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ABSTRACTS

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Session 1: Diagnosing Land-atmosphere interactions

Lessons learned from over two decades of international land surface model inter-comparison projects

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Land surface models (LSMs) were originally implemented in numerical weather prediction (NWP) models to provide interactive lower boundary conditions for atmospheric radiation and turbulence schemes, therefore they compute the fluxes of heat, mass and momentum between the land and the atmosphere for a wide range in surface cover types and climate conditions. The LSM treats unresolved scale-dependent processes as a function of some grid-average state variable though a combination of conceptual models, empirical relationships, theory and fundamental mathematical laws. In the past two decades, LSMs have evolved considerably to include more physical processes in order to meet the growing demands of both the research and the user communities. Processes such as photosynthesis and the associated Carbon fluxes, aerosol emissions, soil moisture prediction (estimate of drought severity, initial values for flash flood prediction), vegetation phenology (biomass evolution, net primary production), bio-geochemistry, surface lateral runoff and exchanges with ground water, atmosphere-lake exchanges, snow pack dynamics, anthropization (irrigated surfaces), and near surface urban meteorology. In the face of climate change, improved simulations by earth system models are needed to better understand the potential feed-backs for both mitigation and adaptation strategies to be developed for society, since such model simulations are the basis for the reports by the Inter-governmental Panel on Climate Change. A part of the needed improvements resides in obtaining a better understanding of which land surface and hydrological processes have potentially the largest feedback with the atmosphere, and the nature of the coupling itself.

Many studies over the past few decades using individual models (coupled NWP and global climate models-GCMs) have found sensitivity to the land surface, but the lack of evaluation using observations and inter-comparison among models hindered model developments. In response, land surface inter-comparison projects (LSMIPs) were initiated with the main goal of incorporating more realistic land surface process representation into GCM and NWP models in order to improve prediction skill. There have been a significant number of international land surface inter-comparison projects, most of which have operated under the auspices of the Global Energy and Water Exchanges (GEWEX) project, which is supported by the World Climate Research Programme (WCRP) within the World Meteorological Organization (WMO). These projects have been run in offline mode (i.e. decoupled from an atmospheric model), mainly in order to avoid the additional complexity of including the feed-backs with the atmosphere. Model parameterization development has greatly benefited in the past two decades from these international collaborative efforts. Also, when forced using a blend of observational and model output data as (input) time varying boundary conditions, LSM simulations form a type of multi-model analysis providing the best estimates of the fluxes and state variables. Such ensembles can provide a measure of LSM uncertainty, and they have also been used in seasonal climate forecast experiments which highlighted the importance of certain land surface variables on prediction (notably soil moisture). The model paradigm of spatially distributed LSMIPs is now used as the basis for multiple operational applications. Finally, the recent projects are focusing on using benchmarking to address what one can expect from models and data sets.

In this talk, I will focus on the science highlights of the offline-LSMIPs, present some of the applications of simulations from such projects, and discuss possible future avenues in order to keep up the great progress made over the last two decades.

Understanding land/atmosphere interactions through the DIurnal land/ atmosphere Coupling Experiment (DICE)

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Results from the GLACE experiment highlighted the areas of the globe that were "hotspots" for land/atmosphere coupling, with stronger coupling strength between soil moisture and precipitation. However, the results from this experiment also showed that there was wide variation in the strength of coupling at the hotspot regions between the participating models. Further analysis following the protocol of the GLACE experiment suggested that interactions between the atmospheric parametrisations were responsible the land/atmosphere coupling strength in some models, but our understanding of these interactions within models is limited.

DICE is an international experiment designed to identify and understand the interactions and feedbacks between the land and atmospheric boundary layer. The GABLS2 (CASES99) experiment has been re-visited, but with the land surface community included within the analysis. This has allowed a multi-stage project whereby the sensitivity characteristics of each component (land and atmosphere) can be assessed and compared with the characteristics of the coupled simulations.

In this presentation we will give details of the protocol used in the experiment, including the justification for each of the stages. Results from the experiment will be presented along with conclusions about characteristics of the integrated system responsible for the coupling strength in the models. These results give a first indication of the difference between the models that could help to understand the differences in coupling strength seen in the results from GLACE.

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No snow or too much snow: implications for the arctic carbon cycle and modelling challenges

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The presence or absence of snow plays an important role in the carbon cycle at high latitudes. Snow covers the landscape for the majority of the year in the Arctic, and changes in the duration and thickness of snow cover can have a lasting impact on the vegetation and ground beneath it. This talk will highlight two such examples from the field, and will discuss the challenges these entail for modelling land-atmosphere interactions and hydrology at high latitudes. The first case study is from a peatland in Northern Norway, where a warming event in mid-winter melted away the protective snow cover, exposing vegetation to subsequent frost events. This led to vegetation damage that affected vegetation productivity in the following summer – reducing the uptake of CO_2 from the atmosphere. The second case study is from high-Arctic Svalbard, where a snow fence experiment has been in place for more than 10 years to increase snow cover during winter. The thicker snow pack insolated the soil from cold winter air, which led to the thawing of an ice-wedge. Dramatically, this caused extensive gully erosion immediately downstream from the snow fence, and led to remobilization of soil carbon. This talk highlights the significant challenges to the modelling community in simulating accurate snow cover and surface hydrology to forecast the development of the arctic carbon cycle and associated climate feedbacks.

Carbon and soil moisture interactions – the Mocabors project

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The feedbacks between climate and the turnover of carbon are strongly dependent on the hydrological cycle. Current Earth System Models (ESMs) do not reproduce these relationships well when precipitation is used to estimate carbon accumulation, presumably due to an inappropriate representation of soil moisture. The mismatch is higher at higher spatial resolution.

The project *Moisture dynamics and carbon sequestration in boreal soils* (Mocabors), funded by the Norwegian Research Council (Klimaforsk; 2016-2020) addresses this specific knowledge gap: the significance of soil moisture in the boreal forest for forest soil C dynamics.

Performing continuous measurements of local soil climate and respiration as well as using a range of modelling approaches at different scales, the project will a) quantify key greenhouse gas fluxes at the soil surface along a soil moisture gradient in order to relate gas fluxes to monitored and modelled soil moisture, b) use extensive National Forest Inventory (NFI) data as well as high resolution map data to improve soil moisture representation at spatial scales appropriate for ESM modelling; c) evaluate the performance of sub-models for soil carbon dynamics as used in ESMs under different soil moisture conditions, and d) combine spatial hydrology maps and soil C dynamics models to predict landscape-scale soil carbon fluxes and their sensitivity to climate.

The contribution describes the site selection, measurement setup and modelling approaches in detail. It will also establish a link to the first flux tower in a forest ecosystem at Lake Hurdal, a part of the Integrated Carbon Observations System (ICOS), as Mocabors uses the location as one of the field sites. An outlook on the model improvements and products from the project will be given as well.

Coupled and uncoupled atmosphere - land surface modelling involving vegetation, permafrost and snow surfaces

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Climate change is impacting the high latitudes more rapidly and significantly than any other region of the Earth because of feedback processes between the atmosphere and the underlying surface. A warmer climate has already led to thawing of permafrost, reduced snow cover and a longer growing season; changes, which in turn influence the atmospheric circulation and the hydrological cycle. Land-Atmosphere Interactions in Cold Environments (LATICE) is a priority research project by the Faculty of Mathematics and Natural Sciences at the University of Oslo. LATICE aims to advance the knowledge base concerning land atmosphere interactions and their role in controlling climate variability and climate change at high northern latitudes through improving parameterizations of processes in earth system models, assessing the influence of climate and land cover changes on water and energy fluxes, integrating remote earth observations with in-situ data and suitable models to allow studies of finer-scale processes governing land-atmosphere interactions, and addressing observational challenges through the development of novel observational products and networks. While the Norwegian Earth System Model (NorESM) is a key tool at the global scale, models at finer scales are crucial to resolve sensitivities within feedback cycles, namely the Weather Research and Forecasting (WRF) model as well as models of hydrology, cryosphere and permafrost systems. Land surface schemes are applied in conjunction with observational analysis, both in an off-line mode and as part of coupled model systems. Improvements will be actively fed back to the core development of NorESM.

Increased shrub and tree cover in high latitudes is an observed response to climate change that can lead to positive feedbacks to the regional climate. We have evaluated the sensitivity of the near surface atmosphere to a potential increase in shrub and tree cover in the northern Fennoscandia region. We applied the Weather Research and Forecasting model (WRF) in evaluating biophysical effects of increased shrub cover on the near surface atmosphere on a fine resolution. Perturbation experiments are performed in which we prescribe a gradual increase of vegetation height in the alpine shrub and tree cover according to empirically established bioclimatic zones within the study region. We focus on the spring and summer atmospheric response. To evaluate the sensitivity of the atmospheric response to inter-annual variability in climate, simulations were conducted for two contrasting years, one warm and one cold year. We find that shrub and tree cover increase leads to a general increase in near surface temperatures with the highest influence seen during the snow melting season, and a more moderate effect during summer. We map and model distributions of selected nature types and use these models for projecting nature-type distributions to different climate change scenarios. Dynamic vegetation modelling has been started, on global (NorESM) and regional (WRF) scales.

Identifying feedbacks between the land surface and the atmosphere in a seasonally snow covered region (Southern Norway)

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Snowmelt influences the energy balance by changing the albedo (the direct effect of snow). It further influences the water balance by changing soil moisture and evapotranspiration, and the partitioning between latent and sensible heat fluxes (the indirect snow hydrological effect). In two previous studies, we identified Southern Norway as a region where significant temperature changes in April and in summer could potentially be explained by land–atmosphere feedbacks. We hypothesise that early spring melting influences the surface energy and water balance directly through the snow–albedo feedback, and indirectly through a soil moisture limitation on evapotranspiration. In Norway, evapotranspiration is energy limited, rather than soil moisture limited, under normal conditions. However, during warm and dry summers, evapotranspiration may be restricted by the available soil moisture. In this study, we assess the soil moisture–temperature coupling in Southern Norway for a warm and dry summer (2006) and a warm summer with normal rainfall (2014). Using the Weather Research and Forecasting (WRF) model we replace the initial ground conditions for 2014 with conditions representative of a snow-poor spring and a snow-rich spring. WRF coupled to Noah-MP was run from mid-May through September at 3 km horizontal resolution in the inner domain. Boundary conditions used to force WRF were taken from the Era-Interim reanalysis. In the WRF perturbations, the direct effects of snow on temperature and other variables was apparent during melting, but indirect effects through soil moisture limitation could not be recognised after the melt-off date. After melting, correlations between modelled soil moisture and surface heat fluxes indicated coupling between the ground and surface heat fluxes (i.e., the terrestrial leg of land–atmosphere coupling), but correlations between surface heat fluxes and temperature (i.e., the atmospheric leg of land–atmosphere coupling) did not, even for the warmest and/or driest parts of the model run. Temperature, evaporation and soil moisture deficit data from a 1x1 km gridded dataset (SeNorge) were used to assess the coupling strength between the land surface and atmosphere. In SeNorge, temperatures are interpolated from observations, whereas other hydrological variables are modelled using the Gridded Water Balance model (GWB) by the Norwegian Water Resources and Energy Directorate. Contrary to model results, preliminary correlation analyses of SeNorge data show wide-spread land–atmosphere coupling for several periods during the 2014 and 2006 summers. The next steps will look into this discrepancy between results from WRF and SeNorge. This study contributes to a greater understanding of land–atmosphere interactions in a wet, temperate climate with seasonal snow cover, in particular the role of soil moisture, and its feedback to the atmosphere.

Solving the surface energy balance: the quality of model estimates of downward radiation and near surface humidity for mainland Norway

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Solar radiation is the exogenous energy provider to Earth. At middle and higher latitudes, surface downward longwave radiation is an equally important radiative driver at the surface. Hydrological and ecological modeling practices are shifting towards including a physically based estimate of the surface energy balance to provide better and more robust estimates of evaporation and snowmelt in a changing climate. This requires high quality estimates of radiation and near surface humidity. This study compares freely available model estimates of daily surface downward shortwave [SW] and longwave radiation [LW], and 2-meter humidity (vapor pressure [VP]) with surface observations between 1982 and 2000. Coarse resolution estimates from the reanalysis dataset MERRA2, the bias-corrected reanalysis data, WATCH Forcing Data methodology applied to ERA-Interim [WFDEI] and The Princeton Global Meteorological Forcing Dataset, version 2 [PGFv2] are compared with two versions of fine scale (1x1 km) empirical estimates based solely on maximum and minimum 2-meter temperature and precipitation (VIC Type Forcing Data [VFD]). Additional hybrid estimates are developed for humidity and longwave radiation, consolidating the WFD humidity and longwave estimates with the daily SeNorge 2-meter temperature [HySN].

In the evaluation of humidity, observations from 91 surface stations are used. By employing quality control routines to observations from agricultural stations, the University of Bergen, and MET Norway observations, time series from in total 11 stations are included in the SW validation. Meanwhile, only two stations have observations of LW radiation, and both are near the coast. We find that the PGFv2 and VFD show a very good correlation at a monthly time scale, but on a daily basis the estimates show lower correlation scores and less variability than observed. The WFDEI and MERRA2 datasets have the highest daily correlation scores. The MERRA2 data does, however, show rather large biases in the radiation estimates. The HySNestimates have the smallest bias in LW and VP, followed closely by the WFDEI estimates. The WFDEI SW estimates are nearly unbiased. For some of the models their skills in estimating SW or VP are regionally dependent. The MERRA2 VP estimates show a weak latitudinal dependence in their bias. The two versions of VFD estimates differ in their biases, and one version shows a bias in SW strongly dependent on altitude and continentality.

Reproduce October 2014 Flood at a small basin in Voss, Western Norway by a fully coupled atmosphere-hydrological modelling system

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During the last week of October 2014, western Norway suffered major flooding after 4 days of intense rainfall. Voss was one of the main villages, which were severely affected. A large amount of rain saturated the soil and caused severe flooding, which destructed houses, bridges and roads. In Odda houses were flushed out into the roaring river and people in villages on the west coast were isolated for days. The impact of the heavy rainfall and the flooding resulted in damage of hundreds of millions Norwegian kroner.

In this study, we applied a fully coupled WRF-Hydro modelling system at a well-monitored small basin in Voss to reproduce this flood event. Due to the traditional separation of hydrological and atmospheric modelling communities, significant gaps exist in our knowledge of the full-chain responses to hydrometeorological extremes, from circulation/transport to discharge. The WRF-Hydro modelling system is a community-based model-coupling framework designed to link multi-scale process models of the atmosphere and terrestrial hydrology, which have been developed to address these gaps (Gochis et al., 2014). The objectives of this study are (1) to understand the meteorological and hydrological dynamical processes that led to this extreme event; (2) to explore the fluxes circulation between atmosphere and land surface by comparing the fully coupled WRF-Hydro mode with the offline WRF-Hydro mode (WRF-only). In order to fulfill the requirement of the complex orography at western Norway, it is downscaled to convection permitting scales at 3 km in a nested domain. Prior to performing the fully coupled WRF-Hydro, the offline WRF-Hydro was calibrated and validated by observed streamflow data. The simulations with/without spectral nudging under the coupled/uncoupled model system have also been discussed. The performance of quantitative precipitation estimates and hydrological forecast products were further analyzed. At the end, we compared precipitation, runoff, soil moisture and land surface heat fluxes between the offline (WRF only) and coupled WRF-Hydro simulations.

Session 2: Integration of earth observation for improved forecasting and impact modelling

Assimilation of snow observations for numerical weather prediction

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Land surface represents a key component of the Earth System. It constitutes the bottom boundary conditions of the atmosphere, and processes that occur at the land-atmosphere interface control the surface branch of the continental hydrological cycle. Land surface processes are represented in weather forecasting models using coupled land-surface-atmosphere models. Initialization of the land surface models conditions is crucial to ensure accurate forecast of surface and near surface weather conditions. It is also the basis of a large range of applications related to water management, flood forecast and drought prediction. Current land data assimilation systems used to initialise NWP models include snow depth analysis, soil moisture analysis, soil temperature and snow temperature analysis.

This paper presents an overview of snow data assimilation for numerical weather prediction. We describe the various snow observations used in NWP systems, including conventional in situ snow depth observations and satellite snow cover. Based on the European Centre for Medium-Range Weather Forecast experience, a snow data assimilation method based on an Optimal Interpolation approach is presented. Using the ECMWF Integrated Forecasting System snow data assimilation impact is evaluated for different configurations of the snow data assimilation system and for different observation types. Results and impact on snow fields and weather forecast performance are presented and discussed. Both surface fields and low-level atmospheric variables are shown to be highly sensitive to the snow initialisation methods.

Ensemble-based subgrid snow data assimilation

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Snow, with high albedo, low thermal conductivity and water storing capacity and low thermal conductivity, strongly modulates the thermal state of the underlying ground in addition to the surface energy and water balance. At the same time, the estimation of the evolution of the seasonal snowpack at the kilometer scale is a major hydrometeorological challenge and thus represents a significant source of uncertainty in land surface schemes. To constrain this uncertainty we are developing a modular ensemble-based subgrid snow data assimilation framework (ESSDA) for satellite-era subgrid snow depth distribution (SSD) reanalyses.

Our frameworks makes use of the ensemble smoother with multilple data assimilation (ES-MDA) to assimilate MODIS and Sentinel 2 fractional snow covered area (fSCA) retrievals into the subgrid snow distribution submodel (SSNOWD). The problem is particularly challenging given that many of the parameters we are updating are bounded in physical space. As such, we also employ the technique of analytical Gaussian anamorphosis and perform the analysis in a transformed space.

The potential of the framework is presented through both synthetic (twin) and real experiments. The latter are carried out for the Bayelva catchment near Ny Ålelsund (79°N, Svalbard, Norway) where independent and accurate ground-based observations of snow cover and snow depth distributions are available. Our evaluation demonstrates that ESSDA provides robust estimates of the evolution of the SSD over a six year long validation period. The use of GA, and our emphasis on the SSD, is what sets ESSDA apart from previously proposed snow reanalysis frameworks. ESSDA is being developed to aid in satellite-based permafrost mapping efforts. Nonetheless, being modular and given the improvements in the data assimilation, the ESSDA approach may also prove valuable for broader hydrometeorological reanalysis and forecast initialization efforts.

Assimilation of SMOS and SMAP Brightness Temperature into a Land Surface Model over Northern Latitudes

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Assimilation of surface soil moisture retrievals from satellite sensors has shown to improve estimates of surface and root zone soil moisture. However, satellite soil moisture and modelled soil moisture often show significant biases. An important source of bias is the use of inconsistent parameters and dynamic fields as input to the retrieval model and data assimilation system. Assimilation of passive microwave brightness temperatures are expected to improve the estimates of land surface conditions, as this will: 1) ensure that a consistent set of parameters and fields are used for the retrieval and the land surface modelling; 2) be a step towards operational land surface data assimilation, which will benefit the numerical weather prediction and hydrological prediction community.

In this study we assimilate multi-angle dual polarization brightness temperature (Tb) observations at the bottom of the atmosphere from the L-band Soil Moisture and Ocean Salinity (SMOS) and Soil Moisture Active Passive missions. The assimilation system uses a spatially distributed ensemble Kalman filter (EnKF), the Community Microwave Emission Model (CMEM) and the ISBA-DIF from the SURFEX land surface modelling platform. The experiments are performed over the MetCoOp grid at a 2.5 km resolution, using forcing data from Met.no. Uncertainties in the forcing are accounted for by perturbing the precipitation, 2 m air temperature, long wave and short wave incoming radiation.

Consistent use of dynamic fields and static parameters within the land surface data assimilation system ensures that this system is robust across spatial scales. This work is a step towards near real time assimilation of surface soil moisture, as the observation latency is reduced by using satellite brightness temperatures instead of retrievals. Future developments include assimilation of other satellite products, e.g., high resolution soil moisture retrievals from Synthetic Aperture Radar (SAR), snow variables and leaf area index.

Regional Snow Modeling in Norway with SURFEX/Crocus

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In Norway, thirty percent of the annual precipitation is snowfall. Knowledge of the snow reservoir is therefore important for energy production and water resource management. As a part of the project SNOWHOW (Better SNOW models for natural hazards and HydropOWer applications) the land surface model SURFEX with the detailed snowpack scheme Crocus has been run over two domains within Norway for three years. The model was forced by a combination of gridded hourly observations of temperature and precipitation and forecasts from the operational weather forecast model AROME MetCoOp. We present an evaluation of the modelled snow depth using observations. The evaluation focuses on snow accumulation and snowmelt. The results are promising, and show that assimilation of snow observations is necessary to improve the model performance.

On the use of an explicit snow scheme in NWP

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The physical parameterization of the soil-biosphere-atmosphere interaction is crucial in both climate simulations and NWP (Numerical weather prediction). A key component in this interaction is ground snow, which alters the physical processes significantly from non snow-covered conditions. In NWP models a good physical parameterization of ground snow is important for accurate predictions of e.g. air temperatures and wind speeds. Theoperational NWP model HARMONIE-AROME (MetCoOp-EPS), which is operated by MET Norway, has a relatively simple 1-layer snow parameterization scheme called D95 (Douville et.al. 1995). From a physical perspective a well working explicit snow scheme should out-perform the relatively simple bulk scheme and improve the near surface fluxes in snow covered areas.

In this presentation we give an overview of the two snow schemes, the one layer snow scheme D95 and an explicit multi-layer snow scheme of intermediate complexity (ISBA-ES). We show its usefulness for operational NWP based on results both with a coupled system and offline simulations. A key component of an operational NWP system is assimilation of observations into the forecasts from the NWP system (data assimilation). We present a strategy and first results for assimilation of ground snow observations into the ISBA-ES snow scheme.

The Mesoscale Ensemble Prediction System (MEPS): a New Tool for Extreme Weather Forecasting

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The mesoscale ensemble prediction system (MEPS) became the operational forecast model for the Norwegian Meteorological Institute (MET) late in 2016. It comprises a 10-member, convective-permitting (2.5 km horizontal resolution) ensemble that provides not only the best guess of the forecast, but also the inherent uncertainty of a weather situation. As such, MEPS represents a powerful resource for heavy precipitation / flood forecasting and risk mitigation.

This work will focus on the performance and added value of MEPS during a number of observed extreme precipitation events. In depth analyses of events, both cool season (non-covective) and warm season (convective), will be presented. The former will leverage an unprecedented dataset of in situ aircraft measurements sampling intense long-distance moisture transport resulting in heavy precipitation. The latter will focus on urban flooding.

These data will be valuable for MET, as they allow for a quantification of forecast uncertainty. In a synergistic manner, NVE will be able to utilize these data to assess the impact of MEPS forecasts on flood prediction. A direct relevance for decision makers is anticipated.

High-resolution stable water isotope measurements as a new constraint on weather prediction and climate models

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The isotopic composition of water vapour and precipitation, expressed by the quantities dD, d18O and d-excess, contains information about the transport conditions of water vapour in the atmosphere. The complex interplay of atmospheric flow and topography in Norway, and the location in the storm track, lead to precipitation arriving from a wide variety of source regions and transport histories. As part of the recently established national infrastructure facility FARLAB, a state-of-the-art measurement facility for stable water isotopes is now available at the University of Bergen. Results from continous high-resolution stable isotope measurements of water vapour and precipitation in Bergen and surface water isotope transect across Southern Norway are presented. In particular the parameter d-excess shows differences in moisture origin between the western and eastern part of Southern Norway. It is outlined how stable isotope measurements at meteorological to seasonal time scales can provide additional powerful constraints on the water cycle in weather forecast and climate models.

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Use of precipitation radar for improving estimates and forecasts of precipitation estimates and streamflow

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Good knowledge about real-time precipitation analyses and forecasts is very important for flood forecasting, inflow prediction, hydropower energy scheduling, energy trading and economic decision making. The RadPrO project aims to develop a state-of-the-art up-to-date NWP model and tools for fast access to real-time best estimate (analyses) and forecasts of precipitation. Also, the developed tools applied to radar and surface rain gauge observations back to 2012 will provide opportunities for calibration of hydrological models. Expected outcomes of the project are:

Improved operational NWP model: In close collaboration with High Resolution Limited Area Model (HIRLAM) group, developing an up-to-date four dimensional and flow-dependent assimilation scheme capable of using half-hourly radar observations. This means the new scheme will use 48 radar scans per day instead of 8 currently.

Improved real-time analyses: Combined information from radar measurements, in-situ observations, and weather model output will be used to optimally estimate the last hour of precipitation. The output will be hourly estimates on a 1 km resolution grid for all of Norway. This process is repeated every hour giving the best possible real-time input for end-users.

Improved historical analyses: The same technique described above will be applied to historical data back to 2012, which is the time period that AROME output is available in MET Norway's archive. This will provide the best possible historical input for calibrating hydrological models.

Improved post-processed forecasts: Forecasts from the NWP model will at any point in time be 2 to 8 hours old. With frequently updated analyses, the NWP forecast output can therefore be statistically updated every hour such that end-users always have the best forecast estimates available.

Consistency between analyses and forecasts: Traditionally the production of analysis and forecast products has been done independently, resulting in products with different meteorological characteristics. RadPrO will introduce the co-production of analyses and forecasts in such a way that their characteristics are much more similar. This is important to hydrological modeling where the data that models are calibrated against (analyses) are consistent with the data used in real-time prediction.
Systematic evaluation of forecasting performance: The performance of both precipitation and streamflow forecasts will be assessed, and criterions that focus on the specific end user needs will be used in the evaluation.

The presentation will give an overview over the work packages in the RadPro project, and present some preliminary evaluations on using radar precipitation products in hydrological modelling. Both the average performance and the performance of the hydrological models for specific events and catchments will be discussed.

Session 3: From modelling to decisions

Do we really need better climate models and scenarios?

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Global climate models (GCM) are indispensable for providing comprehensive and physically consistent projections of future climate change. Regional climate models (RCM) are a complement to GCMs. Thanks to concentrating the modelling effort to only some part (region) of the world, RCMs make it possible to model climate change on a higher resolution than GCMs, by as much as a factor of 10. The latter allows for more detailed representation of spatial and temporal detail not least in the near-surface climate characteristics than what is feasibly achievable with GCMs. Such detail, for example extreme precipitation, mountain ranges, matter for applications such as modelling runoff and net precipitation.

Climate models have been around and developed during the past several decades. The origins of GCMs go back well more than 40 years, and RCMs effectively about 20 years. Over time, climate models have acquired higher resolution, a fuller treatment of the climate system and the number of experiments and projections has greatly increased. Today, climate models do faithful simulation of many aspects of the climate system, but there are also various systematic biases and issues that one needs to consider when analyzing simulations and applying results in, for example, modelling impacts.

In addition to model biases, it is important to appreciate that even a large number of model simulations are a sample of all possible courses of climate variability (under climate change). Ensemble simulations show this more clearly than single projections. Another important determinant is the choice of the driving greenhouse gas emission scenario, assumptions of land use change, and suchlike. That is, what is the “future” that the projection corresponds to and, by extension, how relevant is the particular alternative with respect to climate policy and evolution of climate forcing in the real world.

Climate models will surely continue improving, gain yet higher resolution, include additional processes and run in larger ensembles. However, much of the accompanying value will be incremental rather than decisive in terms of scenarios and applications. Careful interpretation of information from climate models is more crucial for increasing confidence in applications using climate model results, than waiting for the next cycle of improved climate models. Nevertheless, there is further value to be gleaned from climate models as they are developed further, and impact modelling can provide information for this, by communicating any significant issues that are identified.

Added value of regional and convective-permitting simulations of present and future precipitation in Northern Europe

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Climate projections of future precipitation changes are typically available from models run at horizontal resolutions larger than 100 km, but local information is needed for impact studies and to inform stakeholders and policymakers. In addition, large scale climate models must parameterize many processes occurring at spatial scales smaller than the model grid cell, such as convection, causing large errors in modeled precipitation, especially for extremes. Here, we use the regional climate model WRF to perform convection-resolving simulations (3 x 3 km resolution) of historical and future precipitation in Northern Europe (Southern Norway, Denmark, Benelux region). The WRF model is used to downscale global climate model results (CESM, 2 x 2 degrees) for both the historical period (1986 – 2005) and the end of the century (RCP8.5 scenario, 2081-2100). These convection-resolving runs are compared to observations, to global climate model results (CESM, CMIP5) and to regional WRF simulations (15 x 15 km resolution), to evaluate the added value of regional and convection-permitting models in representing precipitation, including extreme and subdaily events, and their added value for future projections in this region.

An integrated assessment framework to study the impacts of forest structure and management on hydrological fluxes in Norway

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Boreal forests play a central role in the landscape water balance in Northern latitudes. Structural forest characteristics as stand density or species composition are known to govern energy partitioning and dominant flow paths. Most hydrological modeling frameworks, however, barely account for spatial and temporal variability in forest structure. Especially in regional to large scale simulations, boreal forests are often represented by one lumped land cover type for which parameters are derived from literature or are determined by calibration. While national forest inventory data provide comprehensive, detailed information on hydrologically relevant forest characteristics, their potential to inform hydrological simulation over larger spatial domains is rarely exploited.

We present a modeling framework that utilizes forest structural information derived from the Norwegian national forest inventory and multi-source remote sensing data to improve and refine the representation of forested landscapes in the distributed hydrological model HBV. In the hydrological simulation, different forest types are distinguished according to structural characteristics and are represented by three key parameters: leaf area index, mean tree height and surface albedo. The classification approach based structural characteristics rather than biomes allows to implicitly account for effects of forest management. Seasonal cycles of LAI and surface albedo are calculated online as a function of air temperature and snow cover to make the framework applicable under transient climate conditions. The modeling framework will be set up for the entire of continental Norway at 1 km spatial resolution and is explicitly designed to study the combined and isolated impacts of climate change, forest management and land use change on hydrological fluxes. We present first results for the pilot regions Nord-Trøndelag and Sør-Trøndelag and examine how forest management has affected regional hydrological fluxes during the second half of the 20th century.

The use of national forest inventory data to model soil moisture and soil carbon dynamics in earth system models

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It is well documented that northern peatlands store disproportionally more of the global soil C pool than their spatial extent suggests. Their net C sink behavior results from anoxic soil conditions, reducing the ecomposition rate below the input rate of dead organic matter. In Fennoscandia (Norway, Sweden and Finland), 10-30 % of the forested boreal zone has peat-forming ground conditions and soil C dynamics similar to open peatland. North American and Russian observations indicate that waterlogged forest soils occur frequently across the whole boreal belt. Thus, it would be erroneous to assume that all boreal forest soils are well-drained. Furthermore, national forest inventory data from Norway suggest a gradually increasing soil C stock from well-drained to peat-forming ground, further extending the area with enhanced C accumulation.

National forest inventory data are well suited to quantify the proportion of peat-forming ground across the boreal zone. More importantly, these network data facilitate the possibility to model the probability of peat formation (as observed at the plot level) dependent on climatic parameters and topographic position with high spatial resolution. Such models can predict the spatial distribution of peat accumulation under alternative climate scenarios.

The national forest inventories in Fennoscandia are ideal to investigate the combined effect of climatic factors and topography on soil moisture and soil C dynamics. In combination, they comprise more than 40 000 permanent plots capturing virtually all precipitation regimes and most temperature regimes (except cold tundra forest) across the circumpolar boreal belt. Thus, NFI data have great potential to parameterize land surface processes in earth system models.

Modeling Snow Dynamics Using a Bayesian Network

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In this paper we propose a novel snow accumulation and melt model, formulated as a Dynamic Bayesian Network (DBN). We encode uncertainty explicitly and train the DBN using Monte Carlo analysis, carried out with a deterministic hydrology model under a wide range of plausible parameter configurations. The trained DBN was tested against field observations of snow water equivalents (SWE). The results indicate that our DBN can be used to reason about uncertainty, without doing resampling from the deterministic model. In all brevity, the DBN's ability to reproduce the mean of the observations was similar to what could be obtained with the deterministic hydrology model, but with a more realistic representation of uncertainty. In addition, even using the DBN uncalibrated gave fairly good results with a correlation of 0:93 between the mean of the simulated data and observations. These results indicate that hybrids of classical deterministic hydrology models and DBNs may provide new solutions to estimation of uncertainty in hydrological predictions.

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Translating weather extremes into the future – a case for Norway

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"Translating weather extremes into the future – a case for Norway" (http://www.cicero.uio.no/en/twex) is a new project in which we take a novel "Tales of future weather" approach. In particular, we use future scenarios tailored to a specific region and stakeholder in order to gain a more realistic picture of what future weather extremes might look like in a specific context. We focus on hydroclimatic extremes associated with a particular circulation pattern (so-called "Atmospheric River"). Atmospheric rivers are known to lead to heavy rainfall in fall and winter along the West Coast of Norway and often cause high-impact floods in Norwegian communities. We translate selected past events into the future (e.g., 2090) by using an approach very similar to what is used today for weather prediction. The data generated in TWEX will be distributed by standard (weather prediction) communication channels of the Norwegian Meteorological Institute and thus, will be accessible by end-user in a well-known data format for analyzing the impact of the events in the future and support decision-making on hazard prevention and adaptation planning.

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Evaluation of summer precipitation from EUR-11 simulations over Norway

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Estimates of future precipitation extremes with high temporal and spatial resolution are essential for local climate adaptation. In Norway, these extremes are expected to increase in most areas, but how reliant are the simulations?

We have evaluated seven fine-scale regional climate model simulations from EURO-CORDEX, focusing on summer precipitation in the period 1989-2008. More specifically, we have compared modeled summer maxima (SM), summer wet event frequency (SWF) and summer wet event total (SWT) for 3-hourly and daily precipitation to two reference datasets; gridded precipitation covering the entire mainland and measured precipitation at 19 sites. Both reference datasets have been transformed to represent ~12 km grid cells, similar to the EUR-11 grid. We believe the use of two reference datasets with their individual flaws is an advantage in our evaluation, as consistent biases can be identified.

We found that the spatial distribution is fairly well simulated in the models. They capture the west to east gradient in the south, although a bit weak in general. Overall, we find that most models compare relatively well to our reference datasets with regards to summer extremes, although overestimation of daily summer maxima (30-50%) is evident, and a slight overestimation of 3-hr summer maxima is seen in all models except one. However, the overestimation is generally within the estimated bounds of uncertainty. We saw a positive bias also in summer wet event frequency (15-35% on average), which again leads to an overestimation of summer totals.

Due to some deviation between the models and to get a grasp on their associated uncertainty, we would recommend a larger number of ensemble members to study future changes in extreme precipitation. The models show different skills depending on the index and the region, and in a larger ensemble the ensemble mean along with low and high percentiles would likely give reasonable projections. To make use of future scenarios we would recommend bias correction, and, as we have identified some outliers within our ensemble, a weighing of models is perhaps appropriate.

Spatially Consistent Post-processing of Daily Mean RCM Temperature Projections in Norway – a Case Study in Trøndelag

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In climate impact studies, good estimations of local climate change are crucial inputs for impact models. A common practice is to obtain these estimates based on outputs from global circulation models (GCMs) and nested regional climate models (RCMs). However, even outputs from RCMs at the finest available spatial resolution are not suitable to use directly in impact models due to their coarse resolution and biases. Consequently, various downscaling and bias-correction methods have been applied to the RCM outputs before their use in regional impact assessments. However, one issue with commonly used bias-correction methods is that they impair the spatial dependence of the GCM/RCM field by treating the grid cells individually.

Within the project "Post-processing of Climate Projection Output for Key Users in Norway" (PostClim) funded by the Research Council of Norway, we propose a new method that combines "downscaling" and "bias-adjustment" in one model we call *locally adaptive spatial nonhomogeneous Gaussian regression (LASNGR)*. The methods is employed to an ensemble of ten EURO-CORDEX projections of the daily mean surface temperature where the postprocessing is performed against the corresponding observed data product SeNorge version 2.1. We consider the daily mean temperature across Norway as a Gaussian random field and assume that an observed daily data set is one realization of a multi-variate Normal distribution. The mean vector of this distribution is a linear function of the local climatology and the ensemble projections while the covariance model also uses additional information such as elevation and land use.

As a preliminary case study, we apply the method to data from Trøndelag, a region in the central part of Norway. We estimate and validate the method in the control period from 1970 to 2005, and issue adjusted projections until 2100.

Vision for the future of operational hydrology - from innovation to operation

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Hydrometeorological information is crucial to societal security, to infrastructure planning, as well as to the income of hydropower producers. Nevertheless how different users and stakeholders are producing or gathering this information is very variable. Depending on the education or background users take different approaches. Even though the HBV-model over the years has achieved a strong position in academia and education, it is not commonly available and adopted to practical cases for end users or for planning purposes. Only the largest hydropower producers can efficiently apply and process hydrometeorological information, but the concepts they are using have been unchanged the last 20 years. Even so the majority of the hydropower producers are too small to have the capability to run such models. Why is this so? Each academic institution and academic seems to have their personal preferences when it comes to hydrological modelling. New insight is gained along several paths, but with different shoes and different maps. And when neither the shoes nor the map fits, it is difficult for others to benefit from the new developments. Even more difficult is it for the end users to benefit of academic achievements since most of the tools where this is implemented are 20 years ahead in methodology and thus not compatible with the tools the users have, if they have a tool at all. Closing the gap between academia, the governmental institutions, hydropower producers, consultants and municipality when it comes to how to produce and process hydrometeorological information would give multiple benefits for all. In academia it would be easier to communicate ideas and need for further developments and so also motivation for funding, the governmental sector would earlier benefit of academic achievements, the consultants would have immediate benefits of a newly educated employee and tighter with the municipalities have a state of the art tool available for their evaluations of hydrometeorological information. A common toolbox or platform would ease communication and reduce misunderstanding and save the society for cost. And it does not have to be achieved on the cost of academic pride. What kind of hammer used is not relevant for the house that you build.

Can hydrological non-stationarity be achieved with event-based conceptual models in northern regions?

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Hydrological models have been developed and operated on the principle of "hydrological stationarity". The bias and uncertainties associated with the application of such models for prediction of future events calls for research into dynamic models that can capture temporal variability in hydrological processes. This study investigates the possible option to add dynamic parameters into event-based conceptual models which will enable the models to capture inter-annual variability in hydrological processes in the northern regions. The hypotheses were that, temporal variability in hydrological processes in northern regions is mainly caused by variability in climate indices such as snow day ratio, warm-dry index, rainfall intensity etc. Thus parameters of event based hydrological models such as the ones based on the principle of runoff coefficients could be strongly correlated with climate indices. Furthermore, functional relationships can be derived between such models parameters and the climate indices, and incorporated into the model. This will enable the model to capture temporal variability in hydrological processes utilizing information only from the meteorological data inputs. The model used in the study is the modified form of the CPI_{snow} model which was developed based on the principle of current precipitation index and runoff coefficient. The model was modified to allow use of dynamic parameters in the Monte Carlo automatic calibration process. The temporal scale of the dynamic parameterization is one year. A static version and dynamic version of the model was applied in four northern catchments in Finland using 22 years' data (1990-2011). The performance of the two versions of the model were evaluated and functional relationships between the dynamic parameters and inter-annual climate indices were derived. The relationships were incorporated into the model and the performance of the model was tested using four independent test catchments located in Finland.

Keywords: Rainfall-runoff modelling; Hydrological non-stationarity; Dynamic parameters; Event-based conceptual models.

Modeling the Hydro-Climatic Effects of Land Use and Land Cover Changes in the Euphrates and Tigris Basin Under a Changing Climate

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The Southeastern Anatolia Project, known by its Turkish initials as GAP, is a regional development project based on utilizing the waters of Euphrates and Tigris (ET) rivers by irrigating vast semi-arid lands and by producing hydroelectric power. Since the beginning of 90s, the irrigation schemes carried out within the scope of GAP has already caused immense land use and land cover (LULC) changes in the region. 25% of the irrigation projects was completed at the current status of GAP, and total irrigable land in the region is about 1.8 million hectares.

In this study, the individual and combined effects of anthropogenic LULC changes through intensification of irrigation and climate change were investigated by performing regional climate model simulations. For this purpose, two different land use maps in addition to default land use map of the regional climate model (RegCM4) that reflects the pre-GAP landscape were used to simulate the current realization level of GAP (25%) and future (upon completion of GAP) LULC change. Reanalysis data (NNRP) for 20 years between 1991 and 2010 and outputs of a global circulation model (EC-EARTH) for the period between 1986 and 2009 have been used to force RegCM4 at a horizontal resolution of 48 km over Eastern Mediterranean and Black Sea region, and later in a nested domain with 12 km resolution over Turkey. The results of larger domain were validated by using high resolution gridded datasets, CRU (Climatic Research Unit) for temperature and precipitation, and GLDAS (Global Land Data Assimilation System) for evapotranspiration.

The regional model tends to overestimate precipitation in the headwaters region while giving fairly good estimates for the downstream areas. Dynamically downscaled results from reanalysis indicate that the annual surface temperatures will decrease by about 0.4 ^{0}C and 0.8 ^{0}C due to the LULC changes in the region, while precipitation will increase 3% and 7%, mostly in spring. Increase in evapotranspiration amounts to 51% and 114% over the pre-GAP conditions, which means significant water loss from the region. Specific humidity amounts are more around 8% and 17%, on annual basis, in simulations respectively with current and future land use maps compared to a simulation with pre-GAP land use conditions. Additionally, future simulations for mid- and end-century were also conducted to simulate the integrated effects of future climate change (RCP 4.5 and RCP 8.5 scenarios by using EC-EARTH) with local anthropogenic climate change (land use and land cover changes) for the assessment of possible changes in the regional water budget. Our experiment reveals that the increasing water demand of the irrigated region is currently barely compensated by the headwaters of the ET basin. Temperature decrease caused by increased evapotranspiration will be at the same order of the increase in temperature due to RCP forcing. The results of the study show that current and future LULC changes will affect the water balance of the basin. The partitioning of waters of ET rivers between energy production, irrigation, and release for the downstream countries is an ongoing complex issue for the riparian countries (Iran, Iraq, Syria, and Turkey) in the region. The dramatic increase in water loss through evapotranspiration may play a crucial role in shaping the future of water resources management and policies in this arid and semi-arid region.

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POSTERS

Seasonal and interannual variability of moisture transport to the East Asian Summer Monsoon

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Precipitation variability is part of the lives of the many people living in the East Asian Monsoon region. While people of this region depend on precipitation for agriculture and water supply, its variability also causes frequent disasters such as flood and droughts. Increasing our understanding of the processes leading to past and present natural climate variability of this key region of the climate system is thus very important.

Using the Lagrangian model FLEXPART and the diagnostic tool WaterSip with wind and humidity from ERA Interim reanalysis as input, the moisture transport to three regions of China where rainfall is dominated by the East Asian Monsoon is diagnosed from evaporation to precipitation for each rain event in the period 1979-2013. Through calculation of moisture budgets along the air parcel trajectories on a 6h time scale we obtain a quantitative estimate for contribution of surface evaporation to the target region precipitation.

We find that in the 34 year climatology moisture sources vary greatly between different seasons. Both moisture sources and transport characteristics change strongly with the seasonal progression of the East Asian Monsoon. The westernmost and farthest source regions contribute during the peak of the monsoon. In July the mean transport distance for South China is 2400 km, compared to a whole year mean of 2100 km in this region. The transport time over these distances is rather short with close to 4 days from evaporation to precipitation. Land contributions (continental recycling) vary strongly with season an subregions, with values as low as 35 % for an autumn month in South China, compared to 98 % in a spring month in the upper reaches (west) of the Yangtze River. The important role of continental recycling partly explains the short average transport distances and atmospheric transport times.

A key result from our approach is that local land areas are important sources for all months and regions; albeit the amount varying with season and region. While most moisture is supplied from surrounding land areas, the contributions from land generally increase with distance away from the coast. This study thus suggests that with the atmosphere on its way from an oceanic source to the interior of China, precipitation is to an increasing degree recycled. The results for China will be contrasted to conditions in Scandinavia, which are more dominated by oceanic moisture transport.

Runoff dynamics in a forested catchment - investigating the relations between river network density, subsurface water capacity and subsurface water celerities

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The DDD (Distance Distribution Dynamics) model uses the distance distribution (DD) of points in the hillslope to the nearest river reach and that of the river network (RN) (distribution of distances in the river network to the outlet) together with information on recession to parameterize the runoff dynamics. The DD's provide the shape of unit hydrographs, and subsurface celerities, and hence, the scale of the unit hydrographs are derived from recession. The tiny Muren catchment (7500 m^2) in Bærumsmarka, Norway, has, due to its size, no perennial flow and no defined river network. Water is, of course, nevertheless transported to the outlet due to a relatively impermeable bedrock underlying a shallow till cover of up to 1 m thickness. During intense and/or prolonged episodes of rainfall and snowmelt, temporary river networks may arise changing the drainage pattern of the catchment. By using the single-flow direction algorithm in Arc GIS, six theoretical river network systems are estimated: The networks differ by the area it takes to create a channel. Areas of 10 m^2, 100 m^2, 500 m^2, 1000 m^2, 2500 m^2 and 5000 m^2, are used and parameters for the DD's extracted. Using an area of 10 m^2 creates a very dense RN, whereas an area of 5000 m^2 only gives one channel in the catchment. Data of precipitation, temperature and runoff exists on an hourly resolution for the Muren catchment for an especially wet period in 1987 for which the DDD model has been calibrated (tuning the distribution of the recession characteristic, Λ), using the different distance distributions. DDD performed well for all variants of DD's but best for DD's derived using the larger areas (500 m^2-5000 m^2), with NSE=0.84 and KGE ranging from 0.87-0.88. DDD estimates the subsurface water capacity, the temporal distribution of groundwater and subsurface water celerities. It was found that the simulated temporal distribution of groundwater, obtained through calibration against runoff, agreed well with the estimated distribution derived from the recession characteristic Λ and mean annual runoff. This is a result supporting an important assumption in the DDD model. Furthermore, the subsurface water capacity and the subsurface water celerity increased as the RN density decreased. The subsurface water celerity ranges from 10^{-6}-10^{-4} m/s for the most dense RN and is an order of magnitude faster for wet conditions using the least dense RN. The subsurface water capacity increased an order of magnitude from the most dense to the least dense RN. The results show that the configuration of the river network in a catchment is important for the transport times of water through the soils and hence for the runoff dynamics. Moreover, the results are consistent with our perception of the relations between river network density, soils and soil moisture and is informative when trying to estimate model parameters for ungauged basins and improve land-atmosphere interactions.

Estimation of energy balance components in a mountain environment based on high resolution climate data

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As part of the LATICE (Land-Atmosphere Interactions in Cold Environments) project, a micro-meteorological tower was installed at Finse (60°35'N 7°31'E, 1220 m.a.s.l.) in September 2015, with instrumentation to perform high temporal resolution measurements of radiation, fluxes of latent and sensible heat and heat flux in soil. The Finse area lies on the north-western edge of the Hardangervidda mountain plateau, where the transition from coastal climate in west to continental climate in east produces a high precipitation gradient (Gjessing, 1997). The tower is located in close proximity to the Finse Alpine research station, in a valley running NW-SE between the glacier Hardangerjøkulen to the southwest and Hallingskarvet to northeast. For the climate normal 1963-1990, the mean annual air temperature was -2° C and no month had a mean temperature above 10° C. The micrometeorological tower is operated in cooperation with The Norwegian Meteorological Institute and the variables wind, air temperature and humidity, surface temperature, precipitation, atmospheric pressure and snow depth are being collected by national standards. Wind, temperature and relative humidity data are collected at two heights (4.4 and 10 m). Details of the data and the site can be found at http://mn.uio.no/latice.

Evapotranspiration is an important part of the surface energy- and water balance but very few state-of-the-art observations of evapotranspiration have been made in Norway. At Finse, measurements of fluxes of sensible and latent heat are made by the eddy covariance method. This is a direct measurement method in the sense that it does not include any empirical constants. However, it is based on a number of simplifications and can only be applied when the used assumptions are met (Foken et al., 2008). Another much used method to estimate fluxes of latent and sensible heat, the Bowen-ratio method, which is based on the energy balance equation and the Bowen-ratio similarity, will be applied using relative humidity and temperature gradient data from the tower, and estimates of sensible and latent heat will be compared to those of the eddy covariance method.

This poster will present results from observations of the energy balance components from the micrometeorological tower located at Finse. Questions that are explored include 1) how assumptions of the eddy covariance method are met at Finse 2) how latent and sensible heat estimated of the Bowen ratio method compares the estimates of the eddy covariance method 3) how surface conditions (snow/wet/dry) affect components of the energy balance.

FOKEN, T., NAPPO, C. J. & SPRINGERLINK 2008. *Micrometeorology*, Springer Berlin Heidelberg.

GJESSING, Y. 1997. Klima og glasiologi på Finse. *In:* SØMME, L. & ØSTBYE, E. (eds.) *Finse - et senter for høyfjellsforskning : et skrift til 25 års jubileet for Høyfjellsøkologisk forskningsstasjon, Finse : 1972-1997.* Finse: Forskningsstasjonen.

Automatic Model Calibration using Multi-objective Optimization

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Model calibration is a process of adjustment of a model parameters to make the outputs of the model producing desired values or satisfying pre-agreed criteria. Since each parameter of the model is normally numerical values, the process of calibration is time-consuming even for a model that has a few number of tuning parameters. Moreover, the calibration process might be complex if a model has multiple outputs. Single objective calibration methods are quite common used in such cases, in which a weight value is assigned to each output for the purpose of converting the multiple outputs to a single value. However, one limitation of such methods is that with a single evaluation value, we are not able to judge a solution is better than the other in which dimension. Therefore, we lose information to implement an accurate evaluation on all the solutions.

In this work we applied a Multi-objective Evolutionary Algorithms (MOEA) from artificial intelligence to find optimal parameters for HBV model using observation data from project Climate Change Impacts on Runoff in North-West India. MOEA is a category of evolutionary algorithms applied to solve problems which contains multiple objectives to be optimized. Instead of transforming multiple outputs into a single value, MOEAs assign multiple values to each solution, where each value represents the evaluation of one objective of the problem. A fast elitist non-dominated sorting algorithm is applied to evaluate solutions with multiple evaluation values. Our objective was to optimize both discharge and glacier outputs of the HBV model for the study area. 14 parameters were optimized in the HBV model. Observation data for a period from 1968 to 1979 were used for calibration and verifying the HBV model. The results demonstrate that MOEA effectively achieves automatic model calibration with more accurate evaluation. We hope this study will drive the development of applying the methods from artificial intelligence to climate and hydrology field in Norway.

Evaluation of conventional climatological datasets for snow- and hydrological modeling in Norway

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The successful modeling of hydrological processes requires reliable meteorological forcing data, which is a crucial but often undervalued element of the model chain. In Norway, the management of water and energy resources as well as forecasting of nature hazards relies largely on the results from hydrological modeling. The main operational hydrological models at the Norwegian Water Resources and Energy Directorate (NVE) use daily conventional climatological datasets of temperature and precipitation on a high-resolution grid as their input data. These *seNorge* gridded datasets are based on observed data only, and are produced by the Norwegian Meteorological Institute (MET).

In this study, a new recently released *seNorge* version (*seNorge2*) is described and evaluated, especially for the purpose of operational snow- and hydrological modeling. The statistical interpolation methods used to produce the *seNorge2* datasets build upon classical spatial interpolation methods and introduce original approaches targeted for our specific domain and particular applications. The quality assessment of the *seNorge2* datasets is based on the summary statistics collected by leave-one-out cross-validation (CV) experiments. The indirect evaluation of the *seNorge2* datasets has been carried out with the help of NVEs operational snow- and hydrological models (seNorge, DDD), in addition to the verification of the consistency between the precipitation datasets and the measurements available for components of the water balance. The evaluation results point out important information for the future *seNorge2* developments. In particular, the daily mean temperature fields constitute an accurate and precise dataset, which we believe can be directly used in several applications. On the other hand, the current *seNorge2* precipitation fields present a systematic underestimation of precipitation for areas characterized by a sparse station network. Moreover, an underestimation have also been detected in the case of intense precipitation. Further developments are thus needed on the statistical interpolation of precipitation. However, both the seNorge snow mapping and the DDD hydrological models have already been able to make profitable use of the new *seNorge2* products, because of the calibration procedure they both incorporate for correcting precipitation input for systematic bias.

A stochastic PQRUT model for flood estimation in small and medium-sized catchments

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The estimation of extreme floods is associated with high uncertainty, in part, due to the limited length of streamflow records. Rainfall-runoff modelling for flood estimation can offer advantages over statistical flood frequency analysis as longer time series of meteorological data are often available. Such methods can also model combinations of factors, such as unusually high rates of snowmelt and extreme rainfall, which lead to extreme discharge events not yet observed, but are, nevertheless, possible. In Norway, an event-based approach using a simple 3-parameter hydrological model, PQRUT, is used for such assess-ments. The standard implementation of this method involves routing a hypothetical precipitation design sequence of a given return period through a hydrological model PQRUT, based on fixed initial conditions. It is assumed that the simulated discharge has the same return period as that of the input rainfall. We pro-pose an alternative, stochastic version of the PQRUT modelling method, in which one simulates a range of initial conditions and meteorological sequences. The proposed method is based on a Monte Carlo proce-dure in which variables setting initial conditions are randomly sampled from their underlying seasonal distributions. The initial soil moisture deficit, discharge and snow water equivalent, prior to over threshold flood events, are identified and then simulated using a multivariate distribution. For input precipitation, it is assumed that flood events are the result of a critical storm duration. The precipitation depth is simu-lated using a Generalized Pareto distribution and is then disaggregated to a time step of 1-hour using storm patterns sampled from observed data. Temperature sequences are also resampled from historical data. For each season, the simulated temperature and precipitation sequences for 100,000 storm events and the randomly sampled initial conditions are used as input to the calibrated PQRUT hydrological model. The probability of the simulated events are estimated based on their plotting positions.

Estimates for the 100- and 1000-year return level based on the stochastic PQRUT model were compared with results for a) statistical frequency analysis, and b) a standard implementation of the event-based PQRUT method, for 20 small and medium-sized catchments in Norway. Compared with the standard implementation of PQRUT, the stochastic PQRUT gives higher values for northern Norway, but the two methods give similar values for mid-Norway. When compared with statistical flood frequency analysis, the stochastic PQRUT model gives higher values for western and northern Norway and lower values in inland Norway. The difference between the estimates can be up to 100 % for some catchments, which highlights the uncertainty in these methods. Neverthless, the agreement between the stochastic PQRUT estimates and statistical flood frequency analysis is better than often reported for today's PQRUT. In addition, the method eliminates the arbitrariness of assigning initial values for runoff, soil moisture and snow melting in the flood estimation process and gives a physically more realistic estimate of the range of precipitation depths capable of producing an event of a given return period in a given season.

Comparison of regionalization approaches' robustness under climate change: a case study in Norway

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Prediction in Ungauged Basins (PUB) has been identified by the International Association of Hydrological Sciences (IAHS) as one of the most challenging topics in current surface hydrology research. Regionalization, as one of the core objectives of PUB initiative, has been used for assessing and predicting hydrological response in ungauged regions. At the same time, the Intergovernmental Panel on Climate Change stated, in its fifth assessment report, that global and regional precipitation regimes are changing due to global warming. Therefore, extrapolating the predictions in both time and space is essential and with high significance for decision-making in ungauged catchments under current and future climate. However, there are seldom researches on prediction in ungauged catchments under climate change. In this study, we will evaluate and compare the performances of regionalization approaches in both observation period and future climate change period to test their robustness. This study applies the distributed HBV model and daily data in Norway, a mountainous region with high meteorological variability, large geographic diversity, and complex interplay between climate and hydrological processes. This study contributes not only to the thoeretical understanding of the underlying factors and connections between hydrological parameters and physical catchment signatures, but also to water balance mapping, and water resources planning and management under current and future conditions.

Using model and satellite data to investigate the effect and uncertainties of light absorbing impurities in snow on the discharge generation in an Indian high-mountain catchment

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Light absorbing impurities in snow and ice (LAISI) originating from atmospheric deposition enhance snow melt by increasing the absorption of short wave radiation. The consequences are a shortening of the snow cover duration due to increased snow melt and, with respect to hydrologic processes, a temporal shift in the discharge generation.

However, the magnitude of these effects as simulated in numerical models have large uncertainties, originating mainly from uncertainties in the wet and dry deposition of light absorbing aerosols, limitations in the model representation of the snowpack, and the lack of observable variables required to estimate model parameters and evaluate the simulated variables connected with the representation of LAISI. This leads to high uncertainties in the additional energy absorbed by the snow due to the presence of LAISI, a key variable in understanding snowpack energy-balance dynamics.

In this study, we assess the effect of LAISI on snow melt and discharge generation and the involved uncertainties in a high mountain catchment located in the western Himalaya by using a distributed hydrological catchment model with focus on the representation of the seasonal snow pack. The snow albedo is hereby calculated from a radiative transfer model for snow, taking the increased absorption of short wave radiation by LAISI into account. Meteorological forcing data is generated from an assimilation of observations and high resolution WRF simulations, and LAISI mixing ratios from deposition rates of Black Carbon simulated with the FLEXPART model. To asses the quality of our simulations and the related uncertainties, we compare the simulated additional energy absorbed by the snow due to the presence of LAISI to the MODIS Dust Radiative Forcing in Snow (MODDRFS) algorithm satellite product.

The Morphological Evolution of a Wind-Shaped Snow Surface during a Storm Event at Finse, Norway

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The large majority of global snow surfaces are shape by the action of wind and blowing snow. While most of the features produced during such event have been identified as snow bedforms, we captured for the first time the slow evolution of a snow surface during a storm at Finse, Norway. Our 30 minutes time-lapse laser scanner data show the migration of dunes as well as the formation of erosional patterns also called sastrugi. In parallel, our local eddy-covariance weather station provides a detailed description of the boundary layer state throughout the whole storm. Based on these two complementary datasets, we will explore the processes responsible to the morphological evolution of a wind-shaped snow surface.

Spatial distribution of peatland in the boreal zone

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Research on peat formation has traditionally focused on the *temporal* aspects, such as long-term peat accumulation rates in different climate zones and relative to climatic change (e.g. the effect of the "Little ice age").

This study focuses on *spatial* aspects of peat formation. A broad-scaled analysis of national forest inventory (NFI) data from Norway, Sweden and Finland reveal parallel patterns in the prevalence of peatland forest. The prevalence increases from 5-10 % of all forested land in the temperate-boreal transition zone to a peak level of 35-45 % in the mid boreal zone in Sweden and Finland. Further north, the prevalence drops to 20-25 % in the northern boreal zone of Sweden and Finland. The general pattern is similar in Norway, but the quantitative levels are distinctively lower (peaking at 10 % in the mid boreal zone, dropping to 7 % in the northern boreal zone). The quantitative differences between Norway, Sweden and Finland probably reflect differences in topographic relief and ability of the landscapes to drain the ground water.

A detailed analysis of the Norwegian NFI data shows that peat formation is clearly influenced by climatic factors and it seems to be driven more by colder summers than by enhanced precipitation. Furthermore, it is evident that peat formation occurs more frequently in sloping terrain and on increasingly steeper slopes when moving from the southern boreal zone towards the north, thereby enlarging the area where peat-forming occurs. Solar radiation affected the prevalence of peat formation, being very low on south-facing slopes with high solar irradiance, whereas the prevalence was significantly higher on north-facing slopes.

The combined effect of climatic drivers and topographic attributes on peat formation should make it possible to predict the spatial distribution of peatland under alternative climate scenarios.

Integrating soil moisture satellite retrievals in land surface simulations

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Over the years a number of satellites have been launched into orbit with the purpose of observing the earth system. In the light of numerical weather prediction, remote sensing has filled large holes in the global observation coverage, these are integrated in the models through data assimilation, providing a better initialization. More recently several missions are launched dedicated to soil moisture, which is classified as an essential climate variable by the World Meteorological Organization. Soil moisture is a critical element in processes like evapotranspiration, latent and sensible heat flux into the atmosphere as well as saturation of soil, with their respective feedbacks. It is thus an important factor in extreme events, both heat waves and flooding. The Soil Moisture and Ocean Salinity (SMOS) satellite operated by ESA provides soil moisture retrievals with a global coverage every 3days. This makes it suitable for integration in a short range weather forecast.

We have used the externalized surface model SURFEX to perform off-line experiments of single points and over a domain in eastern Norway during the summer season. Energy fluxes and vertical water flow in the ground is calculated with a diffusion approach, and level 3 data soil moisture product from SMOS is integrated through Kalman filtering. The simulations should validate the data assimilation technique and also the value of adding soil moisture from SMOS, despite its poor coverage over Norway. Case studies are performed for episodes of poor performance of the operational forecast, and incidents where soil moisture might have local effects on the weather, such as convective afternoon thunderstorms in the summer.

The surface energy exchange of Alpine and Arctic ecosystems in response to snowmelt and rain events

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The surface energy exchange is a key control for an ecosystem's functioning and its interaction with the atmosphere. Especially in Alpine and Arctic regions the partitioning of available net radiation into sensible, latent and ground heat fluxes remains difficult to capture in land surface models. We therefore conducted energy flux measurements with eddy covariance systems on mobile and stationary towers at a low-Alpine site in southern central Norway (Finse), as well as at two high-Arctic sites in western Svalbard (Adventdalen and Tunsjømyra). Finse is located at 1220 m a.s.l., and features sporadic permafrost, a long-term mean annual air temperature of -2 degC (1963-1990) and about 1000 mm total annual precipitation. In contrast, the sites in western Svalbard are located at only 15 m a.s.l., and feature continuous permafrost, a long-term mean annual air temperature of -6.7 degC (1961-1990) and about 200 mm total annual precipitation. Here, we explore seasonal trends of the energy flux partitioning as well as fluctuations after episodic disturbances by snowmelt and heavy rain events. We specifically test how well the response and time relaxation of the Bowen ratio after a disturbance is captured in land surface models evaluated at our sites. Potential mismatches in such data-model comparisons may indicate possibilities for improvements in parameterizations of land surface models in cold regions.

Parameterizing snow redistribution effect of terrain parameters in a conceptual hydrological model

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Improved estimates of snow depth and its spatio-temporal distribution are important for various applications including for flood and avalanche warning as well as energy production planning. Topographic parameters such as elevation, slope and curvature as well as their derivatives such as the mean maximum upwind slope and topographic openness are widely used to parameterize sub-grid snow distribution in statistical models. In this study we extend the snow cover area (SCA) parameterization for topographic effect through parameterization of the sub-grid snow CV and explicit inter-grid snow redistribution in a conceptual rainfall-runoff model. The terrain parameters used are elevation and a wind sheltering index (sx). Model parameters are conditioned using observed flow only, while model outputs are evaluated against both observed flow and MODIS SCA. A split sample based cross validation of model predictions has shown slight improvement in simulated SCA and flow when using the terrain parameter based snow redistribution algorithm.

Hydro-glacial modelling in the Hardangerjøkullen area

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Glaciers are important to outdoor activities and energy production in Norway and they have gained plenty of attention from the public nowadays. Recent studies at NVE and University of Bergen have reported that Hardangerjøkulen, the sixth largest glacier in mainland Norway, could melt down (disappear) at the end of this century. Of course, the future development of the glacier depends on how the climate will change. The runoff from the glacier is important for the downstream ecological system and electricity production of a hydro-electric power plant.

In this work, we establish a hydro-glacial model for the Hardangerjøkulen area. This hydro-glacial model is based on HBV and a glacier empirical method. Using this model, we can estimate snow and ice melting, water balance components as well as glacier mass balance and changes in glacier covered area. This work will look at snow and glacier roles in runoff generation processes and potential impacts on hydropower production for the period from 1990 to the end of this century.

Projected changes in flooding under a future climate in Norway: How 'certain' are our estimates?

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Estimates of extreme flows under a future climate are often based on the application of flood frequency analysis (FFA) methods to hydrological time series simulated using data from climate projections. The uncertainty introduced by these estimation methods is, however, rarely mentioned when presenting estimates for changes in flood magnitude. In this study, an ensemble of hydrological projections for 115 catchments located in Norway is analysed to derive an estimate for the percentage change in the magnitude of the 200-year flood by the end of the 21st century, relative to a reference period (1971-2000). The ensemble is based on bias-adjusted climate data from 10 EUROCORDEX GCM/RCM combinations, 25 alternative parameterisations of the HBV hydrological model and two representative concentration pathways (RCP 4.5 and 8.5). For each hydrological simulation, the discharge series for a 30-year time slice for the reference period and for a future period, 2071-2100, were analysed using both 2- and 3-parameter GEV distributions and a GPD distribution, based on the L-moment method. Confidence intervals for the flood frequency estimates were assessed using parametric bootstrapping, and the distribution of estimates between the 5% and 95% levels were incorporated into the ensemble estimates for each catchment. As reported previously, there are large regional differences in the projected changes in the 200-year flood across Norway, with median projections ranging from -44% to +56% for the change in the daily-averaged flood magnitude based on FFA using the 2-parameter Gumbel distribution. These differences reflect the relative importance of rainfall vs. snowmelt as the dominant flood generating process in different regions, at differing altitudes and as a function of catchment area, as well as dominant storm tracks. The results for the FFA methods which include a shape parameter indicate a similar regional pattern, although projected increases are generally larger than those based on the Gumbel model.

Variance decomposition was used to assess the relative contributions of the following ensemble components to the total variance: climate models, hydrological parameterisations, and the distribution of flood frequency estimates. The results indicate that, in most cases, differences between climate models contribute slightly more than half of the total variance in the ensemble. The contribution of FFA is generally of a similar order of magnitude to that from the climate models and, as expected, is higher for the distributions with a shape parameter (up to 60% of the total variance). Uncertainty from the hydrological model parameterization is relatively small, in comparison with the two other factors, although it can be large for individual catchments (up to 40%) in regions where the dominant flood generating process changes between the reference and the future period. Overall, the results underscore the considerable uncertainty introduced by FFA when developing estimates for flood hazard under a future climate. Although this factor is well appreciated in practical applications of FFA for the current climate, its implications for analyses of future changes should also be considered.

This study is a contribution to the ExPrecFlood project, supported by the Norwegian Research Council and the Norwegian Climate Services Centre.

Empirical Model to extrapolate Aerosol Optical Depth (AOD) over cryospheric portion of Nepal Himalaya

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A new method of estimating the aerosol optical depth (AOD) over the cryosheric portion of Nepalese Himalayan is introduced. Multivariate regression analysis method is carried out to develop a aerosol prediction model. Three topographic parameters- altitude, longitude, and latitude and two meteorologic variables-total columnar water vapor and surface pressure were taken into account for model development. These topographic parameters and meteorologic variables were acquired from a 30 m resolution ASTER digital elevation model (DEM) and daily ERA-interim datasets. Seasonal and inter annual variability in aerosol optical depth are investigated using MODIS (MODerate Imaging Spectrophotometer) product over Nepal during 2000-2015. Result shows that the AOD in winter followed by Autumn is higher then in summer and also elevation dependent. Empirical model that we have developed from spatially average data presented here is able to extrapolated with the coefficient of determination of 0.93. The average model that we have presented in this paper, could potentially be applied to other mountains and in mountain climate research.

Developing indices for climate drivers of high-latitude rain-on-snow events

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Rain-on-snow events can lead to floods and adversely affect ecosystems at high-latitudes. Such compound events may not be fully characterized, from a climatological perspective, by simple indices currently used in the community (e.g. ETCCDI indices of climate extremes; etccdi.pacificclimate.org <http://etccdi.pacificclimate.org/>). This study will develop evidence-based indices for climate drivers of rain-on-snow events for recent decades, with a focus on Norway. The indices will be developed using high-resolution observational datasets (e.g. SeNorge) and datasets of climate model simulations under historical climate forcing (e.g. ARCTIC-CORDEX; EURO-CORDEX, recently bias-adjusted against SeNorge; CMIP5/6). The focus will be on relevant atmospheric drivers, including synoptic situations, and their thermodynamic and dynamics components.

First results from snow and stream water isotope analysis: Spatial and temporal variability of the snow pack and its representation in melt water streams

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As part of the PhD project "Closing the water balance in glacierized and unglacierized catchments", snow samples have been taken of snowpits over the last winter season and were analyzed for stable water isotopes together with stream water samples from the melt runoff from two catchments. These data will be used e.g. for backtracking the origin of moisture or identifying and quantifying different runoff components. Here first results from the measurements will be compared to the statigraphy of snow packs to assess temporal and spatial variation in the snow pack and discharge.

Trends in Seasonal Low Flow in Norway

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Knowledge of the regional and temporal variability of low flow is important for water management, energy production demands and water quality and biodiversity. As climate is warming, hydrological behaviour is changing, and thus likely also low flow. In Norway, low flow is mainly controlled by frost processes in winter, and the balance between rainfall and evapotranspiration in summer. In this study, trends in summer and winter low flow characteristics were investigated for near- natural gauging stations in Norway by the use of 117 mean daily discharge series obtained from a hydrological reference dataset. A 30-year period, 01.10.1984-30.09.2014, was used for the analyses. Two different low flow regime classifications aiming to capture the dominating low flow process for each catchment were assessed and used as a sample basis for seasonal trend analyses. The monthly based low flow regime classification was based on the timing of the two lowest mean monthly discharges, whereas the seasonal ratio based low flow regime classification was based on the ratio between summer and winter low flow. Trends were calculated using the Mann-Kendall trend significance test and the Kendall-Theil robust line magnitude test. The variables investigated were mean discharge (Q), the annual minima 7-day flow (AM(7)) and the day number of occurrence of minima flow (DN). The regime classifications yielded a large portion of winter low flow dominated catchments. Summer low flow regimes were located along the coast and at lower altitudes in southern and western Norway, and winter low flow regimes in the inland, at higher altitudes and in northern Norway. The methods yielded similar spatial distribution of the regimes and indicated temporal stability the recent decades. In general, significant trends towards increasing AM(7) in the southeast and northern Norway, and significant trends towards decreasing AM(7) in coastal western regions of Norway, were found for both the summer and (to a less degree) the winter season. The trends were partly reflected in seasonal Q trends. Trends in DN were weak or absent, except for a significant trend towards earlier DN in winter in an area from south of mid-Norway to northwester parts of the country. The results contribute to the understanding of seasonal low flow on a regional scale and in a changing climate.