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Observing and modelling climate-land-energy-water interactions in cold climate

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ABSTRACT

In high-latitude and high-altitude catchments, cryospheric processes—particularly snow accumulation and melt—are fundamental components of the hydrological cycle. Ongoing changes in climate, land use, and energy systems are altering the spatial and temporal patterns of water availability and demand, with significant implications for water resources and the ecosystem services they underpin. This presentation outlines a systems-based approach to conceptualizing and formulating supply and demand dynamics from the perspective of integrated water and energy systems. It adopts a climate–land–energy–water (CLEW) systems framework, drawing on insights from diverse case studies to examine both overarching system behavior and region-specific processes influenced by climate change, energy transitions, land use change, and ecosystem dynamics. To improve our understanding and management of these interconnected systems, observational data and modeling are essential. These tools enable exploration of future scenarios, assessment of potential co-benefits, and development of strategies for mitigation and adaptation in response to anticipated changes. The presentation discusses various modeling approaches and frameworks, highlighting key challenges related to model structure, integration and coupling, data availability, and scenario design. Recent findings from ongoing research in Norway, Finland, and Central Asia will be shared, focusing on water–energy nexus analysis and integrated modeling efforts in cryosphere-affected catchments.

Keywords: water resources; climate change; energy systems; cryosphere; system understanding

Towards emissions and activity-driven Earth System Modelling

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ABSTRACT

The infrastructure and underlying statistical assumptions which informed the assessment of future climate impacts, and how they relate to policy, remained fundamentally unchanged for several decades. However, a number of parallel factors now define challenges and opportunities for community Earth System Modeming during the IPCC AR7 assessment and beyond. Since 2016, the Paris Agreement has created a timeline for inputs from climate science for assessment and international agreements - with science inputs required for remaining carbon budgets and stocktake of mitigation strategies. As the 1.5C target is exceeded, observed climatic changes provide increasing constraints on climate response and feedbacks, and requires a refinement in the communication of carbon budgets in the context of missed targets. Rapidly evolving climate policy and geopolitics shift the plausible scenario landscape, highlighting aspects of model uncertain response which received little physical modelling attention in the past - including Solar Radiation Management and extensive carbon removals. Thirdly, a growing model ecosystem of climate modelling tools including emulators, machine learning approaches and high resolution models provide a wider context for assessment. These changes carry both new opportunities and capacity for rapid policy impact assessment, demanding an assessment of ESM development adds most value to climate information- to inform processes, tail risks and adaptation - while increasing working on a tighter timeline, in an increasingly challenging geopolitical environment.)

Keywords: carbon budgets; climate policy; climate system modelling

New national climate and hydrological projections for Norway

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ABSTRACT Following publication of the latest climate assessment report, IPCC AR6, the Norwegian Environment Agency has commissioned an update of the report "Climate in Norway", including new climate and hydrological projections for Norway. The report will present changes in climate during the last 2000 years, current climate and hydrological conditions and projected future changes in climate, hydrology and their effects on natural hazards. It will be published by the Norwegian Centre for Climate Services (NCCS) in late October 2025.

The national knowledge base for climate adaptation has undergone substantial improvements since the earlier report (Hanssen-Bauer, et al., 2015) was published. New developments include updated emission scenarios, time periods, selection of climate model projections, methods and a range of new climate indices. National projections are now based on three emission scenarios: RCP2.6 (low), RCP4.5 (medium) and particular emphasis on SSP3-7.0 (high), in contrast to RCP4.5 and RCP8.5 in the previous report. Changes are computed from a more recent reference period, 1991–2020, to the mid-century (2041–2070) and end-of-century (2071–2100) periods. Projected changes now cover 80 years in contrast to the previous report which compared 1971–2000 with 2071–2100. Improvements in bias-adjustment methods, which now consist of both EQM and EQM+3DBC, in contrast to EQM only, have doubled the number of ensemble members and increased the number of bias-adjusted variables. Hydrological modelling now includes a better representation of evapotranspiration (based on the Penman-Monteith equation), which requires input variables such as radiation. Further, runoff in glacierised catchments has been modelled separately. Together, these improvements allow presenting a wider range of hydroclimatological indices. For example, meteorological and hydrological drought are now included in the report.

We will provide a sneak preview of results from the report. The mean projected temperature increase under the high emission scenario is 3,4 °C (2071-2100 relative to 1991-2020). The corresponding precipitation increase is 11 % and the runoff increase is 10 %. The current ensemble displays a smaller increase in temperature than the ensemble used in the previous national assessment report (Hanssen-Bauer et al.,2015) due to the lower radiative forcing in SSP3-7.0 compared to RCP8.5, as well as a shorter period between reference and end of the century. The precipitation increase displays a slightly different pattern than in the previous report, which in turn influences changes in other hydrological variables, such as runoff. Norwegian glaciers have experienced mass loss since the year 2000, which is projected to continue into the future, and the risk of floods and droughts will increase.

Reference: Hanssen-Bauer et al., 2015: Klima i Norge 2100. Kunnskapsgrunnlag for klimatilpasning oppdatert i 2015 (in Norwegian). NCCS report 02/2015.

Keywords: Climate change adaptation; gridded national climate projections

CAMELS-Nordic, a large-scale hydrometeorological and catchment properties dataset for Norway and Sweden

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ABSTRACT

Historically, hydrologic studies have focused on one or a small number of basins. In many cases, these studies were limited by data availability and computational resources. In the last 20 years, the availability of large hydrological datasets, such as gridded meteorological data sets and streamflow timeseries, and increased computing resources have empowered large-sample hydrology studies. Having accessible and high-quality large datasets available to the science community facilitates the evaluation of hydrologic processes and prediction questions. To support modeling and climate research efforts in the Nordics the CAMELS (Catchment Attributes and Meteorology for Large-sample Studies)-Nordic was collected and processed into a coherent dataset for the entirety of Norway and Sweden. CAMELS-Nordic combines not only meteorological and hydrological, but also topography, climate, streamflow, land cover, and soil data with python package to update time series automatically where possible. The development of the data package takes advantage of high-quality and freely available data from various Norwegian, Swedish, and European agencies. It includes: (1) daily forcing data (e.g. observations, interpolations, and modeled data) for catchments located in Norway and Sweden; (2) daily streamflow data; (3) digital elevation model; (4) catchment properties (size, location, elevation, and catchment files); (5) landcover; and (6) soil type data. Dataset time series span 1980 to 2022.

Keywords: Catchment; Large-Scale dataset

Climate change impacts on hydropower production and water availability in Drammen river basin in Norway

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ABSTRACT

More than 90% of the electricity production in Norway originate from hydropower. To match the energy supply with the demand water is stored in reservoirs across seasons from summer when reservoir inflow is high and production is high, to winter when the demand is the highest and inflow is small. The management of hydropower reservoirs aims to maximize income. It means that the day-to-day decision of power production, and reservoir release, is based on energy demand, electricity prices and water availability. Additional constraints include minimum and maximum water levels as well as minimum flow requirements downstream. The restrictions might depend on season.

In a future climate we might expect both a change in annual average, seasonality and variability in reservoir inflows. These changes might also lead to changes in energy production, reservoir management and the frequency and magnitude of low- and high flow periods. As a part of the HorizonEurope project STARS4Water, we aim to assess how climate changes might impact changes in reservoir inflows, hydropower production, reservoir operations, and high and low flow characteristics in the Drammen River basin. We have used two gridded hydrologic models (HBV and LISFLOOD) to simulate runoff for a reference period and a future period for downscaled climate scenarios. Thereafter the energy marked model EOPS has been used to simulate reservoir operations. EOPS is used for sub-areas or river basins, has a detailed representation of the hydropower system, including environmental restrictions, and requires reservoir inflows and energy prices as inputs.

To assess climate change impacts, the changes in characteristics of reservoir inflow, water levels, outflows will be analysed and compared. The presentation is a continuation of Engeland et al (2025)

Keywords: Reservoirs, Water Resources, Hydropower, Climate Change

Engeland, K., Gelati, E., Hegdahl, T. J., Huang, S., and Veie, C. A.: Climate change impacts on reservoir operations and water availability – a case study from Drammen river basin in Norway , EGU General Assembly 2025, Vienna, Austria, 27 Apr–2 May 2025, EGU25-15110, https://doi.org/10.5194/egusphere-egu25-15110, 2025.

Understanding Land–Atmosphere Coupling During Dry Extremes in Norway: A Multi-Reanalysis Comparison

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ABSTRACT

Land–atmosphere interactions are increasingly recognized as critical drivers of hydroclimatic extremes, particularly during periods of prolonged dryness such as heatwaves. These feedback mechanisms were especially evident during the exceptional drought and heatwaves that occurred in Northern Europe in the summers of 2018 and 2022, which drew attention to the importance of accurately representing land surface processes in climate models and reanalysis. Understanding land–atmosphere interactions during heatwaves requires tools that capture processes across spatial scales and varying degrees of coupling. Earth system models (ESMs), while capable of representing global scale coupled dynamics, are limited in their ability to resolve localized feedback due to their coarse spatial resolution. Global reanalysis products such as ERA5 offer enhanced resolution and reliable large-scale atmospheric reconstructions, but they still lack the fine scale needed to capture local feedback mechanisms and coupled processes. In contrast, convection-permitting regional reanalysis can resolve localized feedback more effectively, but may misrepresent broader atmospheric circulation patterns, introducing trade-offs between resolution and synoptic-scale accuracy. These challenges are particularly pronounced in regions like Norway, where complex topography and spatial heterogeneity demand high-resolution modeling to accurately characterize land surface feedback. Additionally, many climate models rely on globally uniform soil parameterizations—particularly soil depth—that introduce systematic biases in soil moisture availability and limit the accurate representation of land–atmosphere feedback under extreme heat conditions. This study investigates the influence of model resolution and coupling strategies on the representation of land–atmosphere feedback by comparing three reanalysis datasets: NorCPM1 (2°), ERA5 (0.25°), and NORA3 (3 km, regionally optimized for the Nordic region). We employ a suite of diagnostic metrics, including evaporative fraction, temperature–evapotranspiration coupling indices, and soil moisture–temperature correlations, to evaluate spatial and temporal variations in feedback strength. Focusing on historical drought periods in Norway, we assess how model resolution, assimilation strategy, and soil parameterization affect the simulation of dry extremes. Results highlight the critical role of high-resolution, convection-permitting reanalysis in capturing localized land–atmosphere feedback and improving the physical realism of heatwave simulations. These findings offer valuable insights for advancing land surface representations in ESMs and improving the predictive skill of subseasonal-to-seasonal (S2S) climate forecasts in high-latitude regions.

Keywords: Land-Atmosphere interactions; Dry Extremes

Extreme Event Attribution Service at MET Norway: Storyline attribution of storm Hans

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Extreme Event Attribution (EEA) is a scientific field dedicated to assessing the influence of climate change on specific weather events. By quantifying the extent to which human-induced climate change has altered the likelihood or intensity of extreme weather phenomena, EEA addresses critical questions about the interplay between natural variability and anthropogenic factors. This information is crucial for understanding climate risks and guiding policy decisions.

MET Norway aims to establish an operational attribution service to provide this information shortly after an extreme event has occurred. Our work is currently focused on two EEA approaches: probabilistic and storyline. Probabilistic attribution involves statistical analysis to assess how climate change has affected the likelihood of an extreme event occurring, often expressed as a change in the probability and intensity of the event. In storyline attribution we employ a regional climate model to simulate events under different scenarios—both with and without the influence of anthropogenic greenhouse gas emissions—to discern the impact of climate change on the event's severity.

This presentation focuses on a storyline attribution case study: the extreme weather event Hans that struck Norway in 2023. We use the Harmonie-Climate (HCLIM) model to perform storyline model runs. The runs are conducted using the Pseudo Global Warming (PGW) approach for a cooler pre-industrial climate and different levels of warming in a future climate. The work is done together with the national weather institutes of Sweden and Finland.

By developing a robust attribution framework, MET Norway, in cooperation with Nordic partners, seeks to enhance the understanding of extreme events and support decision-making processes in climate adaptation. This work not only contributes to scientific knowledge but also empowers stakeholders with actionable insights into future climate risks.

Keywords: extreme event attribution; climate risk; storyline; weather and climate extremes

Identifying mechanisms of soil moisture drought using causality decomposition: A case study in the Yellow River Basin, China

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ABSTRACT

Drought is a temporary anomaly characterized by a period of water scarcity, leading to an abnormal water imbalance or stress that significantly threatens water resources, agriculture and socio-economic conditions. Therefore, understanding the dynamics and onset mechanism of drought events is crucial for developing effective mitigation and adaptation strategies. Taking the Yellow River Basin as a case study, a new perspective from causality decomposition is provided to quantify the contribution of drivers and identify the mechanisms during drought onset. We first identified drought events (including beginning, occurrence and recovery phases) at the pentad timescale for all pixels. We then used the information-theoretic approach to quantify causal interactions between selected drivers and soil moisture, including redundant, unique and synergistic contributions, as well as causality from hidden variables. The results showed that most part of the Yellow River Basin experienced severe droughts between 1979 and 2020, with an increasing trend in severity in the middle and lower reaches. Short-term droughts lasting less than 3 months occurred more frequently in the source area, while droughts in the middle and lower reaches were more likely to be long-term events. Drought events are mainly synergistically driven by contemporaneous and antecedent conditions of precipitation and temperature, while the independent effects of each meteorological factor had a smaller contribution. Meteorological factors could better explain the causes of short-term droughts, but there was more missing information to explain long-term droughts. Long-term droughts were also influenced by alterations in groundwater levels and teleconnections. For instance, in the middle and lower reaches of the basin, ongoing reforestation efforts and human-induced water extraction have led to groundwater depletion, which has affected soil moisture and drought conditions.

Keywords: drought; causal analysis; mechanisms; meteorological factors; human activities

Thawing Permafrost and High Arctic Catchment Response: A Case Study from Fuglebekken, SW Spitsbergen

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ABSTRACT

The Arctic landscape is undergoing significant transformations driven by climate change. In particular, thawing permafrost and alterations in the active layer thickness (ALT) are profoundly impacting hydrological processes. This study examines how changes in the ALT affect the catchment dynamics in the High Arctic leading to increased infiltration and groundwater storage. Our study focuses on the unglaciated Fuglebekken catchment, situated near the Polish Polar Station, Hornsund on Spitsbergen. We integrated (a) field observations from boreholes, piezometers, and surface water measurements with (b) simulations using the HBV rainfall-runoff model.

Our findings highlight the critical importance of groundwater storage in the water cycle of the Fuglebekken catchment, a pattern evident in both our field data and the model outputs. Notably, the slow runoff reservoir displayed substantial changes. This suggests an increasing presence of subsurface flow pathways in the water circulation. Furthermore, the HBV model parameter KS, representing the slow runoff reservoir, exhibited significant temporal variability, peaking at the onset of the ablation season (linked to snowmelt and permafrost thaw) and again in September (associated with high precipitation). In contrast, other model parameters showed less temporal fluctuation and generally remained within their expected ranges. Ultimately, this study provides essential understanding of how the hydrology of High Arctic catchments is evolving under a changing climate.

Keywords: groundwater, piezometers, Hornsund, Spitsbergen, HBV

Impacts of empirical and physical evaporation methods on changes in hydrological components and drought propagations under climate change scenarios

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ABSTRACT

Drought is a natural hazard across the globe and it propagates through the hydrological cycle, leading to meteorological, agricultural and hydrological drought. Since drought propagation is strongly related to climate types and triggering processes, simulation of droughts is sensitive to both climate regimes and hydrological models that vary in structure of describing hydrological processes. Evapotranspiration (ET) is an important hydrological process for drought propagation and it is usually estimated based on soil water storage and Potential Evapotranspiration (PET) in hydrological models. Previous studies show that the choice of PET methods can result different estimates of meteorological drought index and low flows, especially in the context of climate change. However, it still lacks a comprehensive assessment of the effects of PET methods on drought propagation and the associated hydrological processes under climate change scenarios. This study aims to systematically assess the effects of two PET methods: the temperature-based (T) and the Penman-Monteith (PM) methods, on 1) historical hydrological model performance, 2) the projected changes in hydrological components (PET, ET, soil moisture and runoff) and 3) the projected changes in meteorological, agricultural and hydrological drought indices for the whole mainland of Norway. The distributed hydrological model HBV with two PET methods was driven by outputs from six regional climate models under three RCP scenarios (RCP2.6, RCP4.5 and RCP8.5). The preliminary results show that the two PET methods provide similar historical model performance but they lead to increasing discrepancies in projected changes with RCPs. The temperature-based method always overestimates future drought severity compared to the PM method.

Keywords: climate change, ensemble, SPEI, SMI, SRI

Using LSTM for streamflow prediction in ungauged catchments in Norway

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ABSTRACT

Recently, data-driven techniques — particularly Long Short-Term Memory (LSTM) networks — have exploded onto the hydrological modelling scene, demonstrating the potential to outperform traditional process-based models for rainfall-runoff simulation. This development is especially valuable for Norway, where the majority of catchments are ungauged and there is a high societal demand for reliable hydrological predictions to support flood management, infrastructure planning, and climate adaptation over a wide variety of catchments in a diverse, rugged topography. Currently, discharge, including flood events, in Norway's ungauged catchments is estimated using process-based hydrological models calibrated at the individual catchment level. However, such approaches often struggle with predictive accuracy when extrapolated to ungauged regions, especially regions with few good comparative gauged stations. By leveraging LSTM networks trained across multiple catchments, we aim to provide more robust, scalable, and transferable discharge simulations for both gauged and ungauged basins, offering a promising avenue toward improved hydrological forecasting and risk management for Norway.

Firstly, we compile our own dataset for Norway, based on hydrological data from NVE, gridded hydrometeorological time series and a large set of static catchment properties. The dataset is based on the flood forecasting set of about 120 discharge stations and expanded from there based on gauging stations with good enough quality. Then the hydrometeorological time series and static catchment properties for each catchment is added to the dataset.

We then apply a machine learning model (neuralhydrology) to try simulating discharge in a catchment based on temperature, precipitation, and a collection of other hydrometeorological time series and static catchment properties. This is firstly done to gauged catchments to train and validate the model, then applied to both gauged and ungauged catchments to test how well it is performing.

We will evaluate the machine learning model ability to simulate discharge and floods in both gauged and ungauged catchments based on multiple evaluation criteria and compare the results with a set of benchmark models (HBV, DDD).

Keywords: Discharge, floods, modelling, machine learning, LSTM

Assessing Green Roof hydrological performance Under Climate Variability and Change Using High-Resolution Convection-Permitting Climate models

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ABSTRACT

In an era characterized by urban densification and increasing pressures on urban space, along with the costs and availability of construction materials, the optimal design of infrastructure has become a critical focus. Furthermore, cold climate regions are experiencing the impacts of climate change, which manifest in altered precipitation patterns, resulting in more extreme storm events, including snowfall and increased freeze-thaw cycles. According to Maurin et al. (2024), rain-on-snow events have been identified as the leading cause of the highest observed runoff from green roofs, presenting significant challenges for urban areas in preventing flooding.

The present study aims to enhance understanding of the effects of climate variability and change on the hydrological performance of nature-based infrastructure, with a particular emphasis on green roofs during winter, especially in relation to snow and rain-on-snow events in cold climate regions. The goal is to develop guidelines that assist stakeholders in optimizing the design of nature-based solutions (NBS) infrastructure, ensuring they are resilient over time and effectively manage stormwater in a changing climate. This initiative addresses the current gap in research, particularly the lack of location-specific regulations that incorporate future climate projections for stormwater infrastructure design, giving decision-makers accurate information regarding the requirements for long-term and robust infrastructure design.

The study uses models of six different green and grey roof configurations developed in the SFI Klima 2050 project, calibrated for the winter season. These models utilize precipitation and temperature time series originated from high-resolution, convection-permitting climate models with hourly resolution and a 3x3 km gridded projection. Simulations for winter event separation are conducted following the methodology outlined in Maurin et al. (2024).

Results indicate that the changing climate will influence stormwater management strategies during winter, with effects that are unevenly distributed across Norway (9 different cities studied), and pinpoint the need to take into account the local future climate when planning and designing stormwater managements solutions that must remain effective under future climate scenarios. The findings have laid the groundwork for local guidelines aimed at ensuring climate-resilient design of nature-based infrastructure.

Keywords: Rain-on-snow event; Nature based solution

REFERENCE

Maurin, N., Abdalla, E.H.M., Muthanna, T.M., Sivertsen, E., 2024. Understanding the hydrological performance of green and grey roofs during winter in cold climate regions. Science of The Total Environment 945, 174132. https://doi.org/10.1016/j.scitotenv.2024.174132

Snow modelling on climatological, meteorological and hydrological scales

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ABSTRACT

The developers of even the earliest coupled global climate models recognized the need to include the influence of snow on surface energy balance and land-atmosphere interactions, but Earth System Models even now are restricted to coarse horizontal grid scales (between 78 and 312 km at the equator in the Sixth Coupled Model Intercomparison Project, for example) on which snow processes have to be highly simplified and parametrized. Meteorological models using the same physical principles as climate models are now routinely run over limited areas at kilometre grid scales for operational weather forecasting and research. Although such models are generally referred to as "convection permitting" because their resolved dynamics replace the need for parametrizations of convection in larger-scale models, they also have potential benefits for snow modelling because of their abilities to resolve topographic influences on precipitation. Processes of snow redistribution and preferential melt important for the hydrological response of catchments still have to be parametrized on these scales, however, and are not automatically resolved by model dynamics at higher resolutions. Snow modelling at decimetre "snowdrift permitting" scales actually has a decades-long history, but increasing computational resources and the availability of high-resolution remote sensing of snow cover are now allowing further advances. This invited presentation will review contrasts and connections between snow processes across scales and will review the history, state of the art and opportunities for modelling changing climates and seasonal snow dynamics in cold regions.

Keywords: snow modelling, climate, meteorology, hydrololgy

Projected changes in snow avalanche activity in Norway in a future climate towards 2100

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ABSTRACT

Snow avalanches are a common phenomenon in most parts of Norway. They can obstruct roads and railway lines, hit houses and other infrastructure and cause several fatalities every year. It is clear that hydrometeorological factors, such as precipitation and snow melt rates, snow depth, length of the snow season and air temperature are closely connected to avalanche activity. Moreover, the ongoing climate change may affect these factors in several ways. Our research question is thus: "how will the ongoing climate change affect the frequency of snow avalanches in Norway"? This important question has so far been answered mostly by qualitative expert assessments, without many "hard facts". There is therefore a need to provide more objective and quantitative answers to this question. In our presentation, climate and hydrological model projections are linked to simple models or indices for different types of snow avalanches (loose/slab, dry/wet). This allows for quantitative projections and analysis of changes and trends in avalanche activity in Norway at daily 1 x 1 km resolution towards the end of this century. The use of an ensemble of 20 different regional bias-corrected climate projections allows quantification of uncertainties caused by climate models and bias correction methods in the results. The simulation results, for medium and high greenhouse gas emission scenarios (rcp4.5 and ssp3-7.0), show both decreased and increased avalanche activity in a projected future climate, depending among others on the terrain elevation.

Keywords: snow avalanche; climate change

Global ensemble-based snow reanalysis

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ABSTRACT

Snow is an essential climate variable that regulates the global cycles of energy, carbon, and water. At the same time, the state of the snowpack is only partially observable by satellites due to gaps, noise, and indirect retrieval algorithms. The fusion of uncertain snow models and noisy observations through data assimilation, presents a natural solution to this problem of partial observability. Nonetheless, data assimilation has received relatively little attention from the snow remote sensing community despite its potential to serve as a generalized retrieval method that adds value by inferring gap-free hidden snow variables with uncertainty quantification.

This contribution presents ongoing research on applying ensemble-based data assimilation techniques to carry out global snow reanalysis constrained by satellite data. We focus on seasonal snow since accurate snow mass estimation, particularly in mountainous terrain, remains a major unsolved problem in snow hydrology. Our goal is to generate the first consistent global, ensemble-based, daily, kilometer-scale reanalysis of seasonal snow mass (i.e. snow water equivalent) and fractional snow-covered area dynamics.

To produce our reanalysis, we assimilate ESA Snow_cci fractional snow-covered area satellite retrievals into a simple snow model run at a relatively high spatio-temporal resolution. Given the efficiency of our model, we are able to leverage promising iterative ensemble-based DA schemes while ensuring that the problem remains computationally feasible. Therein, we build on recent developments in hybridizing iterative ensemble Kalman and particle methods that provide robust and tractable approximate Bayesian inference. Moreover, we demonstrate how these schemes can be used to hierarchically infer prior hyperparameters related to snow climatology. The new reanalysis approach is evaluated using independent spaceborne, airborne, and in-situ validation data. Finally, we benchmark the performance of our renalysis by comparing it to other global snow products.

Unlike existing global snow mass products, our product is uncertainty-aware and is tailored to target a key knowledge gap concerning mountain snow mass. We highlight that, by combining observations with models, data assimilation can transform largely untapped climate data into actionable climate information on essential climate variables. The baked-in uncertainty quantification in this probabilistic climate information empowers us to make decisions in response to climate change and its impacts.

Keywords: Snow mass, data assimilation, remote sensing, Earth observation

Assessing snow sublimation in Norway: insights from field and laboratory work of SnowSub project

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ABSTRACT

Hydrologic modelling is an important part of decision making within hydropower companies in Norway, as the country produces most of its electricity from hydropower. In the SnowSub project we work towards improving hydrologic modelling within Shyft software, used by companies such as Statkraft AS and Skagerak AS in their operations. A major aspect of hydrology in Norwegian catchments is snow, which acts as a storage for streamflow. However, this storage can lose its reserves due to sublimation. Dry air, strong wind and solar radiation favor sublimation in certain areas of Norway. Sublimation flux can be measured in the field using eddy covariance flux station. However, filed observations can not be controlled, making it difficult to systematically test different hypotheses. Given this, our project combines field measurements in the Tuddal site with experimental studies of sublimation under the controlled conditions of the Cold Climate Container facility at the University of Oslo. These studies provide insights into sublimation and snow processes in Norway, which can further inform hydrological modeling within Shyft.

In this talk, we present results from the two field seasons at Tuddal. Fluxes were analyzed using eddy covariance method and wavelet analysis, with the two methods showing good agreement. The analysis revealed the importance of smaller timescales for distinguishing sublimation fluxes. Laboratory studies were conducted during two periods, in November 2024 and February 2025. The wind tunnel in the laboratory showed good stability of temperatures and relative humidity, allowing us to investigate effects of wind and humidity across temperature ranges from -20 to 0 degrees Celsius and time scales from 3 to 24 hours. Experiments were performed in two setups – one with continuous isotopic content measurement in the air and snowpack, and another measuring mass changes using Petri dishes setup. The results showed that even air speeds below 3.2 m/s can cause noticeable snow mass loss, with relative humidity maintained between 58% to 80%, matching the lower humidity values observed at the Tuddal site.

As a part of the project, we also investigate potential of FSM2 snow model in its ability to capture sublimation effects at our study site. The flexible hydrological modelling framework Shyft can incorporate the FSM2 approach into its architecture, providing a physics-based snow model as part of the operational components. We benchmarked hydrologic models within Shyft across a large sample of catchments in Norway. The results suggest that, although the model performs well in discharge simulations over historical periods, the snow modelling capabilities of the toolbox – despite offering a variety of model choices - still remain limited and could be substantially improved.

This project is supported by Norwegian Research Council NFR 336621.

Keywords: snow; sublimation; Norway; Tuddal; catchment hydrology; Cold Climate Container; laboratory experiments;

Evaluating Model Performance in Simulating Ground Thermal Regimes: A Multi-Model Comparison

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ABSTRACT

Understanding ground thermal regimes is important for assessing permafrost stability and hydrological responses in the High Arctic environments. This study compares ground temperature simulations using the GEOtop 3.0 and CryoGRID 2.0 models over the permafrost-affected Fuglebekken catchment in the Hornsund region of Svalbard. Models with varying levels of complexity in representing coupled heat and moisture transport, snow dynamics, and surface energy balance were assessed against borehole temperature observations for up to 12 meters deep. Input data included high-resolution UAV-derived digital elevation models, meteorological forcing, and soil physical properties. Model performance at the calibration and validation stage was evaluated using the sum of the Kling-Gupta Efficiency (KGE) from layers with observations. The initial ground temperature results from GEOtop show how surface energy exchanges, snow cover, and soil thermal and hydraulic properties interact to control subsurface thermal dynamics. A comparison between GEOtop and CryoGRID showed similar ground temperature trends, but GEOtop provided a more detailed representation of subsurface processes due to its flexible soil parameterisation. Our results highlight the importance of accurately representing snow insulation, soil hydraulic and thermal properties, and surface energy fluxes for reliable ground thermal simulations. This model comparison provides perspectives for selecting and improving models used in permafrost research and Arctic climate change impact assessments.

Keywords: GEOtop; Cryogrid; Ground temperature; Svalbard

Assessing potential benefits of physics-based snow modelling for Norwegian hydropower production planning

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ABSTRACT

For efficient planning of hydropower production, it is crucial to accurately forecast the inflow to hydropower reservoirs. Predictions of snowmelt play an important role in these forecasts for Norwegian hydropower plants since approximately half of the precipitation falls as snow. This work is carried out under the umbrella of the SnowInflow project (NFR 346308), which aims to improve inflow forecasts to these hydropower plants during the critical snowmelt period. The project is a collaboration between the hydropower company Statkraft (Oslo, Norway), the Norwegian Research Centre (NORCE, Bergen, Norway) and the WSL Institute for Snow and Avalanche Research SLF (Davos, Switzerland). We focus on three regions in South Norway, namely Ulla-Førre, Songa and Vik. These three regions produce roughly 5% of Norwegian hydropower. To enhance the inflow forecasts during the snowmelt season in these regions, we will combine physics-based snow modelling, improved snow monitoring and data assimilation.

For snowmelt simulations, Norwegian hydropower producers currently rely predominantly on simple parametric models that only require temperature and precipitation as input. However, these temperature-index models cannot depict all process that govern snowmelt, which may degrade inflow forecasts during the critical snowmelt period. Therefore, in this study we aim to assess whether a physics-based snow model provides more reliable snowmelt simulations than the temperature-index model in Shyft that is currently used operationally at several large hydropower companies. In addition to testing a physics-based model for providing more accurate snowmelt simulations, we also assess whether incorporating data from high resolution remotely sensed snow depth observations can improve the inflow forecasts.

We apply the physics-based snow model FSM2oshd used operationally in Switzerland to our three study regions. The model is tested for the study regions on various spatial resolutions, ranging from 30 to 900 m. As meteorological input we use the MET Nordic dataset, a 1 km hourly product produced by the Norwegian Meteorological Institute. This dataset was downscaled using both statistical and dynamical methods to the various target resolutions. High-resolution snow depth maps derived from airborne LiDAR measurements are incorporated into the model by adjusting the snowfall forcing data. We thus experiment with the use of a physics-based snow model by altering meteorological downscaling techniques, the model resolution and the use of simple assimilation of LiDAR snow depth data into the model.

We assess the different model experiments outlined above using data from independent snow observations (e.g. ground surveys and LiDAR scans that were not assimilated), results from the operational temperature-index model and observations of reservoir inflows. This analysis will provide insights into potential benefits of physics-based snow modelling and data assimilation of airborne LiDAR measurements for Norwegian hydropower producers.

Keywords: Hydropower, Physics-based snow model, LiDAR

Obtaining physical constraints for hydrological model calibration from citizen science snow collection in Scandinavia

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ABSTRACT

Extreme snowpacks are closely linked to hydro-meteorological extreme events. Extensive snow cover can for example be related to flash floods during rain-on-snow events, while low snow cover can lead to droughts later during the year. Both extremes have major socio-economic impacts. Being tuned to the present, many current models will not be able to adequately represent and predict such future extremes. Within the ISOSCAN project, which stands for "Isotope-aided assessment and forecasting of hydroclimatic extremes in Scandinavia with stakeholder co-design", we use a novel and interdisciplinary approach to exploit the large potential of water isotopes in precipitation and the snowpack to improve physical process representations in the hydrological model HYPE.

As an essential part of the approach in our project, we have developed a scalable citizen science sampling framework for collecting surface snow samples. In April 2025, we conducted a first test sampling, inviting recreational nature users in Tromsø, both locals and tourists, to bring back snow from a trip in nature. The test deployment involved the development of an easy-to-use sampling kit that preserves sample quality, instructions suitable for a wide audience, a web app, and a website for outreach. The involvement of local actors appeared essential for running the sampling campaign. In particular, we create pathways for two-way interaction between citizen scientists and project scientists to enable co-creation and to find middle ground.

Here we report on the distribution of samples collected, on feedback and experiences from participants, as well as a first overview over the sample quality for the purpose of hydrological model calibration. The findings are thereby placed into the context of similar efforts conducted in the last years and isotope-enabled model predictions.

Keywords: Hydrological extremes; Citizen science sampling

Investigating Snowpack and Streamflow Changes with Snow Data Assimilation in Hardangervidda

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ABSTRACT

Snowmelt rates have a direct influence on downstream water availability and are changing significantly in response to shifting climatic conditions. However, the specific drivers and direction of these changes require further investigation across different regions and timescales. In this study, we investigated the impact of climate change on snowmelt rates and streamflow in the Hardangervidda region of Norway. The Multiple Snow Data Assimilation System (MuSA) was used to simulate historical (2001–2020) and future (mid- and end-century) snowpack conditions by assimilating a long-term satellite-based record of fractional snow-covered area from MODIS. Using MuSA outputs under the RCP8.5 scenario, we applied the Simple Dynamical Systems approach to simulate future streamflow in the Kvenna catchment.

Our results show that while meltwater volumes increase at mid-century due to higher snowmelt rates, they decline by the end of the century. Annual peak flow decreases in both future periods (by 26% and 36%, respectively) with a seasonal shift in its timing from spring/summer to autumn/winter. Seasonal total discharge increases during winter/spring, but decreases during summer. Our findings highlight substantial changes in snowmelt dynamics and streamflow patterns on the Hardangervidda plateau under future climate scenarios. The anticipated earlier and more variable melt events along with altered peak flow timing may complicate for future reservoir and water resource management.

Keywords: snowpack; snowmelt rates; streamflow; data assimilation, future scenarios

Water extraction from the atmosphere by topography: using novel water isotope observations to obtain better SWE estimates

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ABSTRACT

Extreme hydrological conditions have large social and economic impacts in Scandinavia and elsewhere. However, reliably forecasting these events (dry or wet) is challenging, especially in high latitude regions where traditional observational networks are often sparse. In addition, large uncertainties exist regarding the amount of water that is stored in seasonal snowpacks, mainly due to uncertainties in the distribution of precipitation in complex terrain. Information from atmospheric models in Norway is also limited, as for example reflected a strong precipitation bias along the mountainous west coast of Norway. This combined lack of data impedes hydrological model calibrations and points to a need for additional observational constraints.

To first order, water extraction from the atmosphere by topography can be conceived as a Rayleigh fractionation process. This atmospheric drying produces gradients in the stable water isotope composition of precipitation across mountain ranges and should be reflected in accumulated surface precipitation. Studies in data scarce, mountainous, regions in the Americas have demonstrated this phenomenon using observations of water isotopes in water streams. Here, we adopt a similar approach to assess the potential for estimating the amount of snow deposited across the mountain range of western Norway from water isotopes.

Based on simulations with the isotope-enabled regional model COSMO-iso, we explore the relation between accumulated surface precipitation and water isotope composition for several events and regions. First results show a correspondence between simulated gradients in integrated water vapour and precipitation isotopes. Comparison with observations from several field campaigns shows differences in isotopic gradients that can be explained in terms of atmospheric model deficiencies. Nonetheless, our first results do point towards the potential to constraint the amount of surface snow in the mountain areas of Scandinavia from isotope measurements in surface snow.

Keywords: Hydrological extremes; Atmospheric drying; Snow Water Equivalent

Challenges and Opportunities of an Unfrozen Future on Ecosystem Services from Lakes

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ABSTRACT

Lakes are critical components of global hydrological and biogeochemical cycles, delivering essential ecosystem services such as freshwater supply, biodiversity support, climate regulation, and recreation. Most of the lakes on Earth are still seasonally frozen. However, our assessment of global lake ice cover demonstrates that between 35,300 and up to 230,400 of the approximately 1.4 million lakes ≥10 ha are projected to lose seasonal ice cover in a 2–8°C warmer world, directly affecting the livelihoods and environments of an estimated 394 to 656 million people. When lakes transit from being ice-covered to becoming open-water, they shift from being closed to open chemical reaction systems. This shift significantly affects not only the energy and matter exchange between a lake and its surroundings (i.e., watershed and atmosphere) but also the energy and matter transformation within the lake. The lake internal changes have profound and multifaceted ecological, societal, and economic consequences. The consequences are often challenging. For example, the loss of seasonal ice cover commonly disrupts thermal stratification and water column mixing patterns, alters nutrient cycling, and affects oxygen availability—potentially triggering shifts in species composition and ecosystem productivity. Moreover, a comprehensive reduction in ice cover implies a longer open-water season, which is associated with a prolonged hydrological connectivity between lakes and their watersheds. Such a prolongation of connectivity affects carbon, nutrient, and pollutant loading, often leading to declining water quality and increasing greenhouse gas fluxes from lake surfaces into the atmosphere. The altered hydrological dynamics challenge existing models of lake function and complicate efforts to manage water quality, particularly as lakes become exposed for longer periods to extreme weather conditions when the protective ice cover disappears. In addition, human communities that rely on ice-covered lakes for fishing, transportation, and cultural practices face growing uncertainties, as traditional ways of life become increasingly vulnerable. On the other hand, an unfrozen future also presents new opportunities for lake management and resource utilization. For example, longer open-water periods extend the growing season for aquatic primary producers, potentially increasing fish productivity in certain systems. Reduced ice cover may also enhance hydropower efficiency and create new avenues for water-based transportation and recreation. To gain a complete overview of the challenges and opportunities of an unfrozen future on ecosystem services from lakes, the resistance, resilience, and transition of seasonally ice-covered lake ecosystems to temperature and runoff changes need to be understood. Here, new insights will be presented based on a synthesis of current research and case studies from diverse geographic regions with focus on northern Europe. Emphasis will be placed on addressing the adaptive capacity of lake ecosystems in a warmer world, which strongly influences not only climate change mitigation actions but also modelling approaches.

Keywords: lake ecosystems; ice cover; climate change; ecosystem services; resilience

Inverse modelling of vertical temperature in shallow lakes

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ABSTRACT

Lakes and reservoirs are important part of nature, and it is of great interest to assess how global warming may influence thermal stratification and circulation patterns. Reliable future temperature predictions require physically robust numerical models capable of simulating vertical temperature profiles. Lakes typically respond slowly to changing environmental conditions, but empirical data from a shallow, medium-sized lake reveal substantial hourly temperature variations across the thermocline. This raises questions about the appropriate temporal resolution needed to accurately model lake temperatures for specific sizes and depths. To determine the optimal time resolution, we estimated model parameters by minimizing the difference between observed and simulated vertical temperatures, adjusting resolutions from 10 minutes up to one day. Through this inverse modeling approach, we identified the resolution that best matched empirical data. Sensitivity analysis during calibration highlighted wind speed during spring as particularly influential on summer temperature stratification. Our simulations successfully replicated observed temperature dynamics providing valuable insight into how climatic changes timing of circulation and temperature stratification.

Keywords: Inverse modelling; sensitivity analysis; temperature stratification

Long term changes in lake color diversity in a boreal lake district of Norway

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ABSTRACT

Regional drivers such as recovery from acidification, forest growth, and climate change have promoted increased terrestrial transport of dissolved organic matter (DOM) and iron (Fe), leading to increased lake color. Generally, the focus on this so-called browning effect has been on a regional scale, with few studies examining the diversity of lake color within regions exposed to the same external factors.

Catchment-related factors like topography, geology, vegetation, and hydrological connectivity significantly influence both terrestrial export and DOM cycling within the lakes. Furthermore, as pressure from external drivers such as sulphate deposition has leveled off, variability in DOM levels at a local catchment scale is expected to rise.

DOM levels in lakes are crucial for both ecological functions and societal uses of freshwaters. Therefore, estimating long-term trends in the diversity of lake color within regions is essential.
A long-term study (1983-2023) was conducted in 24 closely localized lakes in a pristine boreal forest area of Østmarka, Norway. The region is exposed to the same weather and geological conditions, suggesting that individual catchment-related factors drive the color variability.

Cluster analysis identified one clear water reference lake and four groups with different color levels. All color groups showed increasing lake color over time and increasing variability in lake color among the groups. In contrast, inorganic ions such as sulphate and calcium generally showed decreasing trends over time, with minor variability among the color groups. No significant trend was observed for pH.

A significant portion of the variability in lake color among the groups was attributed to catchment-related factors such as water retention time and forest cover. These factors will be largely influenced by future changes in temperature and precipitation and must be considered when estimating lake color trends. However, a more individualized approach is required to understand the coupling between climate change and lake color, as there are substantial differences in lake color responses among different lakes.

Keywords: Lake color variability; climate change

Predicting DOC fluxes from boreal headwater catchments: a simple, transferable process-based modelling approach

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ABSTRACT

Catchment dissolved organic carbon (DOC) inputs play a key role in lake water equality and ecology, as well as influencing contaminant transport and drinking water quality. However, a general lack of monitoring data means that DOC inflows to lakes are often poorly constrained, except in the most data-rich catchments. This hampers our ability to understand and predict in-lake water quality, greenhouse gas emissions, and ecological function. To address this, we have developed the SimplyC model for simulating headwater DOC fluxes in data-poor boreal regions. The model is implemented in the Mobius2 modelling framework, allowing model complexity to easily be tailored according to study aims and data availability. DOC fluxes are not only dependent on water discharge, but also on both short-term (seasonal) and long-term variations in DOC concentrations. These in turn depend on factors such as temperature and acidity (mainly driven by recovery from SO_4^{2-} deposition). SimplyC therefore includes a hydrology module, SimplyQ, as well as the most important processes controlling short- and long-term DOC concentrations. The model is however simple enough to allow for easy auto-calibration at data-rich sites and for model parameters to be transferred to data-poor sites. We auto-calibrate SimplyC on 17 Nordic boreal headwater catchments with different characteristics (such as the presence/absence of deeper groundwater and/or smaller lakes in the catchment). The model performs well both for seasonal and long-term variations in DOC fluxes. The model also transfers well to data-poor sites by using dependencies between parameter values and site characteristics learned from other sites.

Keywords: DOC, catchment model

Nitrate sources and fluxes in a changing Arctic: a dynamic modelling study on Svalbard

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ABSTRACT

Field studies are showing that river runoff in parts of Svalbard has unexpectedly high nitrate concentrations, particularly late in the melt season. This is primarily sourced from nitrification of bedrock-derived nitrogen (N), a common bedrock type around the Arctic. Higher bedrock-derived nitrate inputs are likely in the future as glaciers retreat and permafrost thaws, exposing fresh material and changing flow paths. This geogenic nitrate has potential to strongly impact downstream N-limited marine ecosystems, whilst the conversion of nitrate to nitrous oxide in wetlands may present a positive climate feedback. However, difficulties in measuring river discharge in much of Svalbard, together with difficulties in extrapolating point water quality measurements to larger spatial and longer temporal scales, mean that important questions remain regarding the magnitude and fate of this flux at larger spatial scales, and therefore its wider environmental significance. Here, we present ongoing work aimed at addressing these challenges using a new, transferable, catchment-scale dynamic nitrogen model. The model is being developed using the Mobius model building system, allowing us to easily tailor the model to our research aims and available data. We apply the model to simulate nitrate fluxes in Adventdalen, a large permafrost-dominated catchment in central-western Svalbard. We use the model to quantify how the contributions from atmospheric versus bedrock-derived N vary through the year, to test climate sensitivity, and to help prioritise future data collection by highlighting key knowledge and data gaps.

Keywords: nitrate; river; catchment; watershed; model; Arctic; Svalbard

Integrating Freeze-Thaw Dynamics into the HBV Model for Improved Hydrological Simulation in Svalbard

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ABSTRACT

The HBV hydrological model is widely used for simulating runoff and water balance across diverse climatic and geographical regions. Despite its broad applicability, HBV faces limitations in cold-region catchments where permafrost and freeze-thaw dynamics significantly influence hydrological processes. In polar and high-latitude environments, such as Svalbard, the seasonal freezing and thawing of soils and subsurface layers introduces challenges in accurately representing infiltration, storage, and runoff generation.

This study addresses these limitations by adapting a lumped and semi-distributed version of the HBV model to incorporate two key permafrost-related processes: (1) the impermeability of frozen ground, which prevents infiltration into the subsurface during cold periods, and (2) the freeze-thaw cycle of groundwater, which affects the timing and magnitude of subsurface contributions to streamflow.

The adapted model was applied to the Fuglebekken catchment in Hornsund, southwest Spitsbergen, an Arctic basin currently undergoing transition due to permafrost degradation and evolving hydrological regimes. Four model configurations were evaluated: the standard HBV, a version including frozen ground impermeability, a version incorporating freeze-thaw groundwater dynamics, and a combined version with both adaptations. Model performance was assessed against observed streamflow data using the KGE metric.

Results show that while overall performance among the models was similar, the permafrost-adapted configurations outperformed the standard HBV model during years with poor validation results. These findings highlight the added value of explicitly representing cryospheric processes, particularly in a catchment experiencing increasing subsurface storage and flow pathways due to permafrost degradation. The study underlines the necessity of process-based adaptations in hydrological modeling to better represent catchments in transition, ensuring more robust and reliable predictions in Arctic and sub-Arctic environments under ongoing climate change.

Keywords: HBV, freeze-thaw dynamics, catchment transition, Svalbard

Modelling the hydrology of peat restauration

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ABSTRACT

Keywords: peat restauration; process-based simulation

Peat soils have been the subject of human interest for many centuries. Extraction of turf for fuel and drainage for cultivation are centuries old economic activities that have altered the environment of peat-rich landscapes. In Norway, the drainage of peat soils is mainly associated with cultivation and with attempts to facilitate wood production. The purpose of drainage is lowering the water table and thus creating favourable conditions for root development and trafficability. The shift from anaerobic to aerobic conditions causes organic material to decompose; a process that produces CO_2. This process can be stopped only by restoring the water table to its original level. Peat restauration is commonly carried out by blocking or filling the open drainage ditches. The effect of restauration on the hydrology of the individual peat bog and the associated landscape is not well understood. It is the domain of contrast: hydrological connectivity is reduced, but the available pore space (for infiltration) is also reduced. The question of how peat restoration affects landscapes' ability to retain overland flow and prevent flooding downstream has yet to explored fully.

Since empirical data are hard to come by, process simulation is one of the few viable options for the evaluation of peat restauration. A raster-based rainfall-runoff model is presented that approaches soil water content dynamically but not fully process-explicit. Typical raster cell dimensions are 10m, allowing for daily timesteps and basins of several hundreds of square kilometres. In the runoff phase, water is distributed instantaneously and routed through the landscape from source to river. Processes that were deemed crucial for process representativeness were included by means of simple approximations. These include snow accumulation and melt, groundwater contribution to base flow, tile drainage and lake water levels. Due to the simple, mass balance driven, groundwater level simulations of the model, the effect of restauration on runoff generation and transmissivity can be approximated. Its spatial explicitness allows for the parameterisation of individual peat restoration projects, and for the assessment of their effects at the local and catchment scales.

At present, no measurements are available that can confirm or reject all of the model's results. But due to its modular structure, the model's ability to mimic moments in the hydrological cycle can be tested and improved with measurements of a variety of parameters. Due to its spatially explicit nature, the effects of peat restauration of individual bogs or broader strategies can be explored. Not only does the model provide hydrographs at points of interest, it also shows how groundwater levels changes after restauration and how peat bogs affect the wetness of neighbouring areas.

The readily available geospatial data in Norway (soil, land use, terrain, etc.) in combination with the computing power of an off-the-shelf laptop computer allow for a process-based approach to landscape scale process simulation.

Estimating low flow indices anywhere – is LSTM the way to go?

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ABSTRACT

In Norway, selected low flow indices are used to estimate streamflow conditions critical for aquatic ecosystems. As such, they form the basis for multiple decisions in water resource management. Since 2008, the Norwegian Water Resources and Energy Directorate has provided a web service (NEVINA) where users can extract low flow indices at any point in a river network in Norway. In the current project, we aim to improve this service by 1) introducing more user relevant low flow indices, 2) updating the underlying data with high-quality streamflow and meteorological data reflecting the current climate, and 3) evaluating several regionalization methods to find the best model to estimate low flow indices in ungauged catchments, including Long Short-Term Memory (LSTM) networks.

We involved key users to identify their needs and discuss the possibilities and challenges with different low flow indices. Based on the user meetings, we settled on a set of relevant indices and an additional seasonal calculation representing the frost-free season to better reflect the underlying processes in seasonal low flow. To form the dataset used for regionalization, we used daily streamflow records with high-quality low flow measurements covering the years 1991-2020, SeNorge meteorological time series, and static climatic, hydrological and physiographic catchment descriptors.

Different regionalization methods are currently being tested to estimate the low flow indices anywhere. The current linear regression model implemented in NEVINA serves as a benchmark model. Two groups of models are tested against the benchmark: models that are trained on the indices directly (e.g. linear regression, generalised additive models and random forest) and time series models which allow the indices to be calculated from the simulated time series (the machine learning model LSTM and the process-based hydrological model DDD). Time series models may be beneficial as they provide consistency between different low flow indices for a selected catchment. Results based on the LSTM model will pe presented and compared to regression-based methods. The potential for implementing the different methods in NEVINA will be discussed.

Keywords: Low flow, ecological flow, modelling, machine learning, LSTM

The hydrological signature of landslides-towards the forecasting of landslides using hydrological models

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ABSTRACT

Heavy rainfall and/or snowmelt is the main triggering factor of shallow landslides (i.e. debris avalanches and debris flows). In addition, it is well recognized that high subsurface saturation is another important player in the initiation of landslides. The national landslide forecasting and warning service at the Norwegian Water resources and Energy Directorate (NVE), predicts daily the regional occurrence of shallow landslides, which often occur when intense rain and/or snowmelt concurs with high subsurface saturation. Despite the obvious and intuitive hydrological nature of the triggering of landslides, we have yet to detect a distinct hydrological signature, obtained from rainfall-runoff models, which can be used at local scale, in addition to the landslide model currently in use to in the forecasting of landslides. A reason for the lack of advancement in forecasting landslides using rainfall-runoff models is that very few landslides occur in catchments where we have a calibrated hydrological model. We have therefore very little experience with associating the triggering of landslides to modelled hydrological states.

Lately, a system for parameterising the Distance Distribution Dynamics (DDD) model for anywhere in Norway (i.e. at ungauged basins) has been developed at NVE. The DDD model is a rainfall-runoff model, which parsimonious set of parameters can be estimated from landscape characteristics and climatic information. Using information of previous landslide events recorded in the national landslide database, managed by NVE, we can set up the DDD model for the catchment where a landslide occurred and simulate a long timeseries of hydrological variables (since 2014-dd), including the time of the landslide event, at a 1 hr temporal resolution. Relevant landslide information abstracted from the database is landslide location, time of occurrence, landslide type and quality of observation. The model simulates a suite of hydrological variables such as water in the saturated and unsaturated zone, snow variables and flood values together with runoff. By investigating these variables at the time of the landslide event, we expect to better detect a specific hydrological signature that characterise the triggering of landslides. We are at the start of the project (HYMOJOFLO) and the very preliminary results indicate that subsurface saturation, high flows and the rate of change of subsurface filling, compared to the rate of change in runoff, are important players in the triggering of shallow landslides. We plan to analyse a large number of historical landslide events, so that we can have a solid base from which we can associate modelled hydrological states. The ultimate aim of the project is to be able to use modelled simulated hydrological states as a supplementary tool in the forecasting of shallow landslides.

Keywords: Landslides, hydrological modelling, ungauged basins, landslide database

Klimakverna: Understanding municipal needs for localized climate change information

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ABSTRACT

Norwegian Centre for Climate Services (NCCS) is a collaboration between the Norwegian Meteorological Institute (MET), the Norwegian Water Resources and Energy Directorate (NVE), NORCE Norwegian Research Center, the Norwegian Mapping Authority, and the Bjerknes Centre for Climate Research. NCCS provides decision makers in Norway with relevant information regarding climate change for climate adaptation, through climate and hydrological projections at both national and local levels. In the autumn of 2025, NCCS will publish updated knowledge on local climate changes in the report "Climate in Norway." To maintain and streamline the value chain from global and regional climate projections to knowledge for local climate adaptation, the project "Klimakverna" was established in the spring of 2023. Klimakverna aims to contribute to better climate adaptation in Norway by establishing a robust and efficient production and distribution chain for climate projections, and by lowering the threshold for their use.

The Norwegian goverment's instructions regarding civil protection and emergency preparedness involve the principle of responsibility, which states that the responsibility for climate adaptation lies with whoever is responsible for a task or a function affected by climate changes. This implies that everyone in Norwegian society has a responsibility for climate adaptation—public authorities, businesses, and individuals. An investigation by the National Audit Office in 2022 concluded that the work on climate adaptation among national authorities is insufficient. Municipalities experience unclear roles and responsibilities in climate adaptation, both between state sectors and administrative levels. As local planning authorities, community developers, service providers, and infrastructure owners, municipalities play a key role in developing climate-resilient local communities and therefore are an important target group for Klimakverna's work. By providing structured data in relevant and standardized formats, ideally directly into the users' own systems, Klimakverna seeks to improve the dissemination of the scientific knowledge base. Both directly, to various public authorities and impact researchers, but also via other knowledge providers. In this way, Klimakverna contributes to the government's goal of improving the coordination of climate adaptation work nationally.

Downscaling global and regional data is just the beginning, and interaction with different user groups is crucial for producing information that meets society's operational needs. In addition to transforming and improving the data to better fit users' tasks, Klimakverna aims to provide good guidance for the proper use of our information. One initiative is to develop municipal climate fact sheets. Since most Norwegian municipalities have a population of under 20,000, and small and medium-sized municipalities have the greatest need for guidance in climate adaptation, Klimakverna has chosen to focus on this target group. Through close user involvement, we are developing pilots for three selected municipalities with various challenges today and in the future. These municipalities are Rakkestad, Skjåk, and Vestvågøy. The pilots will be presented during the launch of the 'Climate in Norway' report in the autumn of 2025. The goal is to convey information in a local context that is relevant to municipalities' climate adaptation efforts.

Keywords: climate adaptation; climate services; local decision making; actionable climate information; coproduction; user involvement

Mitigating urban runoff and pollution in Oslo Fjord: mapping source area and predicting spatiotemporal variability

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ABSTRACT

Oslo Fjord's ecological status has been deteriorating despite measures that reduced pollution in past decades, and climate change will exacerbate this issue. Studies show that urban pollution from municipal wastewater and urban runoff pose a major challenge. Urban runoff transports particles and pollutants accumulating on urban surfaces, including nutrients, metals, organic micropollutants and microplastics to the Oslo Fjord, thus raising pollution levels causing e.g. eutrophication and contamination of water and biota. Increasing urbanisation results in more impermeable surfaces, causing excess stormwater, local flooding, and transport of these pollutants to the riverine and marine environment. Like many other cities, Oslo is projected to experience more heavy precipitation events due to climate change, which may increase the flux of pollutants from the impermeable urban areas to the fjord. To minimize the adverse impacts of pollutants from urban environments, sustainable stormwater management approaches, such as nature-based solutions (NbS), advocate for implementing pollutant transport control measures at the source. Source control measures, such as bio-retention cells, aim to mitigate large volumes of stormwater generated during extreme weather events and retain pollutants before they reach river systems and, eventually, larger freshwater or marine environments. To investigate the runoff management and contaminant retention potential of source control measures in Oslo's urban environments, it is essential to understand the pathways excess runoff takes on the urban surface (i.e., whether it flows into the stormwater collection system or the river network). Based on this knowledge, a source-based solution can be implemented. This study focuses on the initial part of the research, specifically mapping excess runoff that transports pollutants from urban surfaces and reaches Oslo Fjord via the Akerselva and Frognerbekken streams. The natural watershed area of Akerselva and Frognerbekken is defined as the study area based on NVE's watershed maps. A GIS-based terrain analysis was conducted using a 1×1 m digital terrain model from LiDar scanning from 2019 (hoydedata.no) in conjunction with the FKB-AR5 land use dataset obtained from Geonorge.no. Flow from each 1 m² cell was analysed to determine where the flow accumulates, while considering different urban infrastructures and physiographic characteristics, and the endpoint of each cell was mapped. The cells whose flows accumulates towards the two streams were extracted by excluding cells whose runoff is collected by the sewer networks. Finally, the input hydrographs and pollutographs to Akerselva and Frognerbekken was predicted under the assumption that these contribute to the Oslo Fjord. The results provide insights into the spatiotemporal variability of contaminant loads washed off from connected urban areas and at several inflow locations along the stream channels. This is an important input for selecting source control measures and locations for sustainably managing runoff and contaminant loads, thereby contributing to the preservation of the Oslo Fjord. The project serves as the basis for the next phase of the study, which utilises data and methods developed in the European Horizon 2020 MULTISOURCE project to explore the pollutant retention potential of bioretention cells, such as rain gardens, in mitigating urban runoff and pollutant loads.

Keywords: Oslo fjord; urban runoff; pollution control; sustainable stormwater management

Assessing the performance of Tåsenveien rain garden in Oslo under present and future climate change scenarios

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Abstract

Rain gardens are popular nature-based solutions addressing stormwater management challenges urbanization and climate change pose on the urban environment. As vegetated depressions comprising permeable storage and subsoil layers, rain gardens compensate for natural hydrologic processes lost in built up areas and offer multiple ecosystem services by facilitating surface storage, infiltration and evapotranspiration processes. The ecosystem services rain gardens offer include reduced runoff, improved water quality, and increased biodiversity. The performance of rain gardens, however, is influenced by local factors such as soil media characteristics, vegetation selection, and rainfall conditions hence their design should be adjusted locally. Furthermore, current approaches to rain garden design face substantial limitations in terms of long-term performance of rain gardens and their adaptability to changing climate conditions. This study assesses the performance of Tåsenveien rain garden in Oslo, focusing on its effectiveness in reducing stormwater volume and flow, as well as its capacity to remove pollutants under present and future climate scenarios using the Storm Water Management Model (SWMM). Tåsenveien rain garden, which has an area of about 60 m^2 and a potential surface storage volume of about 19.6 m^3, treats runoff from an area of about 1300 m^2 (including 40% road surfaces). The study utilized precipitation data from Bjølsen (SN18390), continuous sensor-based measurements (turbidity, water level and electroconductivity) taken every 5 minutes at two locations, and event-specific samples of pollutant concentrations (heavy metals and nutrients) collected between October 2022 to September 2024. All models set up and calibrated for the present climate, including proxy sensor records-based pollutant concentration prediction regression models, and the SWMM quantity and quality models, are employed to assess performance of the rain garden under future climate scenarios. The assessment of climate change impacts is based on the Norwegian climate service center's downscaled future climate scenario for Oslo, which predicts a 15% increase in annual precipitation amounts and 20% more precipitation on days with heavy precipitation. The impact of climate change on the inflow hydrograph and pollutograph, as well as changes in the effectiveness of the Tåsenveien rain garden in managing runoff and pollutants, will be illustrated using model-based scenarios. These scenarios will be discussed thoroughly, providing actionable findings for the future design and optimization of rain gardens, thereby contributing valuable insights into sustainable stormwater management strategies, particularly in the context of Oslo.

Keywords: performance of rain gardens; urban runoff; climate change; stormwater management; SWMM; Oslo, Norway

Extreme Event Attribution Service at MET Norway: Probabilistic attribution of the exceptionally warm Arctic summer of 2024

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ABSTRACT

In the summer of 2024, Northern Norway and the Svalbard Archipelago experienced an exceptionally warm season, leading to a drought that affected important regional industries, such as reindeer herding and hydropower operations in mainland Northern Norway and exceptional glacier mass loss at Svalbard. With the Arctic warming at a rate exceeding the global average in recent decades, its vulnerable ecosystems have been put under considerable stress. Understanding the role of climate change in altering the intensity and frequency of extreme events, such as the summer of 2024, is vital for mitigating impacts to ecosystems and informing societal adaptation strategies in the Arctic.

In this study, we analyse the 2024 event and attribute its changes to human-induced climate change. We employ a probabilistic attribution approach, fitting a non-stationary Generalized Extreme Value (GEV) distribution to an annual time series of the warmest 60-day period across the affected region, using global mean temperature (GMT) as a covariate. The methodology integrates observational data with an ensemble of downscaled and bias-adjusted climate model outputs. Furthermore, we explore the influence of climate modes and teleconnections on the 2024 event, as well as a possible compounding effect with marine heatwaves in the Barents Sea.

Preliminary results for the Northern Norwegian counties of Troms and Finnmark reveal a significant positive trend in the warmest annual 60-day period with global warming. When comparing the current climate to a counter-factual pre-industrial climate, we find that such extreme events like the summer of 2024 are at least five times more likely to occur in today's climate.

This study marks the first event studied with a probabilistic attribution approach by the developing Extreme Event Attribution (EEA) Service at MET Norway. This service will provide information on the influence of climate change on extreme weather events and communicate it to the public shortly after an extreme event has occurred. Such information is crucial for understanding climate risks and guiding policy decisions.

Keywords: extreme event attribution; climate risk; weather and climate extremes

Assessing Hectometric Resolution in NWP Models and Its Influence on the Representation of Precipitation in Norway's Coastal Regions with Complex Orography

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ABSTRACT

Accurate representation of precipitation in numerical weather prediction (NWP) models is crucial for, among others, adequate preparedness in extreme precipitation events. Extreme precipitation events can pose a risk to public safety by damaging infrastructure, lead to flooding, landslides and other hazardous conditions. Accurate forecasts allow for implementation of preventive measures that can reduce the potential consequences and thereby decrease the risk resulting from these precipitation events. However, accurate representation of precipitation and moist processes within the NWP models has proven difficult, and the models still struggle in certain conditions. Specifically, mountainous terrain, with the coastal areas of Norway serving as an example, challenges the accuracy of process representation within the models with its steep orography and large spatial variability over small distances.

Recent advances in computational power have allowed for higher resolution in NWP models, resulting in operational models often featuring a horizontal resolution at the kilometre scale. For example, The Norwegian Meteorological Institute (MET) currently operates two regional NWP models with a horizontal resolution of 2.5 km: the MetCoOp Ensemble Prediction System (MEPS) for mainland Norway and AROME-Arctic for Northern Norway and Svalbard, both built on the HARMONIE-AROME NWP model configuration. However, despite these advancements in resolution, the models still struggle to correctly reproduce precipitation, for example in complex coastal areas of Norway, partly due to the model resolution being to course. Kilometre scale resolution has proven insufficient in complex areas for accurately representing the local topography, potentially causing misrepresentation of moist processes. Running the model at hectometric scales allows for more realistic representation of orography and resolves more processes within the model dynamics, theoretically leading to more accurate precipitation forecasts. However, NWP model performance is not solely governed by resolution, but also by the interaction between the model dynamics and model physics and the accuracy of parameterizations within the model physics. These factors may limit the performance gains expected from the increased resolution. Therefore, it is crucial to gain a better understanding of how hectometric-scale resolution affects the model's physics and dynamics in order to comprehend its effects on moist processes and precipitation.

This study presents a case study of an extreme precipitation event that impacted the West Coast of Norway in Autumn 2024. The aim is to investigate and address moist processes and precipitation in complex terrain using the HARMONIE-AROME model configuration. A key objective is to enhance our understanding and application of hectometric-resolution NWP models for more precise weather forecasting. To achieve this, we use advanced analytical tools to analyse outputs from model experiments with varying horizontal and vertical resolution.

Keywords: Hectometric NWP, Precipitation, Complex Terrain

Evaluating persistence in Northern European weather patterns in a changing climate

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ABSTRACT

Persistent weather events—such as heatwaves, floods, and droughts—are of growing concern in a changing climate.. This thesis investigates whether large-scale atmospheric circulation patterns over Northern Europe are becoming more persistent, and how such trends may be linked to extreme weather. Using a dataset of classified circulation types (CTs) derived from ERA5 reanalysis and an ensemble of regional climate model simulations, trends in the frequency and duration of persistent circulation regimes are analyzed. These patterns are compared with observed weather data to identify links between specific CTs and extreme conditions.

Preliminary results suggest that some circulation types associated with dry or wet extremes show signs of increased persistence in recent decades, with regional differences emerging. The presentation will highlight the relationship between circulation types and observed weather conditions, as well as early findings on trends in CT persistence. Emphasis will also be placed on the potential role of Arctic amplification, explored by comparing changes in persistence with shifts in the north–south temperature gradient in the underlying climate models. The results aim to improve our understanding of how circulation dynamics shape persistent weather in a changing climate.

Keywords: Atmospheric circulation; persistence; flood; drought;

Performance of high-resolution snow depth data from ICESat-2 spaceborne laser altimetry

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ABSTRACT

To date, snow depth measurements require manual measurements or targeted field campaigns. The ATLAS sensor onboard the ICESat-2 satellite acquires profiles of surface elevation measurements of very high accuracy. When compared with an accurate digital elevation model (DEM) from snow-free conditions, this data directly translates into snow depth measurements. Previous studies used the spatially summarised ICESat-2 data products ATL06 and ATL08 with an along-profile resolution of 20–100 m. They found that ICESat-2 can provide average snow depth estimates at the watershed scale with decimeter-level uncertainties and that strongly increase with slope. We present results from two approaches to reduce bias/error and improve the spatial resolution of ICESat-2 snow depth data: A) accurate local snow depth profiles from using the lower-level data product ATL03, and B) high-resolution snow depth maps after employing statistical models for bias correction and spatio-temporal integration of ICESat-2 with climate reanalysis and terrain data.

The individual photon data product ATL03 used for approach A) has an along-track resolution of 0.7 m. Each overpass results in a profile pair separated by 90m laterally and consisting of a weak and a strong beam with approximately four times as many return photons. We compare different photon filtering and coregistration methods for field sites in Norway, Finland, and Switzerland including alpine terrain of different topography, sparse and dense forest. We find that ATL03 data closely matches reference snow depth maps from uncrewed aerial vehicles (UAVs). Given locally optimised pre-processing, the uncertainty (mean absolute deviation, MAD) for ICESat-2/UAV data pairs ranges from 0.05 m (sparsely forested, flat) to 0.4 m in a very steep alpine site. Bias (median residual) ranges from a few centimetres to several decimetres. Consistent offsets of up to 25 cm between strong and weak beams suggest inconsistencies in the geolocation of beams of the same pair in ATL03 data. Improved low-level processing on the data provider's side in future ATL03 data versions may reduce the differences between the beams.

To efficiently turn sparse measurements into snow depth maps in approach B), a regression model is fitted to establish a relationship between sparse ICESat-2 snow depth samples, the corresponding ERA5 Land snow depth with very coarse spatial, but high temporal resolution, and topo-climatic predictor features. This relationship is then applied to downscale monthly ERA5

Land snow depth data. The model reproduces the relative snow distribution pattern at 10 m spatial resolution very accurately, both for peak snow and patchy snow meltout in late spring. Compared to airborne laser scanning on Hardangervidda in 2008/2009, with snow depths up to 9 m, we find a RMSE of 1.28 m where bias is greatest for extremes, i.e., very high/low snow depths are under- and overestimated, respectively. The method relies on globally available data and can provide timeseries of monthly snow depth maps for the entire ERA5 time range.

Given accurate reference DEMs, spaceborne laser altimetry from ICESat-2 data can not only provide catchment-scale snow depth averages, but also high-resolution snow depth profiles or maps in areas where no measurements currently exist.

Keywords: Snow depth, Laser altimetry, Statistical downscaling, ICESat-2

Temporal Dynamics and Hydrological Impacts of Snow-Atmosphere Vapor Exchanges in a High-Altitude Catchment

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ABSTRACT

The evolution of the snowpack is strongly influenced by turbulent fluxes, where latent heat transfer alters the snowpack water equivalent through processes such as snow sublimation and deposition, in addition to changing the cold content and structure of the snow. In alpine regions, the contribution of sublimation to the water balance varies widely, with results indicating only a negligible part of snowfall is sublimated, to up to 90% locally at wind-exposed ridges and crests. To improve our understanding of these dynamics, this study integrates small-scale micrometeorological observations with catchment-scale modelling, enabling a multi-scale analysis of snow-atmosphere water vapour exchanges and their impacts on the snowpack water balance in a high-altitude catchment in southern Norway.

We will outline preliminary insights into the temporal scales governing water vapour fluxes and its linkage to environmental drivers, using micrometeorological site data and wavelet analysis. Compared to the commonly used eddy covariance method, processing the high-frequency site data using wavelet analysis allowed for resolving fluxes over small (<1 min) time scales, and offer a detailed analysis of the eddy distribution over time, and as such, new insights into the dynamics governing sublimation. In addition, the wavelet analysis method handled non-stationary time periods where the eddy covariance method fails, indicating the potential for using wavelet analysis over eddy covariance for processing complex micrometeorological data where traditional methods are not possible.

To evaluate the broader hydrological impacts of sublimation and deposition fluxes, we also plan to present results from a snow model framework over the whole catchment and contrast the annual variability between dry and wet winters. Our findings are expected to contribute to a deeper understanding of sublimation and deposition processes in Nordic regions, and how they may change in a future climate. By combining field measurements and modelling approaches, these insights can be used for advancing the parametrisation of winter vapour fluxes for applications in snow hydrology.

Keywords: Sublimation; Eddy covariance; Snow modelling

Data assimilation of sparse snow depth observation with optimized spatial transfer of information

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ABSTRACT

The satellite laser altimeter ICESat-2 provides accurate surface elevation observations across the water towers of our planet. With a high-resolution digital elevation model (DEM), we can use such measurements to retrieve snow depth profiles. Such observations are of great societal relevance because we can potentially use them to infer snow amounts even in remote montane areas, where the role of snow as water tower is not actively monitored. However, these retrievals are not currently used operationally because they are very sparse in space and time: ICESat-2 measures along profiles with a three-month repeat interval. The high spatio-temporal variability of the seasonal snowpack limits the observations' value.

Data Assimilation (DA) methods allow to use information from snow observations to constrain snow models and provide gap-free distributed simulations. The assimilation of observations like snow cover is considered the state-of-the-art for generating retrospective reanalysis, but the use of sparse snow depth observations in DA is an active research area as those could be used in an operational manner.

Covariance localization has been adopted to spatially transfer information from observed locations to similar unobserved locations. Traditionally, the geographical distance has been used to define the similarity between locations. In previous studies, we showed that topographical indices and the climatology of the melt-out date are also relevant parameters for determining the similarity. However, this measure was considered as a fixed hyperparameter. In this work, we exploit airborne lidar snow depth maps acquired by the Airborne Snow Observatory (ASO) to optimize the similarity measure between simulated cells. Gaussian Processes (GP) offer a probabilistic approach to infer the

relative relevance of geographic, topographic and snow-climatology variables through a method called Automatic Relevance Determination (ARD).

Preliminary results from the East River basin in Colorado, USA, indicate that GP can successfully learn repeated snow depth patterns from a water year and improve the spatial transfer of information for successive water years when only a profile is measured. The learned relative relevance is used in a set of full spatio-temporal DA experiments designed to quantify the potential contribution of snow depth observations from the satellite altimeter ICESat-2 for seasonal snow operational forecasts. We chose the East River basin because of the availability of high-quality atmospheric data collected through the Surface Atmosphere Integrated Field Laboratory (SAIL) campaign.

Keywords: Data Assimilation, Seasonal Snow, Satellite Altimetry.

The Climate-Ecological Observatory for Arctic Tundra (COAT) - weather & snow - observations & models

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ABSTRACT

Climate change is occurring at an accelerated pace in the Arctic, transforming Arctic ecosystems. Long-term monitoring is challenging, yet essential for environmental conservation, management, and policy making. The Climate-Ecological Observatory for Arctic Tundra (COAT, www.coat.no) aims to meet these challenges by real-time detection, understanding, and predictions of climate impacts on tundra ecosystems. The observatory is geographically distributed over the Low-Arctic Varanger peninsula in Finnmark, mainland Norway, and the High-Arctic archipelago Svalbard, covering a wide range of climate gradients and management contexts. A substantial effort between 2016-2023 has provided research infrastructure (e.g., operational automatic weather stations, experimental devices, sensor systems, and data portal) to facilitate the long-term monitoring of the terrestrial ecosystem. No other such observatories of climate change impacts on all essential components of terrestrial food webs exist in Norway, and COAT is one of the very few observatories of this kind in the circumpolar Arctic. Important outcomes of COAT are the development of appropriate statistical modelling tools, using new technologies that generate high-quality data with a minimal environmental footprint, and stakeholder-relevant predictions for managed ecosystem components.

As a result of COAT, 17 new weather stations have been established, complementing existing stations on the coast. These are now a part of the station network operated by the Norwegian Meteorological Institute. Most of these stations measure, in addition to the regular weather parameters, snow height, incoming radiation, and soil temperature. Additionally, more than 300 iButton temperature loggers are placed strategically, to sample the small-scale variability in near surface and surface temperature, and snow-on and snow-off. Annual snow surveys are conducted on Svalbard and in Finnmark, with emphasis on snow hardness, e.g. ice layers and depth hoar. In Varanger the first surveys started in 2006. The number of snow profiles have increased with time, to 78 in 2025. The new and unique data is explored using land surface models, to derive variables relevant for the ecosystem modelling, such as snow pack properties. Further, novel data products such as the CARRA reanalysis and the MET Nordic Dataset, with the capability to extend the data-series back in time, are evaluated for their ability to reproduce local weather events, such as rain-on snow events, known to have impacted local ecosystems in these regions.

Keywords: COAT; snow, ecosystem, Arctic, modelling

Surface Temperature Variability in the High Arctic: UAV Thermal Monitoring of Groundwater and Surface Water Interactions

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ABSTRACT

The High Arctic is undergoing rapid climate shifts that are significantly impacting its ecosystems. To gain a clearer picture of these changes, this study uses drones equipped with thermal cameras to monitor ground and water temperatures in the catchments of southwest Spitsbergen. This method delivers high-resolution data in real time, offering a detailed view of surface temperature conditions in this remote and challenging region. By combining drone-based observations with on-the-ground measurements, the research captures temperature patterns at both fine spatial and frequent temporal scales. A new workflow, built with open-source tools, is introduced to generate thermal orthomosaics, improving the accuracy and efficiency of the analysis. These thermal maps help identify variations in land and water surface temperatures and shed light on the factors driving these changes. The study also focuses on thermal patterns in Arctic water systems, such as streams and ponds, enabling the identification of flow paths, including areas where groundwater mixes with surface water. Through this comprehensive approach, the research contributes to a deeper understanding of the interactions between frozen ground, water flow, and weather conditions in the High Arctic.

Keywords: LST; WST; UAV; Svalbard

Observed long-term trends in snow conditions for Norway

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ABSTRACT

Snow conditions are sensitive to increasing temperature and precipitation. Despite a shorter snow season due to temperature increase, an increase in precipitation can lead to an increase in snow amounts in regions that are sufficiently cold. The long-term development of snow conditions for Norway were analysed for 46 stations fulfilling criteria of good quality and at least 70 years of data. Since these stations represented lowlands, ten stations from higher elevations but lower quality or time series length were added. Three indicators were studied: the number of days with snow depth exceeding 1 cm (“snow season”), the number of days with snow depth exceeding 25 cm (“ski season”) and the annual maximum snow depth during each winter season (“snow max”). Trend analyses used the Mann-Kendall trend test for fixed 30-year periods spanning 1901–2020, and for the full measuring period at each measuring station.

Most time series showed both shorter snow season and less snow max. At several locations, the ski season has reduced by 4–6 weeks during the full measuring period (which varies from time series to time series). The greatest reduction was found at Bjørnholt i Nordmarka, which now has eight weeks shorter ski season than at the early 1900s. When comparing trends over different 30-year periods, the period 1961–2020 showed the strongest tendency of shorter snow seasons and snow max. The most recent 30-year period 1991–2020 showed a significant reduction in snow conditions at very few stations, linked to the high inter-annual variability of snow. Trends in snow depth are more nuanced, indicating an increase in snow max at single locations during a period of marked precipitation increase (1991–2020). However, the dataset is too small to reveal robust and systematic patterns in increasing snow depths.

A range of climate indices, including annual maximum snow water equivalent and ski season have been analysed for the report Climate in Norway (Dyrrdal et al., 2025), which will be published by the Norwegian Centre for Climate Services (NCCS) in late October 2025. Several background reports have already been published on historical changes (e.g. Nilsen et al., 2025).

Keywords: Snow depth; ski season; snow cover; historical climate change

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Improving modeling of thermo-hydrological changes in permafrost ground connected to lake level changes in the Qinghai-Tibet-Plateau

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ABSTRACT

Amplified climate change in high-altitude regions has been documented for the last decades and is predicted to increase during the coming decades. A measured significant increase in air temperatures since the 1980s, a decrease in wind speeds, more moist air masses and a general increase in precipitation in the Qinghai-Tibet Plateau (QTP) have major consequences for the thermo-hydrological system in areas with permanently and seasonally frozen ground. The around 1000 larger (>1 km) lakes at the QTP, have experienced increases in water levels since the 1990s. We want to find out if these lake level changes can be linked to thaw of permafrost ground ice, changed infiltration availability in the ground, near-shore subsidence and/or are only a product of changed evaporation and precipitation patterns.

Martin et al. (2023) modeled the thermo-hydrological system for the endorheic lake catchment of lake Paiku Co in the South of the QTP using the CryoGrid model. We improve the existing modeling scheme for the through (1) a switch from ERA5 to HAR (High Asia Refined analysis) data as model forcing and thereby allowing for dynamical downscaling and a correction of the snow-overestimation in the ERA5 data by using the 55-yr Japanese reanalysis product (JRA-55) for the region, and (2) developing a validation scheme for modeled ground ice contents which connects InSAR measured vertical displacement amplitudes of seasonal frost heave and subsidence and ground observations (permafrost cores, excavation pits) with detailed descriptions of the ground ice content in the same locations, and (3) simulations in strategic focus sites and catchments. If these changes provide more accurate and valuable simulations for thermo-hydrological changes and lake level changes, ultimately, the modeling scheme can be extended to distributed simulations over the entire QTP region.

Keywords: thermo-hydrological modeling; ground ice, lake level changes

Evaluating Land-Atmosphere Interactions in the coupled WRF-CTSM model over Nordic Fennoscandia

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ABSTRACT

High latitude regions are experiencing rapid changes under evolving climate conditions. Advanced research tools are essential for understanding these dynamics and their associated feedback mechanisms. Here we present 1) a comprehensive evaluation of the state-of-the-art coupled regional climate model WRF–CTSM in simulating hydroclimatic variables and 2) soil moisture–temperature coupling analysis during the extreme 2018 heatwave.

The WRF–CTSM model couples the Weather Research and Forecasting (WRF) model with the Community Terrestrial Systems Model (CTSM) which enables a more detailed representation of land surface processes and their interactions with the atmosphere. We conducted a high-resolution (10.5 km) 13-year simulation (2010–2022) over Nordic Fennoscandia (Norway, Sweden, and Finland) to assess the model's performance in capturing key hydroclimatic variables such as mean, minimum, and maximum 2 m temperatures, precipitation, snow variables (snow depth, snow water equivalent, fractional snow-covered duration), and surface energy balance components. A multi-source comparison using gridded, satellite-based, and in situ observations indicates that the WRF–CTSM model effectively captures high latitude climate conditions at different timescales.

In addition, we used WRF–CTSM to investigate soil moisture–temperature coupling during the 2018 heatwave with a focus on southern and central Sweden that is considered as a coupling hotspot. A multi-correlation overlay analysis was performed using four different WRF–CTSM configurations. We employed a gridded observational dataset as a reference after validating against in situ measurements to assess the magnitude and variability of the key coupling variables. Our results show that soil moisture–temperature coupling persisted for an average of 40 days. The atmospheric leg contributes on average 88% of the coupling duration with considerable variability across datasets. Our findings highlight the capability of the WRF–CTSM model to simulate complex land–atmosphere interactions in high latitude environments.

Keywords: land-atmosphere interactions; soil moisture-temperature coupling; regional climate modelling; 2018 heatwave