Snow simulation and forecasting through all Norway: the SeNorge model

Stefano Endrizzi[1,*] and Thomas Skaugen[2]
[1] Norwegian Water Resources and Energy Directorate, Hydrology Department, Oslo, Norway.

ABSTRACT: A model has been recently set up (since 2006) that provides the snow conditions, along with other hydrometeorological parameters, for all Norway at 1 km resolution. This model is called "Senorge" (meaning "See Norway"), and is described in this work. It is an operative model that is run daily predicting snow water equivalent, snow depth, snow changes (for melting and snowfalls), and snow wetness, and the results are published daily in the Senorge website (www.senorge.no). Though melting is estimated with a temperature index approach, a simple module describing snow metamorphism has been implemented and tested against several measurements performed in snow pillows. The goals and ambitions are various, and range from water resources monitoring and water availability assessment for hydroelectric power to avalanche warning and evaluation of skiing condition. Efforts are currently being made to improve this model, in particular implementing a full energy balance model and trying some procedures of data assimilation of remotely sensed data. In addition, a progress in the snowpack description in order to provide information about avalanche occurrences is being investigated

KEYWORDS: Norway, Snow modelling, Snow Monitoring

1 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. On the downside, it may significantly contribute to very large and damaging floods, and it can be a risk factor for avalanches. The living conditions of animals and plants are to some extent controlled by the snow distribution and state. Snow influences the climate and, at the same time, directly responds to climate change.

Maps and applications showing the snow covered area are published in a number of countries on more or less regular basis based on satellite imagery. Snow maps presenting other snow variables, such as the snow water equivalent (SWE), are produced in a few countries. The Finnish Environment Institute (SYKE) and Regional Environment Centres publishes daily snow maps (SWE and snow melt) on the Internet (http://www.ymparisto.fi/) based on hydrological models and snow courses observations. The Swedish Meteorological and Hydrological Institute (SMHI) publishes monthly snow maps of simulated SWE for Sweden on http://www.smhi.se/. The National Operational Hydrologic Remote Sensing Center at the National Weather Service (http://www.nohrsc.nws.gov/) publishes a larger set of snow variables as maps supported by a web-based navigation facility. This type of temporal and thematic navigation does not exist in Nordic snow map services. The maps show SWE, snow depth, snow pack temperature, snow precipitation, snow melt and blowing snow sublimation. SWE and snow depth maps are produced from simulation and observations. Maps of SWE in Canada is published by Meteorological Service of Canada (http://www.msc-smc.ec.gc.ca/) based on satellite passive microwave radiometers.

In Norway several snow related maps (SWE – snow depth – snow melting – snow accumulation) are produced daily and are freely available for the public on the SeNorge (which means See Norway) internet site http://senorge.no/. On the same internet site information provided by other models about weather, climate and soil hydrology is available, but their generation is not described in this work.

2. SNOW MODEL

The SeNorge 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 al., 1998), SNTHERM (Jordan, 1991) or GEOtop (Zanotti et al., 2004) 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 snow water equivalent (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 km2 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. 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 $°C^{-1}$ day^{-1}. The maximum value is set to 3.0 mm °C-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.

3. DATA – INTERPOLATION – SIMULATION

Meteorological observations

All available observations from the public meteorological network observing temperature and precipitation are used in the map production. Presently temperature is observed at about 150 and precipitation at about 630 stations. For temperature most of the observations are available in real time. The precipitation network in Norway consists of mostly two types of stations, the synoptic weather stations which report in real time and climatological precipitation stations. The latter group of stations have traditionally not reported in real time, but have sent their reports weekly.

Reporting in real time has recently been introduced at precipitation stations using mobile phone technology at approximately 50 % percent of the stations. This number is continuously increasing. The map production is carried out once a week, and running the spatial interpolation for the last two weeks almost all stations are applied.

Interpolation of temperature and precipitation

Spatially distributed estimates of temperature and precipitation are needed as input to the snow accumulation/snow melt model. Both precipitation and temperature grids are at a spatial resolution of 1 km x 1 km. Temperature is estimated by applying a residual interpolation technique using terrain and geographic position to describe the deterministic component (Tveito et al. 2000).

Precipitation is spatially distributed applying triangulation with terrain adjustment. Triangulation is a standard procedure for describing (spatial) surfaces. Triangles are built between three and three points. In this case the surface will describe precipitation corrected for catch loss based on a simple model proposed by Førland et al. (1996).

In addition a surface describing the elevation between the precipitation stations is established. This is motivated by the assumption that precipitation increases with elevation. Earlier studies have shown that in Norway this increase is 8-10 % at elevations below approximately 1000 m a.s.l and about 4-5 % at higher altitudes. Combining these gradients with the deviation between the elevation surface based on precipitation stations and a digital elevation model on the estimated precipitation surface, produces a terrain-adjusted precipitation grid.

Snow simulation

The snow model is a precipitation/degree-day type model similar to the snow routine in the HBV model (e.g. Bergstrøm 1992) and is described in Tveito et al. (2002) and Engeset et al. (2004). It simulates snow accumulation, snowmelt, as well as production of liquid water and refreezing.

Precipitation and air temperature data are used as input variables. Internal parameters are used for fixed temperature-dependent thresholds for separating rain.

4. SNOW MAPS

The snow maps are produced to reflect the daily and weekly state and change in the snow pack. Focus is on maps showing the snow water balance. The snow simulation period starts at 1 September every year. For each day throughout the year the following maps are produced:

- Snow water equivalent (SWE): millimetres, millimetres change last week, percent of the median value for the 30-year period 1971-2000, and rank of all winters from 1971. Two colour coding tables are applied: one for viewing SWE at parts of the winter with much snow, and one for the start and end of the snow period when the SWE range is small.
- Snowmelt: millimetres last day, and total last week.
- Total runoff: snowmelt and rain in millimetres last day, and total last week.
- Snow state: shows where the snowpack is dry, moist or wet. If the snow is wet it may yield runoff.
- Fresh snow: millimetres last day, and total last week.
- Snow age: number of days since last snow fall.
- Snow depth: centimetres.
- Snow model input: precipitation in millimetres last day and total last week; temperature last day.

All maps are prepared as images in the portable networks graphics (PNG) format. Image picture elements are 8-bit depth, use a pseudo-colour and represent 1x1 km^2 on the ground in the UTM zone 33 coordinates system and projection.

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