SNOW MAP VALIDATION FOR NORWAY

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ABSTRACT

met.no has published snow accumulation maps for Norway for more than 50 years. During the winter 2003-2004 new methods are developed by NVE and *met.no* to produce snow maps accounting for melting, refreezing and winter rain. The maps are daily products updated on a weekly basis. Spatial estimation of air temperature and precipitation is applied to observations from the Norwegian meteorological network. A snow model is used to simulate the snow water equivalent (SWE), liquid water content and runoff on a 1x1 km^2 and one-day resolution. This paper presents the results of validation experiments. The main validation is against snow data from more than 100 catchments (most have >20 observations at annual snow maximum). Simulations are compared to snow pillow observations, as well as simulation and observation of runoff for two large catchments. The results show a very good agreement between simulated and observed SWE in terms of the deviation from normal. Observed geographical patterns are well reproduced all over the country, including years of extremes. Simulated SWE in millimetres agree well with observations in northern and central parts of Norway, although SWE is overestimated in some areas in the south: probably due to the interpolation of precipitation.

INTRODUCTION

Snow plays an important role in the Norwegian society and nature, as it does in many other cold-region countries. Apart from being a recreational benefit to the population, it affects essential functions such as hydropower production, infrastructure maintenance and accessibility, and transport efficiency. It may also contribute significantly to very large and damaging floods, and be a risk factor for avalanches. The living conditions of animals and plants are in many parts controlled by the snow distribution and state. Snow influences the climate and at the same time responds directly to climate change.

Snow observations are sparse, as it is difficult and costly to observe the wide extent and rapid fluctuations of the snow cover. This paper presents validation of an

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approach (described in Engeset et al., 2004), aiming at reproducing the spatial and temporal changes in the snow cover based on spatial interpolation of meteorological data and a distributed snow model. Daily simulation of snow characteristics is updated weekly from the winter 1961-1962. The results are presented in more than 300,000 maps (20 per day) in web- and GIS-based navigation tools. Product confidence is the key issue addressed in this paper, where mainly the snow water equivalent (SWE) maps are validated.

INTERPOLATION OF PRECIPITATION AND TEMPERATURE

The snow model requires daily input of temperature and precipitation data distributed in a 1x1 km^2 resolution grid. Gridded fields are derived from observations in the precipitation (630 stations) and synoptic weather station (150 stations where temperature is observed) networks.

Temperature has a strong relation to altitude and degree of continentality. These relations are used to describe deterministic trends in a residual interpolation approach. The interpolation expressions were originally developed for mean monthly temperatures (Tveito et al., 2000), but shows also good performance also on a daily scale (Tveito et al., 2002).

Precipitation is a difficult element to distribute in space, due to its non-continuous random behaviour. Terrain has an obvious influence on precipitation distribution. Distance to the sea also. Studies have shown that the general circulation give distinct patterns of precipitation in Norway (Tveito, 2002).

Precipitation measurements are encumbered with systematic under-catch due to aerodynamic effects around the gauge. During the winter season, gauges at very exposed sites catch less than 50 % of the true precipitation. Knowing the wind exposure at the station, as well as precipitation state, these losses can be adjusted. Here a temperature threshold is used to define the state of the precipitation (solid, wet or mixed).

As a simple “first”-approach (preliminary reference method), precipitation is estimated using a triangulation technique. Inputs are observed precipitation, corrected for systematic wind losses according to Førland et al. (1996), and temperature (observed or estimated) at the station used to define the state of precipitation. Precipitation is expected to increase by 10 % per 100 m up to altitudes at 1000 m a.s.l. and 5 % at higher altitudes. Two sets of triangles are established, one based on observed and catch-corrected precipitation, and one based on the altitude of the observation stations. If estimated grid precipitation (gridded from triangles) is higher than 0.05 mm, the vertical precipitation gradient is added to the grid precipitation according the difference between the gridded triangle altitude and the “real” terrain model.

SNOW MODEL

The snow model is a precipitation/degree-day type model. It simulates snow accumulation, snowmelt (degree-day approach, e.g. Bergstrøm, 1992), as well as production of liquid water and refreezing. Internal variables are used for fixed temperature-dependent thresholds for separating rain from snow, and to identify snowmelt and refreezing. Snowmelt intensity is specified by a time-varying variable and refreezing intensity by a constant. Only precipitation and air temperature are required as model input data. The availability of such data has lead to extensive use of degree-day models in operational flood forecasting (e.g. WMO 1986) and sensitivity studies of snow-covered basins to climate change (Sælthun et al., 1998, Vehviläinen and Lohvansuu, 1991). Degree-day models may use radiation (Rango and Martinec, 1995). Energy balance models, such as SNOWPACK (Lehning et a., 1998) and SNTHERM (Jordan, 1991) require further meteorological input data. These models represent the physics behind melt and give more accurate representations of the spatial distribution of melt within small research basins. Operational applications are hampered by limited availability of distributed input data.

The state variables SWE and snow liquid water content (LWC) are updated on a daily basis. The model also simulates water yield from snowmelt and rain. The model was earlier developed and tested for point observations (Engeset et al., 2000, Tveito et al., 2002, Engeset et al., 2004).

The model is now developed into a gridded model and operates on spatially interpolated meteorological data. The model is run using a spatial resolution of 1x1 km^2 and a temporal resolution of one day. No correction is applied to precipitation or temperature input data as was done in the earlier studies (Tveito et al., 2002, Engeset et al., 2004), as this is incorporated in the spatial estimation procedure. The calculated values are stored for every day.

The model parameters are based on results from the works by Engeset et al. (2000, 2004), where time series of SWE observations and snow depth observations were used to calibrate the model. However the refreezing rate has been increased from 0.01 to 0.07 to simulate the liquid water content more correctly. This change made no substantial improvements in the SWE simulation. The parameter for maximum relative content of liquid water is set to 0.1. The degree-day melt factor varies according to the sun elevation between a minimum value at 21 December and a maximum value at 23 June. The minimum value is set to 2.0 mm ºC^{-1} day^{-1}. The maximum value is set to 3.0 mm ºC^{-1} day^{-1} in forested areas. In non-forested areas, the maximum value varies according to latitude from 3.5 in southern Norway to 4.0 in northern Norway. The threshold temperatures used to separate snow from rain and to identify melting/refreezing are set to 0.5 °C and 0.0 °C respectively.

This study reports the finding from running the model every winter during a 23-year period, from the autumn of 1980 to the summer of 2003. In this paper autumn 1980 to summer 1981 is coined the winter 1981 and so on.

VALIDATION

Precipitation observations

All available observations from the official *met.no* network are used to establish the precipitation grid. For independent validation, ten stations are kept out from the triangulation for the period 1962-1969.

Snow pillow observations

Snow pillows observe the overburden pressure of the snow pack, and in this manner, NVE records the SWE daily at 19 locations in Norway. Two pillows with long time series, located at Kyrkjestølane (1000 m a.s.l. in central southern Norway) and Vauldalen (840 m a.s.l. in east southern Norway), are compared to the model at the nearest simulation grid cell at the yearly snow maximum.

Water balance

The national flood forecasting service uses the HBV model (Bergstrøm, 1992) to simulate the water balance in about 80 catchments in Norway. The model is calibrated against discharge. Both floods and accumulated amount of discharge over a longer period is used to optimise the calibrated parameters. A well-calibrated model is expected to simulate the total amounts of snow and discharge. Simulation of the snow reservoir in two relatively large catchments in southern Norway, Losna (11,087 km^2) and Elverum (15,428 km^2), is compared to the snow model simulation at yearly snow maxima.

Catchment snow observations at snow maximum

Hydropower production companies collect a large number of snow depth and density data from their catchment areas during the winter. These data are used to estimate the SWE of the snow volume stored in the catchment. The snow is a secondary water reservoir, which melts and fills the water reservoir during the spring and summer for electricity production. Thus snow information is important to production planners and stakeholders in the energy market. The most important time to know the size of the snow reservoir is at maximum, which typically occurs during April or May. At this time demands are high and reservoir contents at a minimum due to high production and low winter inflow.

Snow is typically measured at a number of fixed locations within the catchment. During the last two decades most operators have conformed to snow course measurements of SWE: observations of snow depth at 20 to 100 locations along 200-2000 m long profiles and snow density measured at one to three locations. SWE is calculated as the product of average snow depth and density for each snow course. Data from a one or many snow courses are typically combined into one estimate of the average SWE of the catchment. The techniques used to estimate the catchment SWE varies from operator to operator, and are in many cases based on regression analysis between snow course data and inflow data corrected for precipitation and evaporation.

To test the snow model, catchment SWE observations and simulation are compared. A map of all snow observation polygons (typically drainage area of hydropower reservoirs) is used for calculating catchment average at the snow reservoir maximum each year in the test catchments (Fig. 2). Absolute values and percent of average for a reference period (departure from normal) are tested.

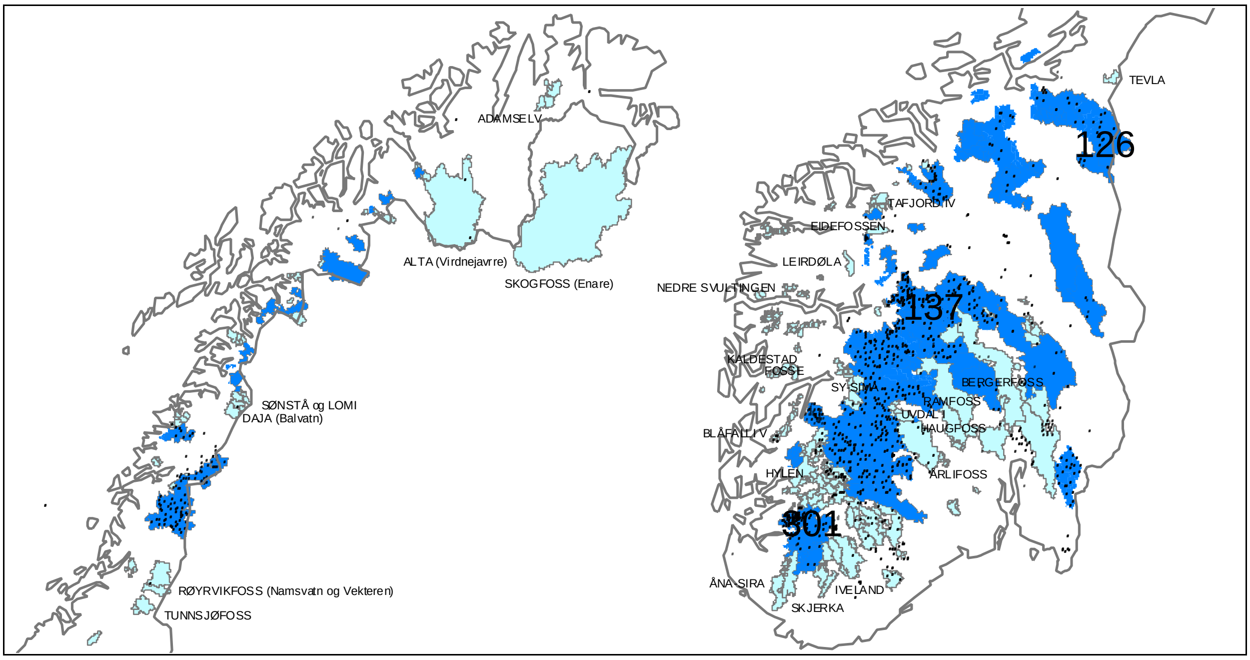

Figure 2. Map of catchments with snow observations at snow maximum (points) and catchments (dark grey), and the hydropower production catchments in Norway (light grey areas). Numbers refer to the three catchments in Fig 7.

RESULTS AND DISCUSSION

Precipitation interpolation

A first limited validation of the interpolation using a limited number of independent precipitation stations indicates that the elevation gradient is too large. Stations located at higher elevations than the surrounding stations gets too high estimates, and stations located at lower levels is somewhat underestimated (Fig. 3). This validation is very limited, and a more thoroughly validation is currently being carried out.

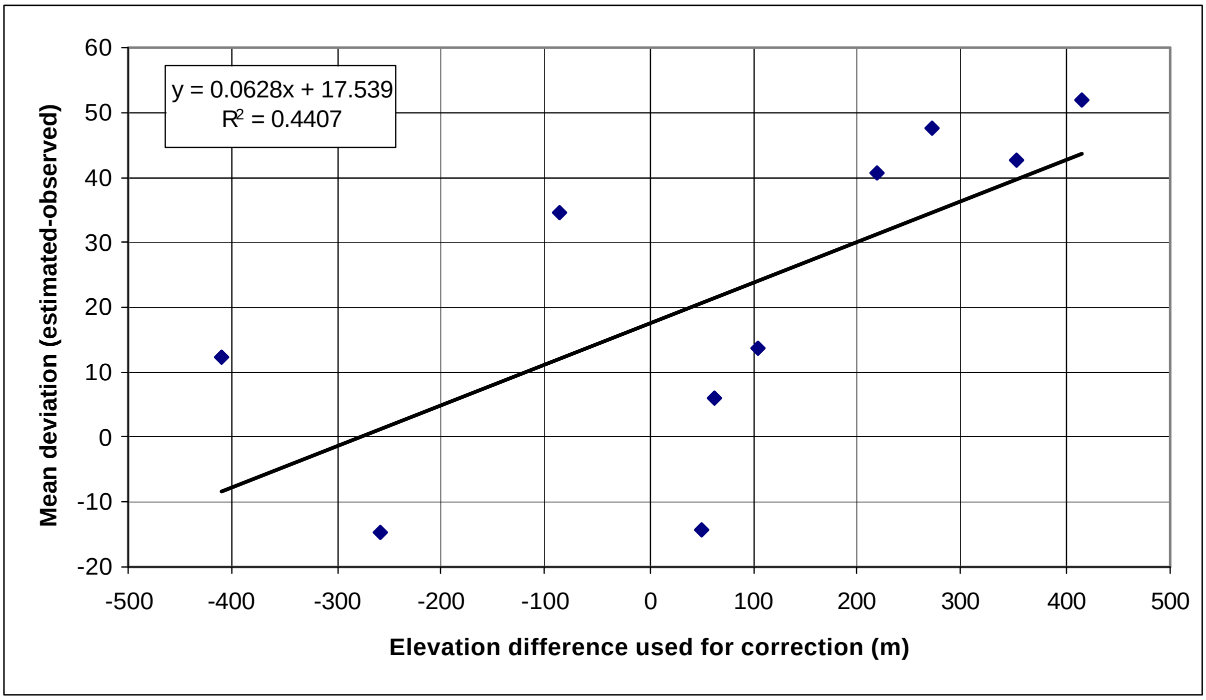

Figure 3. Plot of mean deviation between interpolated and observed precipitation against the elevation of the station at ten stations.

Snow pillow observations

Fig. 4 shows that both year-to-year variation and absolute values of observed maximum SWE are fairly well simulated by the snow model at Vauldalen snow pillow. The pillow is situated close to the precipitation gauge, while the nearest temperature station is located not more than 200 m lower in elevation. For Kyrkjestølane, the year-to-year variation is simulated fairly well for most years, with some exceptions such as 1989.

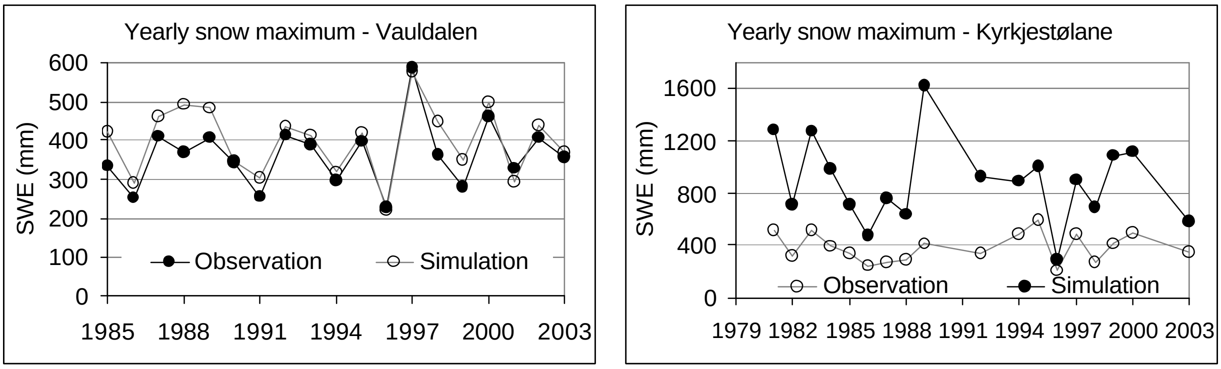

Figure 4. Observed and simulated snow water equivalent at yearly snow maxima at the snow pillows Vauldalen (left) and Kyrkjestølane (right). Kyrkjestølane has no observations in 1990, 1991, 1993 and 2002.

Reducing the snow model results at Kyrkjestølane by 55 % give better accordance with observations. This illustrates the problem of interpolating precipitation and temperature. The Kyrkjestølane snow pillow is located about 900 m above the nearest temperature station and about 200 m above the nearest precipitation station. The effect seems to be a constant overestimation of the precipitation accumulated as snow, maybe combined with an underestimation of the temperature causing more simulated snow events. An additional uncertainty is that this snow pillow is situated in an open and windy area, where wind drift of snow may affect the observations.

Water balance observations and simulation

The HBV model in the Losna and Elverum catchments uses five precipitation stations. Fig. 5 suggests that precipitation is over-estimated by the snow map model. The year-to-year variation is similar that produced by the HBV model.

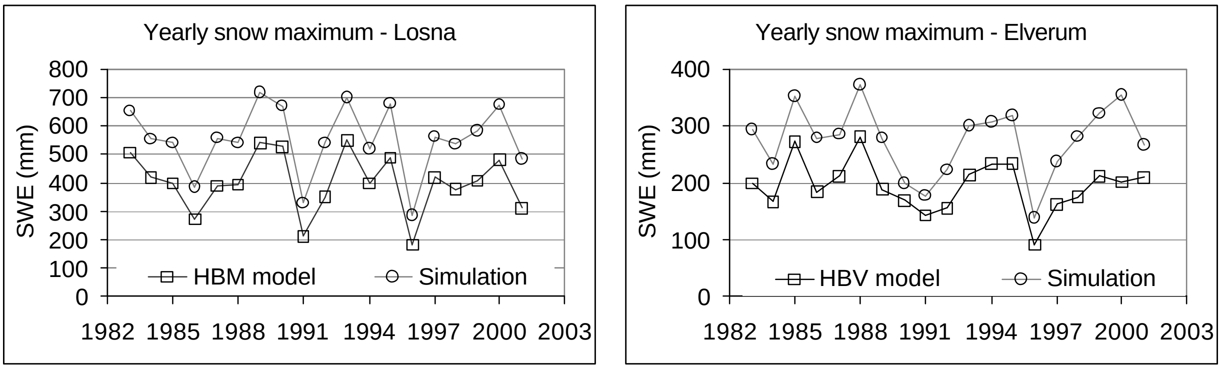

Figure 5. Snow water equivalent at yearly snow maxima simulated by the HBV model and the snow map model at catchments Losna (left) and Elverum (right).

Manual field observations in hydropower catchments

SWE observations are available for 101 catchments in 2003, of which 84, 32 and seven catchments have time series from 1981, 1971 and 1961 respectively. Simulated and observed SWE series are compared. As shown in Fig. 6, the comparison show that the geographical patterns are very well reproduced, and that years with extreme values in different parts of the country as well as the normal winters are possible to simulate using this approach.

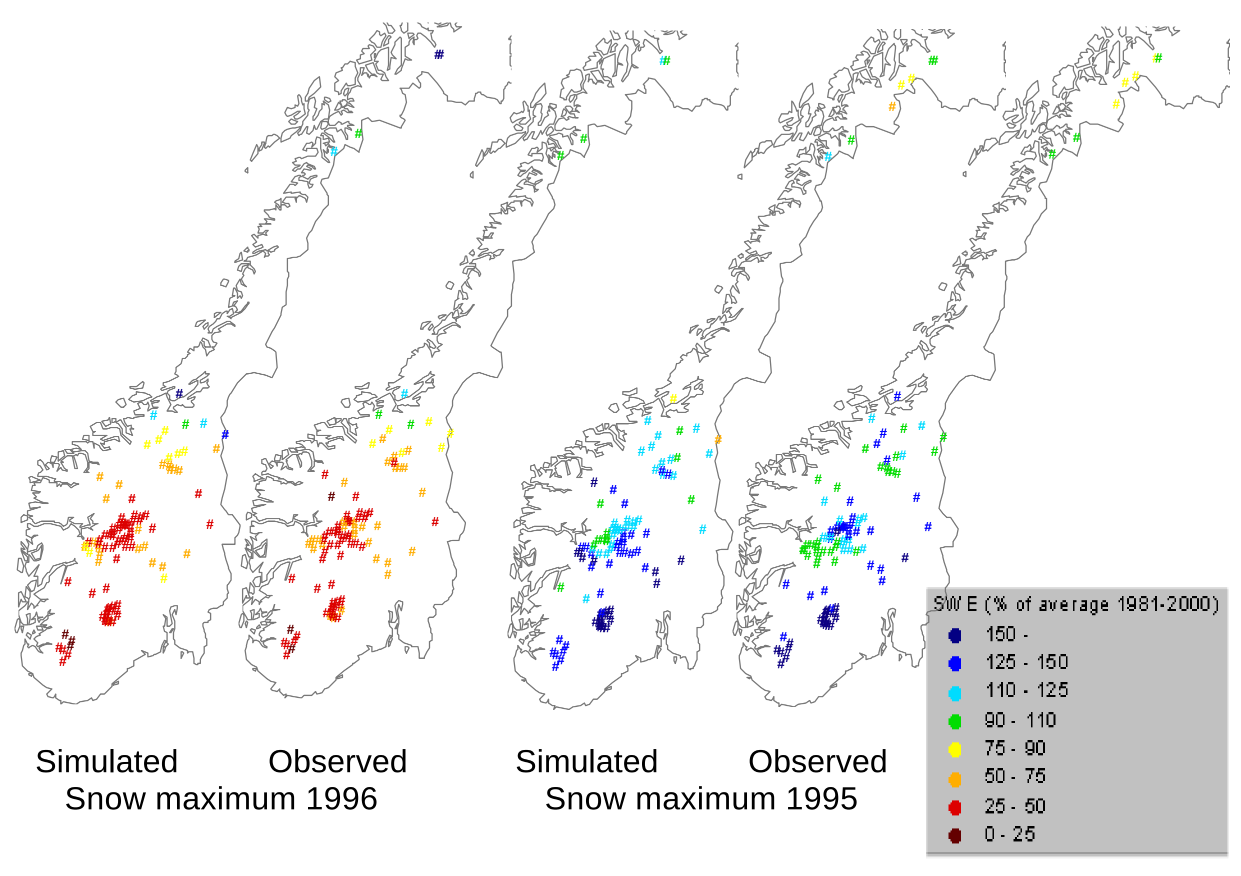

Figure 6. Simulated and observed snow water equivalent at snow maximum in 1996 (two left maps) and 1995 (two right maps) as % of average for 1981-2000.

Time-series plots of simulated and observed SWE at some of the catchments show how the temporal variation is reproduced by the model (Fig. 7). The results are very encouraging. Simulations are in good agreement with observations for most catchments, both in terms of reproducing absolute values and variation from year to year.

In the southern mountains of South Norway, the simulated SWE is in some catchments about double of observed, albeit inter annual variation is well reproduced. This is an area with a rather drop in precipitation values between the wet west coast and the dryer eastern part of Norway. This large precipitation gradient in combination with a very sparse meteorological observation network makes spatial interpolation of precipitation a challenge in this area.

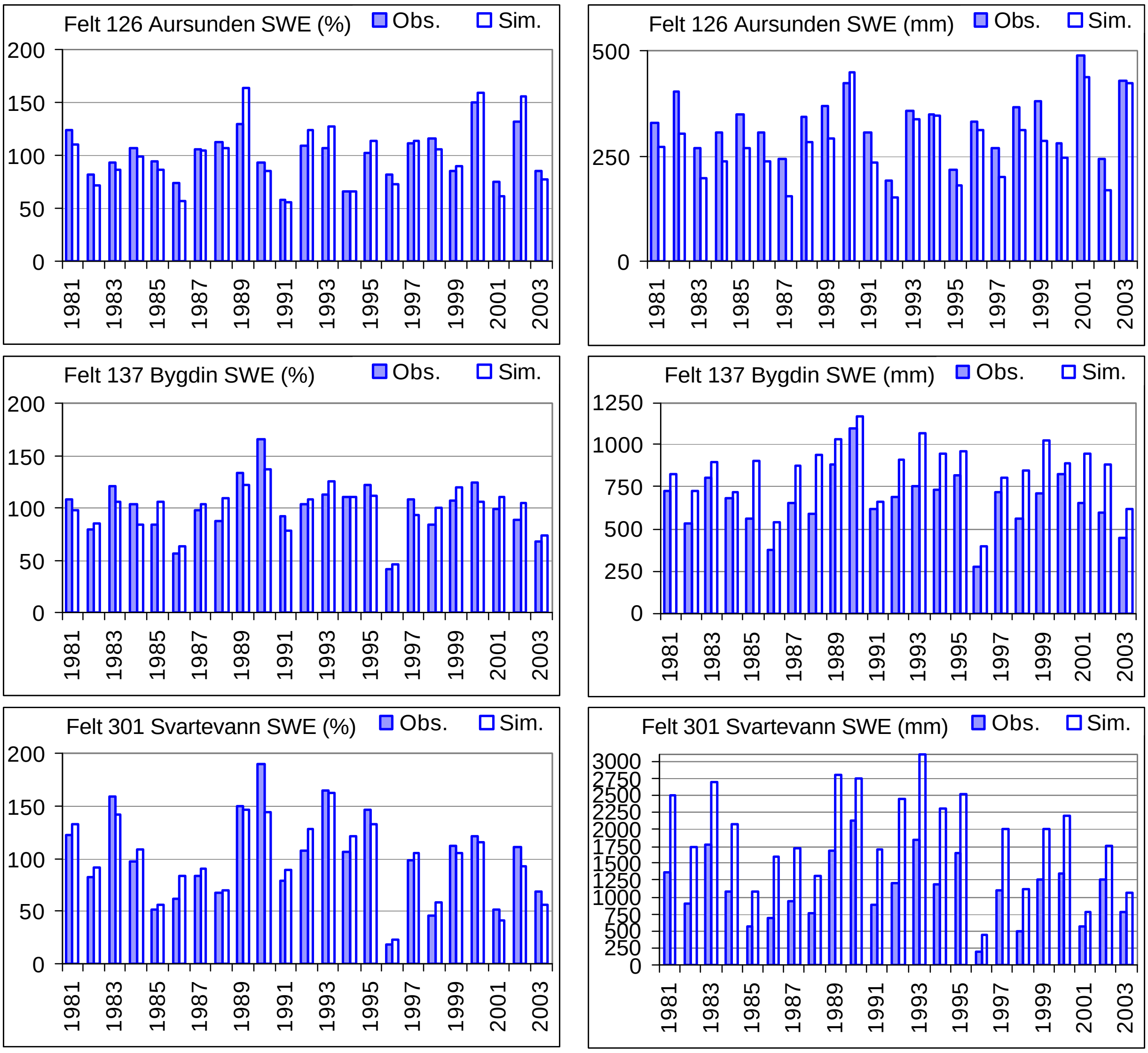

Figure 7. Time series of simulated and observed snow water equivalent for four catchments at snow maximum: Left percent of mean and right millimetres. Data from GLB (Felt 126 and 137) and Sira-Kvina (Felt 301).

CONCLUSIONS

A snow modelling approach is presented, where daily snow maps for Norway are produced using spatial interpolation of precipitation and temperature as input to a distributed snow model. Validation experiments are presented, where snow simulations are compared with observations from more than 100 catchments, snow pillows, and runoff simulations and observations.

The results show very good agreement between simulated and observed SWE in terms of deviation from normal. Observed geographical patterns are well reproduced all over the country, including years of extremes. Simulated SWE in millimetres agree well with observations in northern and central parts of Norway, albeit SWE is overestimated in some areas in the south: probably due to the interpolation of precipitation. Thus a more sophisticated interpolation model is now being developed for precipitation.

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