission, both instantaneously, via aerenchyma when stomata are open, and with a 10-12 hour lag, presumably due to respiration of fresh exudates. The former pathway is more dominant at the more southerly Siikaneva site than at Abisko Palsa. These pathways for emission are overwhelmed at Abisko Palsa, however, by a possible permafrost melt event that needs to be further investigated. Associated spikes in methane emissions were captured by a deep learning model and primarily related to soil temperature changes.

Safe Rivers - Identification of critical points

Oddbjørn Bruland[a]

[a] *NTNU, Norway*

Norsk naturskadepool damages related to weather cost NOK 27 billion over the past 10 years. Floods pose a great socio-economic risk and is a great threat to life and health. Through proper climate adaptation, it is possible to reduce these future risks. There is already a huge backlog in maintenance of infrastructure in Norway and there are very limited national resources for securing watercourses. It is therefore imperative to prioritize measures with the greatest benefit/cost ratio. Trygg Elv's main goal is to develop methods and tools to identify areas in the watercourse where the effect of measures will be greatest. Through the project, an operational model for interpreting flood warning will be obtained at location where the municipality or infrastructure owner has found to be critical. Critical locations, where the river overflows and what happens next. The project will identify topographic factors that combined with different discharges create critical situations. In a GIS system, such information will be used to identify potentially critical areas in a river which the municipalities must have an extra focus on. Connected to local observations this can give information on situations that are developing critically. One can thus have time to prevent the worst case scenarios. In this project results from numerous Hec Ras simulations have been related to topographical parameters extracted for the rivers using GIS and the relations have been analyzed using various statistical machine learning methods.

Flow regime changes in the rivers of SW Spitsbergen

Marzena Osuch[a]

[a] *Institute of Geophysics, Polish Academia of Sciences, Poland*

The study aims to reconstruct the flows and estimate changes in the four High Arctic rivers located at SW Spitsbergen. For this purpose, different rainfall-runoff models were calibrated and validated using the available flow observations. In the second step, these models were used to reconstruct flow conditions from 1979-2020. Based on the obtained series, the changes in the hydrological regime were identified, considering the diversity of the degree of catchment glaciation. Similar trends of change were detected in all catchments. These include earlier snowmelt floods, large increases in autumn flows, a prolongation of hydrological activity, and a decrease in flows in the second half of June and at the beginning of August. As a result of the increase in autumn rainfall, the flood regime in these catchments changed from unimodal (dominated by snowmelt) to bimodal, with two flood periods in July and the second in September. We also tested the uncertainty of the estimated changes taking into account different hydrological models and their parameters. The study was carried out with the SONATA BIS project financed by the Polish National Science Centre (grant no. 2020/38/E/ST10/00139).

Role of snow for changes in hydrological regimes in east Siberian Arctic rivers

David Gustafsson[a], **Jude Musuuza**[a], **Katharina Klemeth**[a], **Denica Bozhinova**[a], **Andrea Popp**[a], **Liudmila Lebedeva**[b], **Tetsuya Hiyama**[c]

[a] *Hydrological Research Unit, Swedish Meteorological and Hydrological Institute, Sweden*

[b] *Melnikov Permafrost Institute, Yakutsk, Russian Federation*

[c] *Institute for Space-Earth Environmental Research, Nagoya University, Nagoya, Japan*

The study investigates the role of snow for the climate change impacts in hydrological regimes across main river basins in central and northwest Yakutia, Eastern Siberia using a hydrological model constrained by in-situ and satellite-based snow and river discharge observations. The river runoff observations in large and medium sized rivers show an increase over recent decades that can be associated with increasing air temperature and precipitation, as well as changes in snow, glaciers, and permafrost. We assessed the relation between changes in snow and streamflow using the satellite-based ESA CCI snow data and the hydrological model HYPE. The streamflow trend analysis showed a general pattern of increasing monthly mean and minimum stream flows from October to April, but more frequent in larger river basins. This can be explained by the increasing autumn precipitation, but the absence of change in annual maximum flow and streamflow in June also suggests relation to changes in the snow. The snow data shows a pattern of decreasing maximum snow water equivalent in the western part of the study area, and a corresponding decreasing trend of number

of days with snow cover and earlier final snow melt out date. These results are in line with the trends in observed streamflow; a short snow cover period and increasing amount of autumn and winter rainfall, as well as a lower maximum snow water equivalent could contribute both to the increasing winter runoff, and the absence of increasing streamflow in early summer. This work was conducted as part of the HYPE-ERAS project funded by FORMAS (project DNR: 2019-02332), RFBR (project No. 20-55-71005), and JST (Grant No. JPMJBF2003) through the Belmont Forum Collaborative Research Action: Resilience in the Rapidly Changing Arctic.

Predicting no-flow conditions in northern headwater catchments influenced by snow

Jason Leach[a]

[a] *Canadian Forest Service, Canada*

Much of our understanding on temporary headwater streams is from arid and sub-humid environments. We know less about no-flow periods in humid headwater catchments that experience seasonal snow cover. This study compares the ability of statistical and process-based models to predict the occurrence of no-flows for headwater streams under shifting climatic conditions. We used 40 years of streamflow data from 13 headwater catchments within the Turkey Lakes Watershed located in Ontario, Canada, near the eastern shores of Lake Superior. These headwater catchments differ substantially in their number of no-flow days (0 to 166 days per year) despite being clustered in a small geographical area with wet climatic conditions (mean annual precipitation of 1210 mm/year). We found that between-catchment variability in no-flow occurrences was associated with differences in wetland cover and groundwater contribution. Inter-annual variability in the number of no-flow days was primarily associated with summer and fall climate conditions. Despite the large seasonal snowpacks that form in this region, snow conditions did not appear to influence the timing or extent of no-flow periods. We found that a process-based model provided better predictions of no-flow periods compared to predictions made using statistical models. The advantage of using process-based models was particularly noticeable when making predictions outside the climatic conditions used to calibrate the model (e.g., calibration during wet and cold years and prediction during dry and hot years). This study provides insights on no-flow periods for headwater streams in northern forested landscapes and how they may respond to changes in climate.

Three decades of river restoration in Sweden: Lessons learned and future challenges

Christer Nilsson[a]

[a] *Umeå University, Sweden*

Forestry radically changed rivers in northern and central Sweden from the mid 1800s to the late 1900s. To facilitate log floating rivers were channelized and straightened and lakes were dammed for water storage. These impacts speeded up water flow, resulting in removal of smaller sediment from the rapids. As a result, rivers became less suitable for aquatic biota. After timber floating was terminated, many of the still free-flowing rivers were restored. Restoration included dam removal and return of sediment to river bottoms, to reduce flow velocities and enable fish spawning. In my presentation I will provide examples from the Vindel and Pite rivers and discuss the geomorphological, hydrological and ecological outcomes of restoration.

River-flow as affected by wildfires, storms, urbanization, regulation, and climate across Sweden

Berit Arheimer[a] **and Göran Lindström**[a]

[a] *Hydrological Research Unit, Swedish Meteorological and Hydrological Institute, Sweden*

The global water crisis emphasises the importance of understanding ongoing changes in water resources. River flow may change from e.g. shifts in land cover, constructions in the river channel, and climatic change. Currently there is a lack of understanding of the relative importance of these drivers, and thus, we analysed timeseries of gauged river flow from 1961 to 2018 for 34 disturbed catchments from across Sweden. We explored: (1) land cover changes from wildfires, storms, and urbanization; (2) dam constructions with regulations for hydropower production; and (3) climate‐change impact in otherwise undisturbed catchments. To quantify how these disturbances have affected the river flow we applied trend analysis and the differences in observations versus hydrological modelling for annual and daily stream flow, seasonal flow regime, and flow duration curves. We found that regulations have the largest impact, reducing spring floods with up to 100% and increasing winter flow by several orders of magnitude, with substantial effects transmitted far downstream. Second largest impact was found for climate, which changed the total river flow up to 20%, and urbanisation, showing a 20% increase in high flows also at medium scales. Tree removal by wildfires and storms has minor impacts at medium and large scales. Overall, the study highlights the benefits of combining observed time series with numerical modelling to exclude the effect of varying weather conditions, when quantifying the effects of various drivers on long‐term streamflow shifts.

Reference: Arheimer and Lindström, 2019: Water Resources Research 55(11), https://doi.org/10.1029/2019WR024759

Identifying challenges to govern water through mainstreaming and nexus thinking

Camilla Sandström[a]

[a] *Umeå University, Sweden*

Mainstreaming and nexus thinking are being promoted as important alternatives to the traditional sectoral approach to water governance. While mainstreaming builds on the idea that water issues should be at the core of decision making in every sector, nexus thinking acknowledge that the water sector is strongly interlinked to other sectors such as energy, agriculture, and forestry. Both approaches stem from the identified need to change the dominant sectoral paradigm with the aim of developing more well-informed, inclusive, and adaptive policies. While the mainstreaming approach has been developed for the (systematic) incorporation of water issues into a specific sector the nexus thinking promote cooperation of diverse actors in coordinating policies across traditional sectors or policy domains. While key opportunities for implementation include developing strategies and policies based on integrative, inclusive, participatory, and adaptive governance principles to address policy incoherence, as well as the recognition of trade-offs and the creation of synergies, both approaches face similar barriers for implementation. These include a lack of political will, unfitting institutional frameworks, and policy mixes to respond effectively to identified challenges. This presentation will discuss potential strategies to overcome these barriers.

How new weather conditions and land use challenge reindeer herding in northern Sweden

Gunhild Ninis Rosqvist[a], Niila Inga, Pia Eriksson, Ward van Pelt, and David Gustafsson

[a] *Stockholm University, Sweden*

Reindeer herding is one of the primary livelihoods for indigenous peoples throughout the Arctic where warming now leads to weather, snow and ice situations previously unencountered. To understand how the new climate state forces societal adaptation, we have studied the impact of recent and rapidly changing weather and snow conditions on reindeer response and herding strategies. Results show that especially snow conditions strongly determine temporal and spatial grazing opportunities and therefore reindeer response. Adaptation demands an increased reindeer herding community flexibility in guiding their reindeer to suitable alternative grazing areas. Instead, herders find their flexibility is becoming increasingly reduced due to industrial and societal activities. The current rapid increase in demand for critical minerals, raw materials and renewable energy to facilitate the 'green transition' in northern Fennoscandia requires access to even more new land. Thus, there is a high-risk adaptation measures to climate change effects may be further hampered.

Will there be enough water? Progress towards a scientifically defensible water balance for Iqaluit's secondary water supply lake

Murray Richardson[a]

[a] *Carleton University, Canada*

"Unnamed Lake" in Nunavut's capital city of Iqaluit represents the community's best hope for a reliable freshwater supply that will meet the communities rapidly growing water demands. The lake has already been used once as a source for emergency resupply to Iqaluit's municipal surface water reservoir, and is now being seriously considered for its potential as a longer-term supply. This is a relatively large and deep lake for the area, thus drawing attention as a promising future water source for the community, yet little is known about the renewable fraction of water that it offers. This issue has been compounded by a virtually impossible-to-gauge lake outflow, a problem that can only be solved through installation of a massive weir with major financial investment and significant delays due to water licensing requirements. Fortunately, we have collected some preliminary information on the major water balance terms of this lake, from spring to fall of 2022 . This presentation will highlight results from terrestrial and open-water eddy covariance measurements, precipitation inputs including end-of-winter snow water equivalent estimates available for recharge, and a best estimate of outflow discharge derived by gauging multiple downstream locations. These observations represent the first available hydrologic observations to help answer the questions: Will there be enough water for Iqaluit? And if so, how long will it last, given the Arctic city's current growth trajectory?

Assessing High Arctic Catchments Using UAV-based Remote Sensing Data: High-Resolution DEMs and Soil Wetness Index Estimation

Abhishek Bamby Alphonse[a]

[a] *Institute of Geophysics, Polish Academia of Sciences*

This study explores the potential of Uncrewed Aerial Vehicles (UAVs) equipped with photogrammetric, thermal, and multi-spectral cameras to acquire high-resolution images for two High Arctic catchments, Fuglebekken and Ariebekken, in the vicinity of the Polish Polar Station, Hornsund in SW Spitsbergen. The UAV surveys were conducted in July 2022, resulting in a finer spatial resolution and higher product accuracy than those acquired by aerial and satellite-based missions. The high-resolution DEMs from Zenmuse P1 provided detailed morphometric characteristics and hydrological parameters, including the delineation of catchments and stream channels and the identification of elevation changes and landscape evolution, such as moraine breaches and coastal erosion. The study also investigated the usage of thermal and multi-spectral data from Zenmuse H20T and MicaSense RedEdge MX to estimate the soil wetness index (SWI) for the catchments, which was accurately calculated using the NDVI-LST triangle method and correlated with in-situ measurements of soil moisture. The results demonstrate the potential of UAV-based remote sensing data in identifying spatial variations in High Arctic catchments and offer valuable insights into the dynamics and functioning of these High Arctic catchments. The study was carried out with the SONATA BIS project financed by the Polish National Science Centre (grant no. 2020/38/E/ST10/00139).

Evaluation of temporal and spatial variability of evaporation in Hornsund area (SW Spitsbergen)

Nicole Hanselmann[a]

[a] *Institute of Geophysics, Polish Academia of Sciences*

Evaporation is an important component of the hydrological cycle but remains understudied in High Arctic Svalbard. In this study, we investigate land evaporation at SW Spitsbergen in High Arctic catchments by evaluating in-situ pan evaporation measurements and calculated potential evaporation. The study area is located in the vicinity of the Polish Polar Station Hornsund in Svalbard. For a better understanding of evaporation in the study area, one pan evaporometer was installed in the summer seasons of 2019-2022 at the meteorological site of the Polish Polar Station. In 2022 additional four pan evaporometers were placed in Fuglebekken and Ariebekken catchments to investigate the spatial variability. Analysis of recent in-situ measurements indicates higher annual evaporation rates than the values from the literature of the early 2000s. The application of multiple potential evaporation formulas revealed that the choice of the calculation method could greatly influence the derived estimates. Calibration of such formulas to High Arctic conditions helps to improve the estimates of potential evaporation applied in hydrological models. The study was carried out with the SONATA BIS project financed by the Polish National Science Centre (grant no. 2020/38/E/ST10/00139).

Ice-dammed lakes in Greenland

Dorthe Petersen[a]

[a] *Asiaq—Greenland Survey, Greenland*

Ice-dammed lakes, which show a cyclic behavior of slowly filling over months or years, interrupted by sudden, quick, and full drainage of the lake in a Jökellhaup or glacial lake outburst flood (GLOF) event, are not uncommon in Greenland along the margins of glaciers and the Greenland Ice Sheet (GrIS). Many of these lakes are situated in very remote locations, where even the GLOF events might go unnoticed by humans, although the events can have significant influence on the local environment. However, the GLOF events are likely to become more important for the Greenlandic society as industry, tourism etc. develops. For example, the possibilities to utilize the still unharnessed larger hydro power potentials in Greenland have gained growing awareness and interest in recent years. The catchment of each of Greenland's larger hydro power potentials includes a part of GrIS and more of them further include one or more ice-dammed lakes. Only few of the Greenlandic ice-dammed lakes have so far been investigated in-situ. Here we present information derived from downstream hydrometric stations, which document both stable behavior as well as large changes, and we give examples of the possible consequences for hydro power projects.

Thermal Regime of High Arctic Tundra Ponds, Polar Bear Pass, Nunavut, Canada

Kathy Lynn Young[a]

[a] *York University, Canada*

This study evaluates the seasonal and inter-seasonal temperature regime of small tundra ponds ubiquitous to an extensive low-gradient wetland in the Canadian High Arctic. Pond temperatures can modify evaporation and ground thaw rates, losses of greenhouse gases and control the timing and emergence of insects and larvae critical for migratory bird feeding habits. We focus our study on thaw ponds with a range of hydrologic linkages and size across at Polar Bear Pass (PBP), Bathurst Island, and whenever possible compare their thermal signals to other arctic ponds. Pond temperatures and water levels were evaluated using Hobo temperature water level loggers, Ecotones and verified by regular manual measurements. Other environmental data collected included microclimate, frost table depths and water conductivity. Our results show that there is much variability in pond thermal regimes over seasons, years and space. Cumulative relative pond temperatures were similar across years, with ponds normally reaching 10-15°C for short to longer periods except in 2013, a cold summer season when pond temperatures never exceeded > 5ºC. Pond frost tables and water conductivities respond to variable pond thermal patterns and substrate conditions. This study contributes to the ongoing discussion of climate warming and its impact on arctic landscapes

Talik groundwater and streamflow generation at the small watershed in continuous permafrost

Liudmila Lebedeva[a,b]

[a] *Central Asian Regional Glaciological Centre, Almaty, Kazakhstan*

[b] *Melnikov Permafrost Institute, Russia*

Hydrological and hydrogeological processes in continuous permafrost environment are associated with the existence of through and non-through talik aquifers. The aim of the study was to evaluate the relationship between suprapermafrost subaerial talik aquifers and streamflow generation on the example of a small watershed of the Shestakovka River in the continuous permafrost zone of Central Yakutia, Russia. Talik aquifers up to 20 m thick occupy about 20% of the catchment and are confined to gentle slopes composed of sandy deposits and covered with sparse bearberry pine forests. The groundwater level in taliks has a pronounced seasonal variation with the highest values during the period of maximum freezing from January to March and a decline during the warm season. Water balance calculations show that about 70% of the annual runoff is formed by talik groundwater. 80% of the watershed, covered with pine forests without taliks, larch-birch forests and swamps, contribute only 32% of the river flow or 10 mm/year. On the springflood rise, the streamflow is formed mainly by the swamps and larch-birch forests, where snowmelt water flows down the roof of the frozen ground in the organic layer into the river. Hydrochemical and isotope data suggest that taliks groundwater contribute to the river during the summer-autumn low water period.

Hydrogeological conceptual model of aquifers in catchments headed by temperate glaciers

Aude Vincent, Clémence Daigre, Ophélie Fischer, Guðfinna Aðalgeirsdóttir, Sophie Violette, Jane Hart, Snævarr Guðmundsson, and Finnur Pálssont

Achieving understanding and quantification of unknown aquifer systems in glacial context is crucial to forecast the evolution under climate change of water resources and of potential floods and landslides hazards. We focus on four south-eastern outlet glaciers of the main Icelandic icecap, Vatnajökull. New data are being acquired in the field to characterise groundwater dynamics. From this we propose a hydrogeological conceptual model: two distinct aquifers and their hydraulic conductivities are identified. A comprehensive water balance at the scale of the watershed has been obtained. Recharge to the aquifers is up to 4 times higher under the glaciers than on the plain, and we demonstrate the glacial melt recharge impact on the groundwater dynamic.

Overview of NASA SnowEx campaign in Alaska, U.S.

Svetlana Stuefer[a]

[a] *University of Alaska Fairbanks, USA*

Snow Experiment (SnowEx) was initiated by NASA's Terrestrial Hydrology Program in 2017 to "enable trade studies for a snow satellite mission design." The focus of SnowEx is on testing and maturing technology for satellite remote sensing of global snow water equivalent (SWE). A suite of airborne and ground-based validation measurements was collected in fall 2022 and spring 2023 in northern Alaska to quantify and compare the capabilities of radar and altimetry sensors to address

SWE and snow depth measurement questions unique to taiga and tundra snowpacks. Three SnowEx sites were selected in Interior Alaska, a boreal forest environment with discontinuous permafrost and seasonal taiga snowpack. Two SnowEx sites were located on the North Slope of Alaska, a region dominated by low-stature land cover, tundra snowpack, and continuous permafrost. In March 2023, snow characteristics (microstructure, depth, density, SWE, hardness) were measured at 169 study plots distributed across five SnowEx sites. These ground-based snow measurements were accompanied by two concurrent airborne missions (lidar and SWESARR) at all five sites. A similar set of instruments was tested by the SnowEx team in mountain ranges and temperate forests of the Western U.S. in 2017─2021. When taken together, the SnowEx field campaigns provide snow datasets in support of testing and advancement of remote sensing, modeling, and measurements techniques needed for the development of global SWE products. This presentation focuses on the objectives of the boreal forest and tundra SnowEx campaign and presents an overview of SnowEx March 2023 field activities in Alaska.

Investigating the Impacts of Rain on Snow Events on Snowpack Stratigraphy in Northern Finland

Leena Leppänen[a,b], Sirpa Rasmus[a], Henri Wallen[a]

[a] *Arctic Centre, University of Lapland, Rovaniemi, Finland*

[b] *Arctic Space Centre, Finnish Meteorological Institute, Sodankylä, Finland*

Rain on snow events have been increasingly prevalent in northern regions as a result of climate warming, leading to the formation of hard ice layers within the snowpack. This poses a significant challenge for herbivores, including reindeer, that depend on accessing food beneath the snow cover. In this study, we investigate the snowpack stratigraphy and weather parameters at the Arctic Space Centre in Sodankylä operated by the Finnish Meteorological Institute. Our aim is to gain a better understanding of the changes occurring in the snowpack resulting from rain on snow events. To differentiate between liquid and solid precipitation events, we utilize distrometer data, enabling us to identify the specific contributions of liquid precipitation to the overall snowpack composition. Snowpack stratigraphy is measured through weekly snow pit observations, providing detailed information on the layering and properties of the snowpack. Additionally, we incorporate the use of a physical snow model, SNOWPACK, to simulate the snow structure between weekly snow pit observations. Furthermore, we analyze alterations in prevailing wind directions and precipitation patterns within a reindeer herding district near the station. This investigation aims to provide valuable insights into the factors influencing observed changes in the snowpack. Ultimately, the findings from this research could have implications for reindeer herders in mitigating the adverse effects of rain on snow events on reindeer foraging.

Exploring the potential of different spatial snow observations for hydrological modelling in mountainous catchments

Ilaria Clemenzi[a], David Gustafsson[a], Wolf-Dietrich Marchand[b], Björn Norell[c], Jie Zhang[d], Rickard Pettersson[d], Veijo Pohjola[d], Viktor Fagerström[a], Daniel Wennerberg[a]

[a] *SMHI, Sweden*

[b] *Norwegian Water Resources and Energy Directorate, Norway*

[c] *Vattenregleringsföretagen AB, Sweden*

[d] *Uppsala University, Sweden*

Snow process heterogeneity and interaction in mountainous environments challenge accurate snow and runoff predictions. This study compared different snow distribution representations to enhance runoff predictions in the Överuman catchment, Northern Sweden, and the impact of using distributed snow observations from ground penetrating radar in addition to runoff data in the hydrological model calibration. We modelled snow spatial distribution with various approaches, including a temperature-based method, a snowfall distribution function based on wind and topography and a snow depletion curve in the semi-distributed hydrological model HYPE. We found that the models with a snow distribution based on wind and topography improved snow water equivalent (SWE) predictions close to the accumulation peak. These models could use distributed snow information and perform similarly to models with a depletion curve for runoff predictions. Snow observations improved model calibration robustness for SWE and runoff predictions. To further these findings, we analysed snow depth data from new uncrewed aerial vehicle acquisitions to explore their potential in, e.g. model discretisation and data assimilation for snow and runoff predictions in mountainous catchments.

Winter heavy precipitation event in December 2021 in interior Alaska

Kazuyoshi Suzuki[a] , T. Dan, M. Zupanski, H. Hirashima, G. Iwahana, H. Park and H. Kobayashi

[a] *Japan Agency for Marine-Earth Science and Technology, Japan*

A record-breaking precipitation event was observed in interior Alaska in December 2021. Daily maximum precipitation of nearly 100 mm was recorded on December 26 in both Fairbanks and Poker Flat, located farther north in the near Arctic Circle. In December, monthly precipitation exceeded 200 mm at both locations, with Poker Flat recording the higher precipitation. In this study, we clarified the contribution of rainfall and snowfall to precipitation events exceeding summer precipitation in the Arctic in late December using a snow model, in-situ observation, and dataset reanalysis. The effects of record-breaking precipitation events on the snowpack and soil layer and the water and energy balance were analyzed. Meanwhile, we worked on developing an Arctic region reanalysis system using Polar WRF-MLEF. We aimed to reproduce anomalous precipitation from the reanalysis values using our reanalysis system. The mechanisms of extreme precipitation were also discussed.

Analyzing vegetation effects on snow depth variability in Alaska with airborne lidar

Lora May[a], Svetlana Stuefer[a] and Christopher Larsen[a]

[a] *University of Alaska, Fairbanks, USA*

Seasonal snowpack plays a critical role in hydrologic and ecologic processes. In boreal forest regions snow depth was thought to be markedly different across land cover types. Identifying the vegetation metrics responsible for possible snow depth and SWE spatial variability continues to be a challenge. Airborne lidar has advanced our understanding of links between forest snow distribution and vegetation impacts. This study analyzes high resolution (0.5 m) lidar data sets acquired during NASA's SnowEx field campaign in Alaska. Airborne lidar data was collected for a boreal forest site during snow-off and peak snow-on accumulation in 2022 and 2023. Lidar snow depth (98 ∓ 15 cm) and canopy height maps, at 0.5 m resolution, were created from lidar data sets. A total of 85.9 million lidar snow depth and canopy height values were available for this study. A subset of 6.1 million of the total depths and heights was used to run the analysis. Extensive in situ field snow depth and SWE measurements were collected concurrently with the peak snow-on lidar survey. This presentation summarizes results on quantifying snow depth variability between land cover types and different canopy heights within boreal forests using NASA SnowEx Alaska data.

The effect of forest management interventions on hydrological connectivity in boreal headwater catchments

Fischer, Benjamin[a], **Hjalmar Laudon**[b], **Jan Seibert**[a,c], **Kevin Bishop**[a]

[a] *Uppsala University, Sweden*

[b] *Swedish University of Agricultural Sciences, Sweden*

[c] *University of Zurich, Switzerland*

Sweden has a long history of isotope hydrograph separation (IHS) studies in single forested catchments showing that pre-event dominates stormflow. However, boreal headwater catchments consist not only of forested but of a patchwork of different landscape elements such as peatlands, restored wetlands, forests, and clear-cut areas. Therefore, how these catchments respond to rainfall events is still being determined. Especially in terms of a changing climate, there are concerns that these management interventions could alter the hydrological "connectivity" of these landscapes. To investigate how specific forest management interventions influence how rainfall becomes runoff, we collected rainfall and streamflow samples in catchments (2 clear-cut catchments, 2 restored wetland catchments, 2 forested and 2 peatlands). The water samples were analysed on δ18O, δ2H, pH, EC & DOC. An IHS was performed to investigate how much pre-event water contributes to streamflow. The IHS results showed that catchments with clear-cuts and peatlands had a slightly higher event water contribution than the forested catchments. Instead, the restored wetlands had lower pre-event water contributions and were more similar to lakes in their isotopic signature. Hence, these first results demonstrate IHS as a valuable tool to investigate the hydrological "connectivity" of these landscapes allowing to understand better the flow path of water and, therefore, the export of nutrients to downstream regions.

Using hyper-resolution forest snow models to study the impact of a changing environment

Tobias Jonas[a], **Giulia Mazzotti, Johanna Malle, Clare Webster**

[a] *WSL Institute for Snow and Avalanche Research SLF, Switzerland*

Snow accumulation and melt processes under heterogeneous forest canopies are highly variable in space and time. Recent advances in model development and the increasing availability of detailed canopy structure datasets allow for accurate meter-resolution snow model simulations capable of resolving tree-scale processes, shedding new light on the complex process interactions that govern forest snow dynamics. Here, we demonstrate the capabilities of FSM2, our latest forest snow model specifically designed for hyper-resolution simulations under variable canopy cover. A key component of FSM2 is the use of the external radiation transfer model CanRad that enables calculation of realistic subcanopy shortwave patterns bound by the surrounding 3-dimensional canopy structure. These calculations are accurate enough to track shadows of individual trees, and efficient enough to be used for regional simulations at meter-resolution. We present two sets of model experiments: First, we applied FSM2 to a model domain encompassing steep forested slopes within a sub-alpine valley near Davos, Switzerland. These simulations reveal how snow cover evolution is jointly affected by canopy structure, terrain characteristics, and meteorological conditions. Second, we manipulated the canopy datasets input into CanRad to represent future forest structure, e.g., after logging, beetle infestation, or fire. This approach allowed us to investigate the effect of selective logging scenarios on subcanopy microclimate under current and future climate conditions. Results from these type of modelling experiments help to better understand how snowpacks and ecohydrological regimes may evolve in response to both, forest disturbances and a warming climate.

2. *Posters:*

Distributed model test for Ume river system

Morgane Jouenne[a] and Oddbjørn Bruland[a]

[a] NTNU, Norway

Ume river system has several power stations, intakes and reservoir. The hydrological forecasting is important for optimizing the use of water through the cascades. So far the traditional approach based on the HBV have been used. In this study a distributed model system will be tested to identify possible benefits compared to existing forecasting system.

Temporal variations of river water surface slopes from ICESat-2

Linda Christoffersen[a], Karina Nielsen[a], Peter Bauer-Gottwein[a], and Louise Sørensenn[a]

[a] Technical University of Denmark, Denmark

ICESat-2 is a laser altimetry satellite launched in 2018. It simultaneously measures the surface elevation with six laser beams grouped in three pairs of two. This configuration allows measurements at six positions across 6.6 km across-track. Utilizing this beam configuration enables us to measure the local water surface slope from the water surface elevation along sections of the river. These local river water surface slopes can improve the performance of hydrodynamic models. We have developed software to processes ICESat-2 data and estimates the local water surface slope where the satellite ground track crosses the SWOT River Database. The process is independent of the intersection angle between the satellite track and the river centre line. The performance has been demonstrated for the Amur River in Asia where 4 years of data resulted in 7306 water surface slope estimates between 0.6 cm/km and 651.04 cm/km. Estimates were produced across 1693 river reaches with a median standard error of 0.5 cm/km. On average, this produced 4 water surface slope estimates per river reach, with the largest number of slope estimates of 22 for a reach. This enables us to investigate the temporal variations of water surface slopes, detecting areas affected by backwater effects due to slope breaks, cross-section changes, or tributary junctions. "

The role of assimilating earth observations and in situ data for seasonal hydrological forecasting

Jude Musuuza[a], Louise Crochemore, and Ilias Pechlivanidis

[a] *SMHI, Sweden*

Earth Observation (EO) data are a valuable complement to in situ measurements in hydrology because they provide information in locations where direct measurements are unavailable or prohibitively expensive to make. Recent advances have enabled the assimilation of different datasets into hydrological models to better estimate states and fluxes, which leads to improved hydrometeorological forecasts. The assimilated data exert additional controls on the quality of forecasts; it is therefore important to apportion the contributions from the hydrometeorological forcing and assimilated data. Model outputs are commonly used to benchmark forecast systems during the assessment of their performance. We propose a diagnostic framework that uses observation as benchmark to assess the sources of skill and infer the seasonal importance of assimilated and forcing datasets. The framework is tested using two forcing datasets derived from historical observations and a downscaled Global Circulation Model (GCM) to assimilate four EO and two in situ observations to generate the initial states for generating the forecasts. In addition, we use the Swedish snowmelt-dominated Umeälven catchment and the HYPE model over the period 2001-2015. The results show that all assimilations improve the forecast skill but the improvement depends on the season and assimilated data. The lead times during which data assimilation influences forecast skill also differ between datasets and seasons and the assimilated datasets generally exert more control on the streamflow forecasting skill than meteorological forcing data.

Cryospheric impacts on hydrologic and biogeochemical cycling in alpine, sub-arctic environments

Andrea L. Popp[a], Nicolas Valiente, Kristoffer Aalstad, Sigrid Trier Kjær, Yeliz A. Yilmaz, Norbert Pirk, Alexander Eiler, Peter Dörsch, Dag O. Hessen, Lena M. Tallaksen, and Laurel G. Larsen

[a] *SMHI, Sweden*

Headwater catchments considerably influence global carbon and nitrogen cycles through GHG transport, storage, and emissions. However, the dynamics of GHGs in these systems, especially in cold regions undergoing rapid transformation, remain elusive. To better understand the hydrological and biogeochemical changes in cold regions, we obtained field- and satellite-derived data from two sub-arctic catchments (one glaciated, one non-glaciated) in the north-western part of the Hardangervidda mountain plateau (South Central Norway). During the summers of 2020 and 2021, we analysed various water sources including streams, lakes, groundwater, snow and ice for environmental tracers and GHGs (i.e., CO_2, CH_4 and N_2O). Integrating the the environmental tracers with a Bayesian mixing model allowed us to assess the source water contributions to surface waters. To estimate snow cover anomalies between 2020 and 2021 compared to a five-year mean, we retrieved fractional snow cover durations (FSCDs) from 2016 to 2021 by applying a spectral unmixing algorithm to merged Sentinel-2 and Landsat 8 imagery. The observed GHG saturations varied significantly across water sources, with groundwater being the most supersaturated. Our results suggest that snow cover, glacial meltwater, and subsurface water routing mainly control GHGs at our study site, shedding light on the interplay between hydrology, the cryosphere and GHG dynamics in high-latitude aquatic systems.

High-resolution monitoring of snow water resources in Switzerland

Tobias Jonas[a], Jan Magnusson, Louis Queno, Bertrand Cluzet, Giulia Mazzotti, Rebecca Mott

[a] WSL Institute for Snow and Avalanche Research SLF, Switzerland

National services have developed diverse approaches to tackle the challenges of snow water resources monitoring. Switzerland is a comparably small country and can rely on a dense network of snow monitoring stations. Today, an increasing number of flood events are associated with complex weather situations such as rain-on-snow. These circumstances require physically-based snow models, which require a wide scope of meteorological forcings, while data assimilation techniques compatible with these models are not straightforward. Here we present our latest multi-model framework set up to monitor snow water resources across Switzerland a 250m spatial resolution. Forcing data is derived from the numerical weather prediction model COSMO-1E run by MeteoSwiss at 1km resolution. Process-specific instances of the physically-based multi-layer snowpack model FSM represent subunits of grid cells with different landcover properties such as, e.g., open terrain, forests, and glaciers. Data from 450 snow monitoring sites are assimilated to sequentially update the model simulations over the course of the winter season. We demonstrate that these approaches effectively improve simulated snow states and melt fluxes relative to reference open loop simulations. A separate model chain is available to provide daily snow water equivalent grids at 1km spatial resolution for the past six decades. This snow-climatological reference dataset enables characterization of the current winter relative to the long term mean for any given day of the year. Datasets from the Swiss Operational Monitoring System are available for snow model intercomparison and development purposes.

Investigating the impacts of liming on microbial communities in acidified rivers within Nova Scotia

Kailyn Hanke[a], Maggie Hosmer, Morgan Langille, Shannon Sterling, John Rohde

[a] Dalhousie University, Canada

Delays in recovery from soil acidification is harming terrestrial and aquatic ecosystems in Nova Scotia. Liming is currently the only strategy that can reverse the effects of acidification in river ecosystems. Liming describes a process where “lime dosers” deposit crushed limestone directly into rivers to raise the pH of the water. Lime dosers have been installed on some of Nova Scotia’s most acidified rivers, including the Killag River, and have resulted in rebounding of Salmon populations. The effects of liming on microbial communities is unknown. We used 16s rRNA gene sequencing to study the impacts of liming on bacterial communities in the Killag River. Our results suggest that the bacterial community structure is overall robust; however, certain bacteria are differentially abundant in limed and unlimed water. Bacterial community profiling is an inexpensive and robust method to monitor for unintended consequences that may arise from liming.

Snowpack trends in an Alaskan northern basin

Anna M. Wagner[a], Zoe Courville[b], and Nawa Raj Pradhan[c]

[a] *Cold Regions Research and Engineering Laboratory, Alaska, USA*

[b] *Cold Regions Research and Engineering Laboratory, New Hampshire, USA*

[c] *Coastal Hydraulics Laboratory, Mississippi, USA*

Snow accumulation and ablation characteristics are changing, and although snow cover extent is generally decreasing globally, changes in local and regional snowmelt timing can result in faster snowmelt rates and lead to flooding. Flooding may be intensified even in areas where winter precipitation is projected to decline, which can lead to infrastructure damage including roads, buildings, and industrial facilities where the flood protection design is limited to historical conditions and forcing. Numerical flood simulation and prediction using a large-scale hydrological model can be improved by implementing snow extent estimated from a finer scale snow model. To assist with these predictions, we have developed a spatially explicit snow climatology that employs a historical climate record for Chena River watershed in Alaska. We used a spatially distributed snow model, SnowModel, to develop a 40-year historical record. Our presentation includes an overview of the variability of snowpack, and the trends in snowpack duration including the onset of snow arrival in the fall, and snowmelt in the spring. Predictions of soil temperature sensitivities to climate conditions will also be presented.

A new framework for watershed characterization and cumulative effects assessment with application to mining-impacted subarctic watersheds of central Yukon, Canada

Murray Richardson[a] and John Foster

[a] *Carleton University, Canada*

A new spatial-analytic framework for continuous quantification and representation of watershed characteristics including land-use/landcover (LULC) proportions, geomorphic metrics and climate variables, is presented. The conventional approach for summarizing watershed characteristics along stream reaches or upstream of monitoring stations involves a discrete, vector-based approach whereby watershed boundaries are delineated from digital terrain information, and characterized according to the underlying landcover types or other variables of interest within the drainage area. The landscape accumulation model approach is a simple, continuous (raster-based) technique in which watershed characteristics are propagated downslope through a digital elevation model for summarization at any point along a stream network or its adjacent hillslopes. The outputs can be visualized or queried in a GIS environment at multiple scales, and used as input into hydrologic and water quality models. Using Placer gold mining-impacted watersheds of central Yukon as a case study, we demonstrate an efficient way to quantify, visualize and summarize the extent of anthropogenic disturbances throughout the ~52,000 square kilometre Stewart River watershed. Surface disturbances from Placer mining may seem individually minor, but accumulate to become collectively significant, impacting a disproportionately large percentage of the drainage network in road accessible portions of the Stewart River watershed. Using outputs from this analysis, recent progress towards watershed cumulative effects assessment in support of land-use planning by the central Yukon First Nation of Na-Cho Nyak Dun will also be discussed.

Development of an efficient distributed snow measurement system for hydropower planning

Björn Norell[a], **David Gustafsson**[b], **Nils-Henrik Lind**[c], **Jie Zhang**[d], **Wolf Marchand**[e]

[a] *Umeälvens vattenregleringsföretag, Östersund, Sweden*

[b] *SMHI, Norrköping, Sweden*

[c] *Ubmeje tjeälddie Sami Village, Storuman, Sweden*

[d] *Uppsala University, Uppsala, Sweden*

[e] *Norwegian Water Resources and Energy Directorate, Trondheim, Norway*

Snow accumulation in mountainous areas is inhomogeneously distributed. This study is testing the hypothesis that despite the high inter-annual variability in snow distribution, there are locations which together provide the spatial distribution and the average snow amount in the catchment. At Lake Överuman, a hydropower reservoir located in the upper part of River Umeälven in northern Sweden, a snow survey program has been designed to enhance the seasonal inflow forecasts. Eight snow courses with a total length of 74 km have been established in the catchment. Snowmobile based ground penetrating radar measurements complemented with manual snow depth and density sampling have been performed along the snow courses once per year since 2017, around the peak snow accumulation. Further projects, using satellite microwave sensing for frequent wide-area SWE estimation, have required repeated reference snow surveys. Therefore, a method using the GPR data for selecting monthly manual snow depth probing sites has been proposed. The manual snow survey's ability to improve runoff predictions shows that the tested method may provide a very cost-effective way for obtaining similar information to that from expensive GPR measurements. However, the combination of repeated manual surveys and continued GPR measurements may also remain an alternative. This work was conducted as part of the SnowSat project funded by Vinnova (project No. 2020-03395) and the DRONES project funded by the Swedish Energy Agency (project No. 2021-004656).