ABSTRACTS
ORAL PRESENTATIONS

Norsk hydrologiråd, 7th conference on Modelling Hydrology, Climate and Land Surface Processes: ***Modelling, forecasting, communicating, and handling weather-induced natural hazards***

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Abstract

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Global HYPE modelling as a short-cut to national/regional prediction systems

"Early warnings for all" is a mission raised by the World Meteorological Organisation at the UN 2023 water conference, although productions systems forecasting floods and droughts normally takes several years or decades to set-up, especially in sparsely monitored regions. The global catchment model HYPE (hydrological Predictions for the Environment) uses open data and source code in step-wise parameter estimation (Arheimer et al., 2020) to provide a modelling framework for regional refinements in data-poor regions (e.g. Andersson et al., 2017; Stadnyk, et al., 2020). In this presentation we will explain the global model concept, how it is shared and evaluated at various scales. We will show examples of model refinements using new data and local process knowledge, so that the results become applicable in national/regional planning to avoid hazards. We will also discuss capacity development needed for the model to be operated in different institutional settings.

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Trends in hydrometeorological avalanche indicators in Norway and Svalbard in 1957-2023

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ABSTRACT

In Norway, avalanches are common in the mountainous areas during the winter and spring seasons, obstructing roads and railway lines, and sometimes causing fatalities when a house, vehicle or a skier is hit and possibly buried by an avalanche. Moreover, north of Norway, on the Arctic islands of Svalbard, the settlements have in recent years had to increasingly cope with avalanches and the danger they pose to the local society and tourists. Most of the fatal avalanche accidents in Norway happen in connection with winter-sport activities (skiing, snowboarding, winter-climbing, snow-mobiling etc.) where the persons themselves trigger the avalanche. However, a vast majority of the total number of avalanches are triggered by natural causes without any direct human interaction, i.e. due to hydrometeorological, snow- and weather-related factors. It is these naturally triggered avalanches that cause damage to infrastructure (roads, railways, houses, powerlines).

It is obvious that hydrometeorological factors, such as snow depth, length of the snow season, wind speed and direction, air temperature, as well as rain and snow precipitation are closely connected to avalanche activity. Moreover, the ongoing climate change may have affected these factors in several ways. For example, the air temperature and precipitation have been generally increasing in Norway during the last decades. Also, the snow conditions in Norway have been changing and show a general reduction in the maximum yearly snow depth and a shortening of the snow season (i.e. starting later and ending earlier). On Svalbard, the climate has been changing even more rapidly during the recent decades. Consequently, a natural question to ask is: "How has avalanche activity in Norway and Svalbard changed during the last 50-100 years along with a changing climate?" While there are many long time series of air temperature, precipitation, snow depth, etc. observations in Norway, there are very few, if any, similarly long time series of observed avalanche activity. Therefore, it remains still uncertain how avalanche activity may have changed during the last 50-100 years.

In order to provide answers to our research question on changes in historical avalanche activity, we derive four different avalanche activity "proxy" indicators, calculated on the basis of different hydrometeorological variables, such as air temperature, liquid and solid precipitation, wind speed, snow depth, snow melt, and runoff from snowpack (daily values at 1×1 km resolution). We analyse and present changes and historical trends in our avalanche indicators over the 65-year period from 1957 to 2023 for mainland Norway. Moreover, we evaluate the performance of our indicators against time series of daily avalanche problems and danger levels issued by the Norwegian avalanche warning service (NAWS) since 2013, as well as against satellite-based detection of avalanche activity. For avalanche indicator analysis on Svalbard (the Nordenskiöld Land region), we use hydrometeorological data from the "C3S Arctic Regional Reanalysis" (CARRA) data set available since 1991 at daily 2.5×2.5 km resolution.

Keywords: avalanches; climate change

Modeling streamflow response to climate change in Wamkurumadzi River, Shire Basin in Malawi using the SWAT Model

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ABSTRACT

Climate change is expected to bring increased variability in future streamflow depending on the hydroclimate of the region and the specific characteristics of the catchment studied. Empirical evidence continues to show that Malawi is one of the countries that has experienced significant variations in hydrometeorological conditions, ranging from severe drought conditions to extreme flood events almost every year. However, there is still a gap in evaluating the long-term impact of climate change on streamflow mainly due to high rate of missing hydro-climatic data in most of the region. This study evaluates how climate change affects the flow of Wamkurumadzi River, a key tributary of Shire River in Malawi using the Soil and Water Assessment Tool (SWAT). Historical climate data from 1981 to 2015 and eight hypothetical climate change scenarios (e.g. combination of $\Delta T = +2^0C$ and $+4^0C$ and $\Delta P = \pm 10\%$ and $\pm 20\ \%$) were applied to simulate streamflow. Sequential Uncertainty Fitting 2 (SUFI-2) within SWAT-Calibration and Uncertainty Procedures (SWAT-CUP) was used for calibration from the year 1984 to 1999 and validation from the year 2000 to 2015. Model performance was acceptable according to evaluation criteria, with the Nash-Sutcliffe (NSE) coefficient of 0.78 and coefficient of determination (R^2) of 0.96 during calibration and NSE of 0.93 and R^2 of 0.98 during validation.

The results of historical trends showed a slight decrease in annual rainfall. On the other hand, there was no trend in annual temperature, whereas the trend in observed river flow suggests a predominance of increasing trends at monthly and annual timescales. The hypothetical climate change scenarios revealed that most prominent changes in river discharge were due to changes in precipitation (±10 and ±20%), whereas temperature had limited projected effect. For instance, scenario 8 ($\Delta P = +20\%$ and $\Delta T = 4^oC$) gave a relatively slight increase in simulated mean daily discharge of $2.13 m^3/s$ as compared to scenario 5 ($\Delta P = -20\%$ and $\Delta 4^oC$), which gave the lowest mean daily discharge of $1.77\ m^3/s$. Overall, the results indicate that the streamflow is sensitive to both precipitation and temperature but changes in precipitation gave a relatively higher effect on the magnitude of the mean daily, monthly and seasonal discharge compared to changes in temperature.

Keywords: Climate change; SWAT model; Streamflow; Wamkurumadzi River

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A machine learning revolution for weather forecasting?

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ABSTRACT

Machine learning has had a transformative effect in many fields, driven by advances in algorithms, hardware and huge datasets. In the field of weather forecasting there are a vast array of problems where machine learning is being explored as a possible force for good. At the European Centre for Medium-Range Weather Forecasts we have been bringing promising machine learning applications towards operationalisation to improve global forecasts. The past year has seen a rapid-rise of data-driven forecasting system, models capable of making forecasts with no explicit knowledge of physics. We will discuss these models, how they perform and forecast what the future holds for machine learning's impact in weather forecasting.

Flood forecasting everywhere- putting PUB to work.

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ABSTRACT

In this study the Prediction in Ungauged Basins is taken very literally in that we present a system that enables the setting up and running a rainfall-runoff model, the Distance Distribution Dynamics (DDD) model for any catchment in Norway. The system (called HSO- Hydrologiske Simuleringer for Overalt) can be used in operational flood forecasting since hydrological simulation results for an arbitrary catchment are obtained in a few minutes. A GIS map tool is used to calculate catchment boundaries, the hypsographic curve and other catchment characteristics such as vegetation and mean annual discharge needed to estimate DDD model parameters. Terrain information and catchment boundaries are furthermore used to extract meteorological information from gridded (1 x 1 km) maps for both historical and forecast periods. The historical period may be of such a length (>30 years, daily temporal resolution) that the mean annual flood (MAF) can be reasonably estimated and compared to forecasted runoff values for hazard assessments. A flood forecaster is hence no longer limited to only assessing hydrological simulation results from hydrological models calibrated for a small number of gauged catchments. Rather, she can set up a model for ungauged catchments where the forecasted precipitation is the most intense or where vulnerable infrastructure is located. The relative comparison between simulated forecasted runoff and the simulated MAF is informative for hazard assessments and is not depending too much on how precise the estimate of the MAF is in absolute terms. However, estimates of MAF by HSO give an average error (RMSNE) of 23% which is identical to that of the regional flood frequency analysis (RFFA2018; Engeland et al, 2020) currently used operationally in Norway. Tested for 41 gauged catchments, the average Kling-Gupta efficiency (KGE) criterion is $KGE = 0.71$ without having the possibility of adjusting for volume errors. Using a pilot version of HSO in operational flood forecasting has resulted in the inclusion and the exclusion of geographical regions receiving flood warnings. Future developments include higher temporal resolution of meteorological input data so that flood forecasting and flood estimation can be carried out for smaller and faster responding ungauged catchments. Improved meteorological grids, and improved model algorithms will further improve the HSO.

Keywords: flood forecasting; ungauged catchments

The Distributed Regression hydrological Model (DRM)

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ABSTRACT

This paper presents the distributed regression hydrological model (DRM). The DRM is a hybrid model that combines association with hydrological processes and machine learning techniques. It was designed based on the following guiding principles. At first, the model should run relatively fast, meaning it should utilize parallel processing. The selected equations in the model should be associated with physical processes and seek to keep the objective space as smooth as possible. The code should minimize the usage of thresholds and "if sentences" that makes the objective space non-differentiable. Such implementations give gradient-based calibration methods an advantage.

Another guiding principle was that the model should be able to run with only air temperature and precipitation as input. These are commonly used in hydropower and are typically available at daily temporal resolutions. Further, the model should utilize the power of recurrent neural networks (NN) using output from the hydrological calculations as an input to the NN. The model structure in DRM consists of two major parts: HYDMOD and LSTM. The first calculate snow accumulation and melt, infiltration to the soil, evapotranspiration, and runoff in a distributed grid. The sum of the runoff from all grid cells represents the catchment runoff. Secondly, the LSTM-NN is forced with the fluxes and states from the HYDMOD to calculate a modified runoff signal.

Within DRM, a three-step calibration procedure is available. At first, the model runs a discrete Bayesian parameter optimization in the HYDMOD. It starts with many runs selecting the parameter values from uniform distributions. After a certain number of trials (user-specified), it updates the discrete parameter distributions (Bayesian) and starts all over. Furthermore, a one-at-the-time gradient search improves the parameter set further. Finally, the backpropagation algorithm trains the LSTM NN using observed streamflow. Within DRM several objective criteria can be used in the calibration process (MAE, NSE, KGE, and more).

In this research, the DRM model was applied to seventy catchments located in southern Norway. The model was calibrated and validated using many different types of objective criteria. Preliminary results indicate that the DRM model is promising, but further testing and improvement are required.

A detailed description of the DRM model, the data used to test it, and a variety of results will be presented at the conference.

Keywords: hydrology, model, machine learning, physics

Stormwater calculations using AI to predict and prevent flooding along railway lines. Case study: Meråkerbanen

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ABSTRACT

The management of stormwater runoff is critical for maintaining the safety and sustainability of infrastructure and urban environments (EPA, 2021). Stormwater calculations are integrated for designing systems that can effectively handle the volume of water generated during rainfall events (ASCE, 2016). Recently, automated stormwater calculations have gained traction following significant increases in processing efficiency and accuracy (Liu et al., 2019).

Automated stormwater calculations involve the integration of multiple data sources and the utilization of advanced processing techniques to perform complex calculations quickly and accurately (Chen et al., 2018). This approach has been successfully implemented in multiple stages of a collaborative project between Bane Nor and the 7 Analytics (7A), focusing on the Meråkerbanen railway line in Mid-Norway. The project aims to demonstrate how automated stormwater calculations can be applied in the context of railway design and maintenance, to avoid water to disturb railway operations.

Furthermore, the field of natural hazard prediction is constantly advancing, with the development of increasingly sophisticated models and continuous improvements in data processing hardware and software for the deployment and updating of these models (Kreibich et al., 2019). This includes the incorporation of novel data sources, state-of-the-art modelling algorithms, and strategies for empirical model adaptation beyond traditional single-catchment calibration (Blöschl et al., 2020).

As an extension, 7A are prototyping a forecasting and warning system employing real-time data and predictive models to deliver timely and accurate warnings of forecasted events. The system is designed to offer advanced notice of potential hazards, allowing for appropriate actions to be taken to minimize the impact of extreme events. To be effective, a real-time forecasting and warning system must exhibit high accuracy and reliability, with minimal false alarms or unwarned events. Additionally, the system must operate in real-time, with rapid data processing and dissemination capabilities, to provide prompt warnings and alerts to relevant stakeholders (Wagner et al., 2014).

The developed model can be enriched with data from various external sources, including precipitation and flow sensors. In this pilot study the automated stormwater model is integrated with historical weather data and forecasts from the Norwegian Meteorological Institute, as well as flow data from a Pipelife sensor in one culvert along the Meråkerbanen railway line. All the data is processed using sophisticated algorithms and predictive models to identify patterns and trends that may signal an extreme event (Huang et al., 2018).

By designing and developing the tools independently, they can operate as stand-alone tools solving specific problems. Furthermore, it is possible to connect modules, hence adopting a more holistic

approach to strengthen the understanding of interactions between natural processes, environment, and climate change.

Finally, the adoption of automated stormwater calculations can be a game changer for the stormwater management as we can develop an even more efficient and accurate software for designing, monitoring, and maintaining stormwater infrastructure. Likewise, advancements in natural hazard prediction modelling will play a critical role to ensure the safety and resilience of our communities in the face of climate change and related natural hazards (Kreibich et al., 2019).

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Keywords: Stormwater calculation along railway; warning AI-model

River discharge extremes in Norwegian regulated catchments: hydrologic model simulations including human interventions

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ABSTRACT

In the coming years and decades, Norway will likely be affected by more frequent and severe extreme weather events, including both intense precipitation and drought. Predicting how these hazards will result in extreme high and low river discharge in a changing climate requires robust hydrologic models representing all relevant physical and human processes. While hydrologic modelling in catchments affected by human activities is more challenging than in pristine environments, it is mainly in the former that water-related natural hazards have the largest societal impacts. Therefore it is crucial to test and refine hydrologic predictions in human influenced catchments.

We apply the spatially distributed hydrologic and water resources model LISFLOOD to regulated Norwegian catchments, aiming to evaluate, and possibly improve, the simulation of high and low discharge conditions under the influence of human interventions. LISFLOOD simulates hydrologic processes on several sub-grid land use and cover classes, routing discharge along river networks. It can also simulate lakes and reservoir regulation, as well as human water abstractions, consumption and return flows.

We focus primarily on the Drammen catchment, which is heavily regulated and serves several water users, with the possibility to extend the analysis to other catchments in Norway. Land use, vegetation, soil and river data are derived from the LISFLOOD setup at 5 km resolution used in the European Flood Awareness System. The model is forced with daily SeNorge_2018 and European Meteorological Observations atmospheric data at, respectively, 1 km and 1 arcminute spatial resolution. Detailed information for the Drammen catchment, in particular regarding human water use and regulation, is available through collaboration with the STARS4Water research project, which focuses on how climate change affects water resources availability at catchment scale and the potential impacts on ecosystems and society. Model evaluation is based on observed river discharge and reservoir water storage time series obtained from the Norwegian Water Resources and Energy Directorate. We aim to assess the ability of the model to reproduce extreme high and low discharge conditions, and whether representing human interventions improves model performance.

Keywords: hydrologic modelling; discharge extremes; human water use; reservoirs.

SPI-Based Hybrid Wavelet–ANN Models for Drought Forecasting in north Tunisia

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ABSTRACT

Severe drought events in recent decades, along with the potential increase of drought frequency and severity due to climate change, have highlighted the urgent need for arid and semi-arid countries to establish effective early-warning of drought hazards systems that incorporate accurate drought monitoring, reliable drought forecasting, and effective information dissemination. Moreover, drought forecasting is necessary for water resources, agriculture, food security and eco-environmental management. Recently, stand-alone machine learning techniques such as artificial neural networks (ANN) were used to forecast climate data. However, lately, hybrid models have been introduced, which are created by integrating different time series decomposition techniques into standalone models, since the accuracy of stand-alone models used in the drought prediction being low particularly for mid-term and long-term drought predictions. This study assessed then the capability of the hybrid neural network model to forecast meteorological drought based on the standardized precipitation index (SPI). Model input data pre-processing with wavelet multiresolution decomposition (MWD) for improving the performance of the models was carried out apriori. First, MWD is used to decompose SPI3 data time series into their sub-bands. Then the ANN ensemble model allowed to identify the statistical links between the decomposed inputs and the decomposed outputs according to temporal scales and to predict each SPI3 decomposition. Ensemble drought forecasts were carried out. SPI3 time series were used to achieve 1, 3 and 6-month lead time predictions. For operational forecasting, the forecasts obtained from the decompositions are summed to represent the true precipitation forecast value. The SPI was computed at 3 months time scale (SPI3) from 70 years of data for several rainfall stations located in the Medjerda basin located in northern Tunisia witch is a semi-arid region. The results reveal that the hybrid model yielded acceptable accuracy for SPI3 forecasting for long-term forecasting in terms of coefficient of determination (R2) and Nash-Sutcliffe efficiency (NSE). Considering the Medjerda region, the hybrid wavelet model outperformed the stand-alone model for not only 1-month lead time with R2 exceeding 0.8 in the majority of rainfall stations. Thus, the wavelet hybrid model is recommended as a robust model for drought forecasting.

Keywords: Drought, forecasting, SPI, Hybrid models, multiresolution wavelet decomposition, ANN

Probabilistic impact-based approaches for flood forecasting and prediction

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ABSTRACT

Flooding affects more people globally than any other hazard with the number of major flood events significantly increasing in recent decades, and accounting for over 20% of disaster losses during 2000-19 (UNDRR, 2019). Recent developments in flood forecasting and management have increasingly taken a risk-based approach that combines the *likelihood* of an event occurring and *with* the severity of the potential impacts. Commonly the likelihood of flooding is derived from new ensemble or probabilistic modelling systems and impacts derived using GIS approaches.

Such Impact-based Forecasting and Warning (IbFW) methods have been promoted by the World Meteorological Organisation and are increasingly used by international, national and regional organisations. For example, by humanitarian organisations to support Forecast-based Action or Forecast-based Financing to release funds ahead of disasters. Similar flood risk methods can also be applied for long-term climate predictions and planning.

This talk will present some of the UK developments in this area, including national scale ensemble flood forecasting using the Grid-to-Grid (G2G) distributed hydrological model and applications such as the Surface Water Flooding Hazard Impact Model and PREDICTOR (PREDICTing flooding impacts from cOnvective Rainfall).

A land data assimilation system for NWP initial conditions and hydrometeorological forecasting

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ABSTRACT

Extreme rainfall, flash flood, drought, slush and snow avalanches, landslides, and their variability under global warming, are major hazards to lives and property, and may affect business and industrial development negatively. Despite advances in numerical weather prediction (NWP) models and post-processing techniques over the past few decades, prediction of intense, small-scale precipitation and their consequences remains a challenge. Most NWP systems are currently using simplified land surface schemes, so called "bucket models" for soil water, single layer snow schemes and very limited interaction between soil and the vegetation. These simplified land surface schemes are dependent on surface data assimilation to correct their insufficiencies and the modeled variables are not representing "real" physical values. As a consequence the value of the output variables and usage of this data in other models and services is limited. In this work we present the transition to more advanced land surface schemes in the operational NWP system at MET-Norway. We present how multi-layer soil, snow and vegetation schemes affect our NWP forecasts and how this system could be utilized in a stand-alone Land Data Assimilation System (LDAS), which may facilitate improved NWP initial conditions and early warning of flash floods and agricultural drought. The LDAS is driven by the Nordic Analysis produced by MET-Norway. It covers Scandinavia with a spatial resolution of 1 km. The offline forcing data set contains surface parameters including 2 meter temperature and precipitation. The precipitation forecast is corrected using observations from MET-Norway's radar network and station based rain gauges. The LDAS system is run daily with hourly output data of e.g. multi-layer soil moisture/temperature, snow depth and water equivalent, surface and subsurface runoff. Flash-floods and routing of water in fast responding watersheds (as seen for most parts of Norway) are tackled using the TOPMODEL approach (named TOPODYN) in the NWP land surface model. This module models the lateral distribution of soil water among watersheds and eventually into the rivers, allowing for a computation of river discharge. In addition, the Squeegee method which summarizes the grid-cell runoff within a catchment and uses this as an estimate of the river discharge, will be applied. With this LDAS MET-Norway aims at delivering accurate and reliable hydrometeorological forecasts and warnings for enhanced preparedness and reduced loss of life, critical infrastructure and livelihood.

Keywords: NWP; Land data assimilation

How can we make ensemble flood forecast more reliable ?

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ABSTRACT

Ensemble forecasts of floods are used to assess uncertainty inf flood forecasts for the coming days. These ensembles can subsequently be used for assessing the risk for high impacts. Hydrological ensemble forecasts are established by using meteorological ensembles as forcings to a hydrological model. To make best possible risk assessments, hydrological ensembles that correctly describes the actual uncertainty in the forecasts are needed. This property of an ensemble forecast is named reliability. A secondary objective is to make the ensemble spread as narrow as possible – a property called sharpness. To achieve reliable and sharp ensemble forecasts of both meteorological variables, streamflows, and floods in particular, processing approaches are required. In this study we will compare how different processing approaches can be used to obtain more reliable flood forecasts for a set of catchments used for operational flood forecasting in Norway.

Keywords: flood forecasting, ensemble forecasting, processing

Understanding the influence of soil moisture and surface water fluxes on extreme convective precipitation events during summer in South Norway

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ABSTRACT

Climate change is predicted to be especially pronounced in the higher latitude regions. Precipitation will likely increase in subpolar and polar areas with higher occurrence of extreme precipitation both in winter and summer. Norway is especially vulnerable to flash floods caused by heavy precipitation due to its topographic conditions with steep slopes and a shallow soil layer. In this context it is essential to have accurate forecasts of extreme precipitation events that might lead to flooding. These heavy precipitation events occur mostly during convective conditions in summer and are notoriously difficult to predict due to their short evolution time and our lack in understanding underlying processes at the land-atmosphere-boundary. The H2O projects of the Norwegian Meteorological Institute aims to improve the understanding of processes between soil, vegetation and the atmosphere in Norway and identify the role of soil moisture in the development of convective summer precipitation. Soil moisture is usually neglected in models as soil water content measurements are sparse and the relationship between land and atmosphere is not fully understood. In this project, observations of soil moisture and turbulent fluxes during the summer seasons in 2021 and 2022 in South Norway will be used to improve the ability of land surface models (LSM) to represent real-world surface conditions. Ultimately, the observations should help improve forecasts of extreme convective precipitation by numerical weather prediction (NWP) models with the goal to implement these findings into operational weather forecasts of Norway. Model results will be compared with the spatial and temporal patterns observed by real-world measurements before and during extreme convective precipitation. Our results show that the latent heat flux (LE) was dominating the surface energy balance and LE, sensible heat flux (H) and evapotranspiration (ET) were highest under convective conditions showing the high amounts of energy that are transported from the surface to the atmosphere under these conditions. The dominance of water-related fluxes showed that soil moisture as an essential part of the water cycle can no longer be neglected in weather forecasting. The NWP model results tend to overestimate evapotranspiration compared to observations. This is likely linked to the complex heterogenous pattern of soil moisture we measured, which is directly linked to ET and LE rates of soil and vegetation and indicates that the forcing data that is currently used for NWP models has to be expanded by observations of soil moisture and evapotranspiration.

Keywords: Extreme precipitation; land-atmosphere-interactions; soil moisture; convective events; weather forecast; observations; numerical weather prediction

Assimilation of surface sensitive satellite microwave observations at high latitudes to better forecast extreme events

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ABSTRACT

One way to improve the forecast of natural hazards could be to generate more realistic initial conditions / atmospheric analysis for numerical weather prediction (NWP) using more surface-sensitive satellite observations. In fact, polar regions benefit from a high-density coverage of satellite observations that could compensate for the sparse network of conventional data. However, due to large model errors at these latitudes, the satellite observations are underused. To improve the assimilation of surface-sensitive channels, we need to better model the surface parameters. Karbou et al. (2006) demonstrated that one can retrieve this information using the brightness temperature from a window channel and allocate the retrieval to assimilate adjacent sounding channels at higher frequencies. Positive impacts were obtained at a global scale. However, less is known about the impact in a regional model, this study describes the impact of using a better representation of the surface to improve the radiative transfer simulations and 3D-VAR data assimilation of observations from AMSU-A, MHS, ATMS and MWHS-2 over land, snow and sea ice. Assimilation experiments using the "so-called dynamic emissivity" have been run in the framework of HARMONIE-AROME giving neutral to positive impacts on forecast skills. Emphasis on the impact on extreme event cases will be given.

Keywords: data assimilation, microwave, high latitudes, forecast system

Abstract Kerstin Stahl for Lillehammer conference 2023

From drought impact information to impact-based forecasting: progress and setbacks

Compared to other natural hazards' damages, the impacts of drought are often diverse, affecting multiple sectors with different time lags. Research has found more immediate relations of meteorological drought and soil moisture drought to yield losses in rainfed annual crops in the agricultural sector for example, whereas hydrological drought shows variably longer relations to impacts on public water supply or energy production. This system complexity challenges the scenario predictions that are needed for planning and they hamper the forecasting that is needed to initiate mitigation measures. Improving on such prediction tasks demands drought impact data. Impact data can help understand systems and allow developing or validating impact models. This contribution synthesizes more than 10 years of efforts of designing and populating multi-sectorial drought impact databases that can serve a number of tasks in drought risk management. The data have shown differences across Europe in terms of impacted sectors, but achieving an unbiased coverage of data based on text-based reports remains a challenge, even when applying automatic webcrawl tools. Impact based prediction experiments show potential for the development of models within fairly similar impact-regions. Modelling outside the range of training data in space or time is more difficult and more systematic data and adapted methods might be required to improve impact-based forecasting.

Monitoring drought indices for decision support concerning the management of cereal productivity in Tunisia

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ABSTRACT

Drought is one of the most worrying climatic phenomena in Tunisia. It has become a reality with direct repercussions on strategic sectors, including cereal production which contributes to the satisfaction of food needs. Drought makes farmers vulnerable, especially smaller ones. Given the stakes: security of cereal supplies, food security, financial difficulties of farmers to get out of the crisis, impacts on the milk and meat sectors and the agro-food sector of basic products, it led to putting in place a national drought insurance "the Fund for Compensation for Agricultural Damage Related to Natural Disasters (FIDAC)" managed by the Tunisian Agricultural Mutual Insurance Fund (CTAMA). Quantified indices are necessary to identify and describe the state of drought, for the choice of subscriptions to agricultural insurance for a cereal farmer, as well as to assess the provisions for an insurer. The study's objectives are to support drought-related agricultural risk management and to strengthen satellite imagery processing capabilities to adapt to this risk. The innovation of the work concerns the assembly of a set of drought indices that can be used by cereal farmers and the drought insurance system in Tunisia. To assess drought, two indices are estimated (1) the standardized precipitation index for the period of 3 months SPI-3 based on long series of precipitation (1950-2019). To identify the severity of drought: duration, intensity, and magnitude which correspond to the positive sum of the SPI for all the months within a drought event are calculated. (2) the water stress coefficient WSC which is the ratio of actual evapotranspiration ET to potential evapotranspiration PET driving from remote sensing sources. MODIS PET and ET data within eight days and 500 m resolutions are applied for 21 years of data (2000-2020). The two indices are compared to field evidence which is the percentage of drought-damaged areas per administrative unity (Imada) published by the National authorities. Results highlight that the SPI-3 reflects only one facet of the drought, the lack of rainfall. Other factors related to soil type and air temperature and crop type are not considered. For the WSC a bias correction method is then used to correct the WSC cumulative distribution. Results show that two thresholds are required to correct WSC maps to assign zero for low levels and one for high levels. In addition, quantile-quantile regression is worth completing WSC map correction. Through the Competitiveness Cluster of Bizerte who bring their expertise in university/industry interfacing, these results were disseminated among operators and the public to create a network of cereal users of these indices and to build the capacity of young and old technicians in drought expertise. Farmers benefit from this innovation upstream for monitoring the campaign and for readjusting the coverage requested and downstream for the recovery of damages.

Keywords: drought, agriculture insurance, SPI-3, water stress coefficient, FIDAC, CTAMA

Serious gaming as a tool for involving local stakeholders in risk management

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ABSTRACT

Serious games are designed to couple the entertainment medium with a serious aim, often related to some kind of educational purpose. Their ability to represent complex scenarios, providing a safe environment in which the players can explore various choices and strategies, together with their ability to engage the participants, make them effective tools in different fields. In particular, serious games can be beneficial for involving stakeholders in participatory decision-making processing, providing a tool for enhancing the discussion, facilitating the common understanding of the issue, and promoting the exchange of each other's views, innovative solutions and social learning. Examples of applications in natural hazards and disaster risk management exist. Here we present the case of APicitJeu, a role-playing game developed to stimulate the discussion about fire risk prevention strategies among local stakeholders of land management. The game is designed to be played by a group of minimum six players under the supervision of a facilitator and it uses the interface of an agent-based model as the game board. The model simulates the ecological dynamics of a hypothetical territory and shows the players the effects of their decisions about forest and pasture management over time, to help them visualize the results of human-environment interactions in a long-time perspective. The stakeholders are asked to exchange their real roles and to recreate the interactions that exist in reality, such as consultations and negotiations, within the protected environment of the game. APicitJeu has been tested in three game sessions organised in a north-western Italian alpine valley during spring 2022. The observation of the sessions confirmed the ability of the game to help the participants share their points of view, and identify and discuss the main local land management issues and strategies for fire prevention, sometimes leading to innovative proposals. Furthermore, the game sessions triggered a positive process among local actors, by raising awareness about the importance of a shared planning strategy. These results prove the value of serious gaming for engaging stakeholders in natural hazards risk management and encourage further research to extend the methodology to other kinds of risk and to address specific issues, such as risk communication and perception.

Keywords: serious gaming; stakeholders engagement

Evolving Early Warnings with the Power of Impact Data

Juhana Hyrkkänen, Finnish Meteorological Institute

The better availability and use of weather impact data has significantly promoted the Early Warning Systems of National Meteorological and Hydrological Services (NMHS). This has remarkably changed the paradigm of forecasting from “what the weather will be” to “what the weather will do.” Instead of focusing solely on describing the weather conditions, it is more effective to anticipate the potential impacts of the weather. End users can gain a clearer understanding of the potential severity of the weather and receive guidance on how to respond accurately.

The evolution of impact-based warnings over the past decade has engaged the entire meteorological community, including organizations like WMO and NMHSs. More recently, impact-based warnings have significantly improved due to the availability of an even larger amount of data from various parts of society, often referred to as 'big data'. Moreover, the implementation of advanced computer techniques like AI and Machine Learning has proven to be even more pivotal in enhancing these warnings.

In addition to discussing the general evolution of weather warnings, this presentation will showcase specific examples that highlight the types of impact-based forecasts and warnings provided by the Finnish Meteorological Institute.

FlomRisk

– user centered design to support impact-based flood warnings

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ABSTRACT

The Norwegian Water Resources and Energy Directorate (NVE) has the national responsibility to manage flood, landslides, and avalanches by way of planning, protection, warning, emergency management and R&D. Since 1995 NVE has assessed the national risk for floods, with daily updates on the webpage varsom.no – and on yr.no in collaboration with the Norwegian Meteorological Institute and the Norwegian Broadcasting Corporation.

As a country with 1748 kilometer from north to south and 400 river basins NVE is limited to assess flood risk on a regional level, which means that our main target groups – local governments and emergency preparedness sector – must translate the regional warnings into potential local impacts.

In line with request by local government and recommendations by the World Meteorological organization NVE started up a 4-year pilot project in 2022 with the aim to develop an impact-based flood warning system. This includes developing a tool enabling local governments and emergency preparedness sector to execute actions at the right level based on the regional warnings. In doing so we have taken a user centered design approach, inviting the local governments in our five pilot municipalities into the process of identifying and developing the solution. The pilots each represent different flood challenges and systems and skillsets of responding to flood.

In collaboration with our five pilot municipalities and the consultant agency Comte Bureau we have embarked on a service design journey. During approximately 6 months, we will investigate, reveal, and understand the user needs, both the visible and underlying needs. We are using different methods (including, but not limited to interviews, workshops, observations, and simulations) to learn from our pilot municipalities, and personnel involved in emergency preparedness. We will continue to co-create with our pilot municipalities and iterate until we have a solution that is based on and developed together with the end-users.

Service design as methodology and a co-creating approach is not only pivotal to innovative processes, but emergency responses are also a unique phycological context were decisions need to be taken at a split second and the potential outcome of a decision or non-decision may have huge consequences. It is crucial that the right person get the right information at the right time in the right way. Thus, to truly understand such situations and what the users need, we must put ourselves in their shoes and invite the users to be a part of the entire process.

Keywords: flood warnings; natural hazards; flooding; avalanches; communication; impact-based warning; service design; user centered approach

Actionable warnings

– a joint effort on how to communicate warnings with one voice

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The Norwegian Meteorological Institutes main task is to help secure life and property. Since 2007 and the launch of the weather service Yr, a collaboration between the Norwegian Broadcasting Corporation (NRK) and the Norwegian Meteorological Institute (MET Norway), the focus has been on communicating weather forecasts digitally on the web page and in our apps. Currently Yr has on average roughly nine million unique users on a weekly basis.

Yr's main goal is to make our users ready for all kinds of weather. Yr provides weather forecasts for about 13 million locations world wide, but weather warnings and warnings about natural hazards are, for the time being, limited to Norway. Although Yr has an exceptional outreach, we strive to be better at communicating severe weather conditions and natural hazards. Yr also provides warnings of natural hazards from The Norwegian Water Resources and Energy Directorate (NVE) and we collaborate on Varsom to offer warnings on sms or e-mail tailored to the emergency response actors or the public in general. Last year we expanded our collaboration with a joint effort on how to communicate warnings with one voice. Our common goal is that warnings are not only understood, but they are acted on. The question is, do we provide our users with the right skillset to do so?

Each year you hear about tourists that have put themselves in danger by skiing a mountain where avalanches might occur, or just by visiting one of the many tourist attractions in Norway and not being prepared. For some of them, the outcome has been deadly. We have also had accidents where children have been injured or died. All deaths are tragic, and we need to ensure that warnings from Yr and Varsom are received, understood and acted upon, so that we can prevent accidents.

One of the conclusions in our pre-study was that we do not know enough about how users relate to warnings and what they do to prevent potential accidents or damages. We also realized that we don't have the expertise to analyze what users act upon (behavioral psychology) and we have little resources on service design. To achieve that we decided to apply for a governmental funding initiative to support projects in public innovation, called Stimulab. Stimulab granted us the support and helped us to find the consulting agencies that we partnered up with, Halogen, Agenda Kaupang and Knowit. The consulting agencies, led by Halogen, have worked together with us on this project that began last year and lasts throughout this year.

We know from experience that visual communication and clear language are key ingredients for a message to reach the public. Our outreach is exceptional and diverse, both in our services and in social and traditional media. Both MET Norway and NVE have made changes to how weather warnings are communicated, the focus has shifted from solely describing the weather or natural hazard to enhancing possible consequences for the end-user. The change is good, but we now have to master the way we communicate it.

Keywords: weather warnings; natural hazards; heavy rainfall; wildfires; flooding; avalanches; landslides; icing (wessels and installations); snow; communication

Safe rivers – is it possible – or not?

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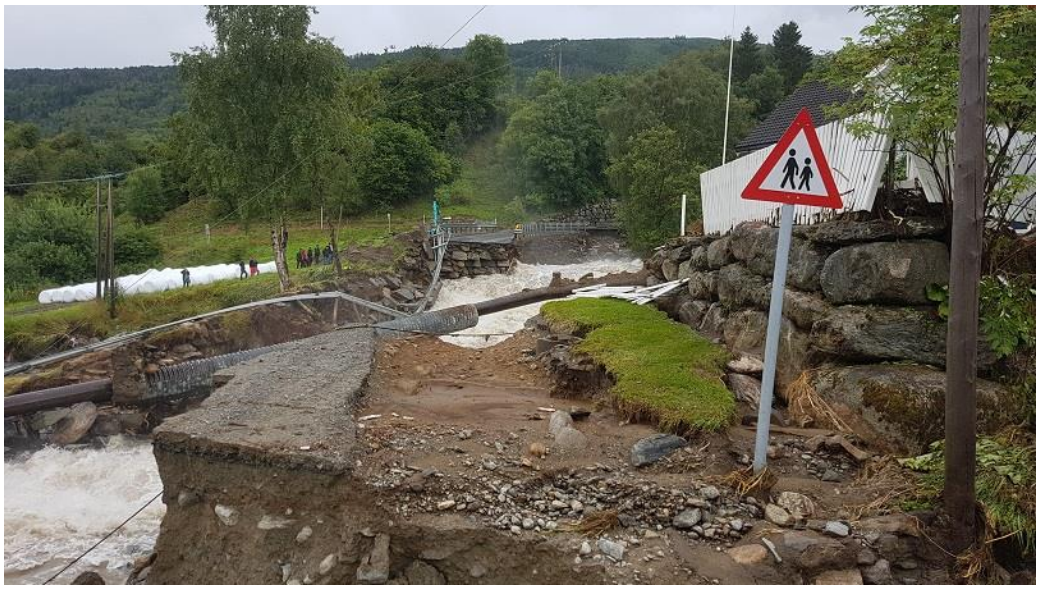
ABSTRACT

Over the last decades we have experienced severe and disastrous consequences of hydrological extremes. Floods and landslides that have caused loss of many lives, enormous damages of properties and infrastructure and huge personal and societal costs.
"Hans" is the most recent extreme event in Norway, but in the last few years we have experienced several local flash flood events that have not been as well predicted and prepared for "Hans". Is it at all possible to protect ourselves against these?
Do we have the tool to predict the cause and consequence of extremely local and intense flash floods? If we have a precise meteorological forecast our hydrological models are able to tell us that we will get a flood in the rivers in the region on green, yellow or red level. As most of our rivers do not have gauged timeseries the size of the flood must be related to the closest monitored river which usually is one of the larger rivers in the region. A river that probably not at all will respond to a local rain event. So even if we had precise local meteorological forecasts of extreme rain events would we be able to transform these into a specific warning at yellow or red level for small, ungauged rivers? In that case we have solved the cause issue, but it is not enough to tell that we know something will happen if we do not know where it will cause problems. The majority of Norwegian municipalities neither have the experience nor the tools to know what the consequences might be. Our hydrological models might tell us how many m3/s we can expect, but not if this causes serious flooding somewhere or high water velocities eroding away roads or houses or rivers taking new direction. It does not tell the municipalities where they should focus their efforts before and during the event.
Consequence based warnings are a step in the right direction, and we need to both develop the competency to understand the consequences and the tools to predict were, what and when they are likely to get challenges and finally how to communicate this to those that have to make the right decisions "on the fly"."



Mitigation measure manual

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ABSTRACT

The mitigation measure manual is a digital manual about structural measures to mitigate natural hazards. It is called "sikringshåndboka" in Norwegian and is available on https://sikringshandboka.nve.no/. The manual contains three natural hazard topics: "flood and erosion", "quick clay landslides", and "landslides, rockfalls and snow avalanches". The objective of the mitigation manual is to compile existing knowledge and to provide advice during the whole process of establishing a mitigation measure including the four phases: i) planning, ii) design, iii) construction and iv) management, operation and maintenance. Consequently, the manual will contribute to reduce risk from natural hazards.

The main motivation to create the mitigation measure manual was intergenerational knowledge transfer. The project should collect and share practical experience with flood mitigation and erosion protection within the Norwegian Water Resources and Energy Directorate. Furthermore, the knowledge should be shared with the public to build capacity within natural hazard mitigation. In a further step, the topics for quick clay landslides and landslides on steep slopes, i.e., landslides, rockfalls and snow avalanches, were added.

The content of the manual is organized in modules. Each module describes a distinct task. Related modules are linked to facilitate efficient navigation within the manual. Special focus was paid to figures and videos. The figures are a mixture between technical drawings and sketches. This concept shall ease the understanding for more different users e.g., engineers as well as municipal employees or landowners. Figure 1 shows an example of an isometric figure about flood hazard. Furthermore, typical contractor operations are published as short practical videos e.g., an excavator placing stones in an interlocking pattern to protect a riverbank against erosion (available on https://youtu.be/96p6vqy2i8s).

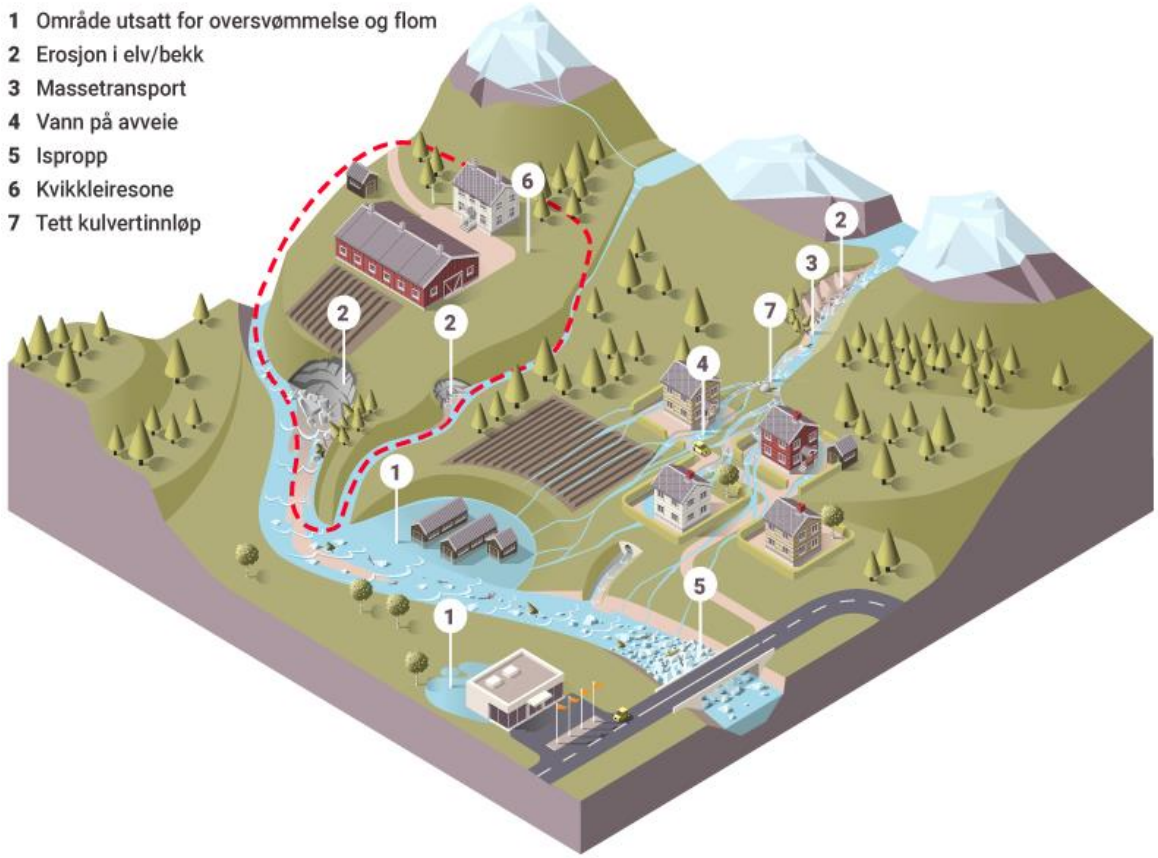

Figure 1: Isometrical figure showing possible challenges with flood and erosion: 1) Inundation and flooding, 2) erosion, 3) mass transport, 4) water out of riverbed, 5) ice run plug, 6) erosion at a quick clay zone, 7) clogged culvert inlet.

The topic "flood and erosion" was published in 2021. The remaining topics on "quick clay landslides" and "landslides, rock falls and snow avalanches" are scheduled launched in autumn 2023. The digital format as well as the organization in modules will ease adding additional modules also after the launch. Possible extensions are e.g., within natural based solutions or novel mitigation techniques.

Keywords: mitigation measure; flood; landslides

Floods during the last millennium – what are the trends and how exceptional was the Storofsen flood in 1789 ?

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ABSTRACT

Floods are natural disasters that destroy infrastructure and sometimes claim human lives. Future flood events are predicted to become larger and more frequent. To plan for the future, it is valuable to have knowledge about the past. The largest known flood occurring in Norway during historical time is the infamous Storofsen in late July, 1789. In this study we investigated the hydrometeorological conditions creating Storofsen and placed this extraordinary event into the context where the evolution of floods during three historical time periods: Medieval Warm Period (MWP), Little Ice Age (LIA) and Industrial Time (IT) is analyzed. This study focus on two catchments in south-eastern Norway (Lam and Elverum) where the 1789-flood caused large impacts and the actual flood levels are known. The hydrological modelling framework Shyft was used to simulate discharge and key water balance components. Paleo climate output from the Norwegian Earth System Model (NorESM1-F) for the three period MWP, LIA and IT was used as model forcings to establish a dataset of simulated floods from the past millennium. The same model was used to establish precipitation events capable reproduce Storofsen. The results show that (i) there are slightly higher and more frequent floods during the LIA as compared to MWP and IT (ii) the flood seasonality is consistent for all three periods, where the annual maximum floods occur in May/June at Lalm and May at Elverum. Furthermore, none of the simulated floods occurred in late July, confirming that the Storofsen flood was exceptional. Several of the simulated floods exceeded the Storofsen flood with up to 100% within each of the periods, however, we believe that these simulated peaks are unrealistic. Peak mean precipitation required to cause a simulated flood with the magnitude of Storofsen was found to be 612 and 93.6 mm/day for Lalm and Elverum, respectively.

Keywords: flood; paleo climate; Shyft

Handling and mitigation of a Flood Event - Before, during and after

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Voss is located in the westcoast of Norway. Challenges linked to a wetter and wilder climate have already reached the area, and you will be given an insight into how the local authorities manage before, during, and after a flood event. Flood protection is complicated and possible solutions generate a lot of conflict of interest the municipality must deal with.

ABSTRACTS
POSTERE

Benchmarking multiple hydrology models at seventy catchments in southern Norway – work in progress

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ABSTRACT

Hydrological models are mathematical representations of the water cycle, primarily focusing on the land surface. They include processes of precipitation, snow, infiltration, evaporation, runoff, and more. The models are used to understand and predict the movement of water through the Earth's surface and subsurface, as well as to evaluate the impacts of land use, climate change, and other factors impacting the availability of water resources. In the hydropower industry, hydrological models have been used for decades to predict and forecast both mountain snowpacks and reservoir inflow. This is typically done by forcing the models with historical records and future weather data. The inflow forecasts are commonly used to optimize water usage for hydropower production but can also be used to evaluate different flood mitigating measures.

During the last sixty years or so, a huge number of different models have been presented in the hydrologic research literature. For practitioners as well as researchers it is a challenge to choose which models to use in different settings. One way to come around this challenge is to try out multiple models and measure the performance quantitively.

In this research, we have applied three different hydrological models in multiple configurations to seventy catchments in southern Norway. The first model is the Statkraft Hydrology Forecasting Toolbox (SHyFT), a distributed model that can be run in four different process configurations. The second model is the Neural Hydrology LSTM neural network models (NH-LSTM) developed by F. Kratzert and co-workers. The last model is the Distributed Regression hydrological Model (DRM), developed by Matheussen at Å Energi. This model combines a classical distributed hydrological model and an LSTM neural network.

The data used to calibrate and validate the hydrological models in this work comes from several sources and includes daily values of air temperature, precipitation, wind speed, relative humidity, and observed streamflow. It also has different sources of soil, land use, and terrain data. Open datasets from Unites States (CAMELS), Norway (The Norwegian Water Resources and Energy Directorate (nve.no) and The Norwegian Meteorological Institute (met.no)), EU (ECMWF-ERA5), along with internal datasets from Å Energi are used in this study.

In this research, a total of four experiments were conducted. For each experiment the historical data were split into a calibration and a validation period. The models were then calibrated using the Nash-Sutcliffe Efficiency (NSE) and the Kling-Gupta-Efficiency (KGE). After this, a benchmark of the different model's performances was carried out.

The initial results indicate that the SHyFT model performs better than the others. Further testing is ongoing, and the results will be presented at the conference.

Keywords: hydrology, benchmark, machine learning, conceptual, physical

A data-driven model for Fennoscandian wildfire danger

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ABSTRACT

Wildfires are natural phenomena that pose a threat to humans and contribute to considerable carbon and methane emissions. Mapping of wildfire danger at national and international levels are typically based on traditional fire danger indices that use meteorological data as input, such as the Canadian forest fire weather index (FWI). Today's plethora of available data sets allow for direct investigations of which combination of absolute and relative states of hydrometeorological variables are most important for fire occurrences over large regions. We employ a data-driven approach (primarily using the Random Forest algorithm) to identify dominant natural predictors for month-to-month wildfire occurrences across Fennoscandia. This region has received little attention in the fire literature, compared to other boreal regions and more fire-prone regions further south. Shallow volumetric soil water anomaly stood out as the dominant predictor, followed by predictors related to temperature and deep volumetric soil water. The selected predictors emphasise the importance of other predictors than weather alone. The final model showed similar fire danger prediction capability as FWI, illustrating the potential of data-driven models to be used jointly with process-based approaches, in order to evaluate the agreement and spread among different types of models. The predictors used in our study are available in most climate models and transferable to different climate scenarios. Accordingly, our model allows for analyses of future changes in fire occurrence characteristics.

Keywords: wildfire; data-driven model; machine-learning; Fennoscandia

The EMERGE project
Multi-hazards and emergent risks in Northern Europe's remote and vulnerable regions

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ABSTRACT

The EMERGE project, funded by the Natural Environment Research Council (NERC), has formed a new partnership across northern Europe in the last 2 years, between the University of Strathclyde, the Icelandic Meteorological Office, the Norwegian Water Resources and Energy Directorate, the British Geological Survey, Newcastle University and the Scottish Environment Protection Agency, by bringing together experts to explore the interaction of hazards (in particular rainfall, landslides and floods) and their emergent risks in remote regions with low density population and limited transport links and supply chains.

We have organized four workshops. The first workshop was conducted virtually in February 2022. The following workshops were organized in Oslo, Norway in May 2022, in Glasgow, Scotland in March 2023 and finally a workshop in Reykjavík, Iceland in May 2023. All were attended by representants of local communities and local stakeholders with whom we discussed their unique challenges in remote regions and the main natural hazards affecting them.

The unique challenges posed by compounding risks of weather-driven natural hazards in remote regions, the latest science in remote areas, and the key science, observational, prediction and monitoring gaps were themes discussed across all workshops. In the Oslo workshop we discussed warning service and warning communication, challenges in local response and assistance, and the role of research, monitoring and data collection in hazard prevention. Remote resilience, the science and policy developments needed to face the challenge of interacting natural hazards in a warming climate, warning and response were also key themes at the Glasgow workshop. During the Reykjavik workshop we discussed the challenge of issuing timely and meaningful warnings to the public about natural hazards, including the needs of the tourism sector, and the close working relationships between government monitoring agencies, first-responders, and educational institutes.

Herein will be presented some of the main outcomes from the workshops as well some of the experiences of remote and rural communities in Norway, Scotland and Iceland.

The outputs from EMERGE project will form the basis of a new forum that fosters open scientific collaboration, knowledge brokering and information sharing relating to extreme events, and identify the needs and opportunities specific to remote regions across northern Europe.

Keywords: remote areas, compounding risks, emergent hazard

From climate projections to guidelines on climate change allowances

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ABSTRACT

For several years, climate change allowances ("klimapåslag", in Norwegian) for heavy precipitation, floods, and storm surges have been communicated to a technical audience through climate factsheets ("klimaprofiler", in Norwegian). According to the general guidelines issued by the Norwegian Centre for Climate Services (NCCS), a climate change allowance states how much the current design value should be increased to account for future climate change. The resulting climate-adjusted values are used as a tool in risk assessments and planning. Climate change allowances for heavy rainfall are issued for different durations and return values, whereas climate change allowances for floods distinguish between the flood-generating process. These climate change allowances are derived from projections for 2071–2100 relative to the reference period 1971–2000 and are therefore valid for the end of this century.

Based on evaluation from practitioners at different workshops, NCCS has been made aware that more guidance is needed to help users translate the knowledge base into action. Guidance on the use of climate change allowances is available on a national and regional basis but is also requested on local scales. Since the time periods used to calculate the climate change allowances are fixed, some users inquire about the use of climate change allowances for a shorter time frame. In special cases, the observed climate has already experienced marked increases to an order of magnitude that is similar to the climate change allowance. In this case, users have asked whether this could be accounted for by using a smaller climate change allowance. Practical examples on use are also requested.

During the coming years, NCCS will update the report Climate in Norway 2100 and issue accompanying climate change allowances. This poster will outline recommendations on what new guidelines on climate change allowances should include, both in general and specifically for floods and heavy precipitation. Recommendations will be based on scientific developments on projected heavy rainfall and flood magnitudes, bridged with user needs stated at various stakeholder workshops organized by NCCS.

Keywords: Climate change adaptation; Climate change allowance

Return values for extreme precipitation in Norway - a comparison of estimates from a new approach combining ensemble data and gridded observations to PMP values

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ABSTRACT

The occurrence of extreme precipitation events causing surface water excess and flooding is becoming an increasing societal expense due to the rise in precipitation levels. It is therefore crucial to understand and get better knowledge about extreme precipitation events to predict their likelihood and frequency, as well as to estimate design values for critical infrastructure and constructions.

Analysis of extreme precipitation events requires long timeseries, which can be challenging using conventional or relatively short observational data records. To increase the event sample size we have applied a data set from the numerical seasonal prediction system SEAS5 at ECMWF. The data were fitted to a GEV-distribution and compared to an equivalent GEV-distribution for the gridded observational data set SeNorge. A method to estimate return values by combining the two datasets, taking advantage of the large sample size from SEAS5 and the spatial distribution from SeNorge is proposed. By using a normalized "growth curve" from both data sets and the location parameter from SeNorge the correct level of the frequency curve for short return periods is determined.

An additional correction to the scale parameter was employed to ensure appropriate levels of the curve for return values at longer return periods, based on a spatial adjustment factor.

The resulting return value estimates are considered to be more robust than previous calculated estimates, due to the inherited small confidence interval from SEAS5. We compare the new estimates of long return period values with existing values for PMP (Probable Maximum Precipitation), where we also evaluate the spatial variability of the traditional method for PMP values, which are point estimates, to the new spatially consistent approach.

Keywords: precipitation; desing values; long return periods

Enabling the comparison of high-resolution precipitation observations with numerical weather prediction model simulations at every model time-step

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Precipitation characteristics are expected to change in the future as a consequence of global climate change. For example, high-intensity precipitation is expected to become more frequent in some areas of the world. The short time scales and small spatial scales of intense precipitation events pose challenges for numerical weather prediction (NWP) models. Measurements of precipitation characteristics from in-situ and remote sensing instrumentation are often available at much higher time resolution than common NWP model output, and need to be aggregated for validation studies. Here we present a methodology to enable the comparison of precipitation observations and model output at the time scale of the model time steps. Our analysis is focused on an extreme, convective precipitation event during 30th July 2019 in Bergen, Norway (60.38ºN, 5.33ºE, 12 m a.s.l.). We use high-resolution measurements of precipitation characteristics from a Micro Rain Radar Metek MRR-2, an Ott Parsivel2 Disdrometer, and a TPS-3100 Hotplate Pluviometer. Model precipitation was extracted from the operational NWP model MetCoOp that uses a horizontal grid spacing of 2.5 km and 65 vertical levels as part of the HARMONIE AROME model configuration. Using DDH (Diagnostics par Domaines Horizontaux), a novel tool for extracting prognostic variables from the model at a time-step resolution, we extracted a detailed dataset from a NWP model reforecast at every time step (75s), for a 62.5 by 62.5 km subdomain centred around the measurement site. We characterised precipitation by investigating five parameters, namely rain rate, liquid water content, mean volume diameter, the normalised intercept parameter, and terminal fall velocity. The newly developed methodology enabled a direct comparison of the observed precipitation characteristics with corresponding parameters from the model prediction for the convective rainfall event. Despite a generally reasonable correspondence between all parameters in the model and observations, the model struggled with underestimation of rainfall intensity during the high-intensity periods. The onset and intensity of precipitation depended strongly on location for the investigated event. Higher time resolution provided more detailed insight into intensity, timing and spatial variability of the modelled precipitation compared to the more commonly used hourly interval. Our new methodology can be easily applied to other precipitation events, such as frontal rainfall events, and thus provide process-level understanding of precipitation characteristics simulated by high-resolution NWP models.