SNOW MAP SYSTEM FOR NORWAY

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ABSTRACT

During the winter 2004 new methods are developed by NVE and *met.no* to produce snow maps accounting for accumulation, melt, refreezing and winter rain. The maps substitute traditional snow accumulation maps, and are daily products updated on a weekly basis. Spatial estimation of temperature and precipitation is applied to observations from the Norwegian meteorological network. A snow model operating on a 1x1 km^2 and one-day resolution is used. The development of a web- and GIS-based system for producing the maps is presented. GIS technology is used for spatial estimation of weather elements, snow simulation during the winter, and presenting results as maps in order to serve Government and local authorities in early-warning of floods and hydro-electricity production and distribution shortages. A suite of 20 maps are produced daily and presented to users in web- and GIS-based interfaces. Maps of snow water equivalent (percent of normal, millimetres and rank), snow melt, runoff, snow state, fresh snow, snow age, snow depth and snow energy equivalent show daily and weekly totals or change. Web-based interfaces provide easy access and navigation in a 300,000-map archive from 1962. Snow maps combine with hydrology and energy-related data in ArcGIS and ArcIMS.

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 down-side it may contribute significantly to very large and damaging floods, and 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 responds directly 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 publish daily snow maps (SWE and snow melt) on the Internet (*http://www.ymparisto.fi/*) based on hydrological models and snow courses observations. Swedish Meteorological and Hydrological Institute (SMHI) publishes monthly snow maps of simulated SWE for Sweden on *http://www.smhi.se/*.

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 snow maps show SWE, snow depth, snow pack temperature, snow precipitation, snow melt and blowing snow sublimation. SWE and 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.

USER REQUIREMENTS

The national flood forecasting service is one of the most demanding users in terms of spatial and temporal resolution, near real-time and prognosis analysis, and national coverage. The service would like to use the snow maps for analysis and as a means of communications with local authorities and the public. The key elements of interest are SWE, snow cover extent and snow state (wetness).

Snow data are needed within management, planning and monitoring of hydropower production, distribution and markets overlap with those of flood forecasting. The focus is mainly on SWE. Less frequent data updates are required compared to flood forecasting and the snow maximum being the single most important point in time. SWE are required for catchments, and converted to the energy content of the snow using the energy equivalent factor specific of each dam or hydropower generator. The electricity production potential is assessed on the basis of the filling rate of the hydropower reservoirs, the size of the snow reservoir of the catchments, and scenarios of seasonal production and demands. Analysis and monitoring of geographical patterns of the snow distribution and filling rates are useful for distribution grid and market price management. This may be used to anticipate and mitigate loads on grid bottlenecks and defining local price areas.

All users benefit from map presentations, time-series plots (e.g., showing current snow situation compared to previous years) and GIS-functionality (e.g., catchment statistics and elevation-area distribution of snow). Tools for time-series and GIS analysis will be developed in the next phase of the project.

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 increase 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 from snow, and to identify snowmelt and refreezing. Snowmelt intensity is specified by a time-varying variable and refreezing intensity by a constant. The state variables SWE and snow liquid water content (LWC) are updated on a daily basis. The model simulates water yield from snowmelt and rain.

SNOW MAP SYSTEM

Processing chain

The data processing is carried out in five logical blocks as shown in Fig. 1. Meteorological observations are collected automatically or manually from the observation network: all temperature and 50-70 % precipitation observations from Friday to Friday are available in the production database at *met.no* by Tuesday afternoon. The point observations are distributed in space thus producing the gridded data. The gridded data is retrieved by NVE, who carries out steps 3 through 5. Visual checks are performed at all steps, and the presentations are only copied to the web service only if no errors are identified. Except from visual quality control in all steps, all processing is automated using Perl and shell scripting languages.

Snow maps based on meteorological observations have at least four days lag (maps until Friday are available on Tuesday). In order to offer snow maps for the next few days (always until tomorrow), the system executes steps 3 to 5 automatically at a daily basis using precipitation and temperature grids from the 48-h prognosis produced by the weather forecast model HIRLAM at *met.no*.

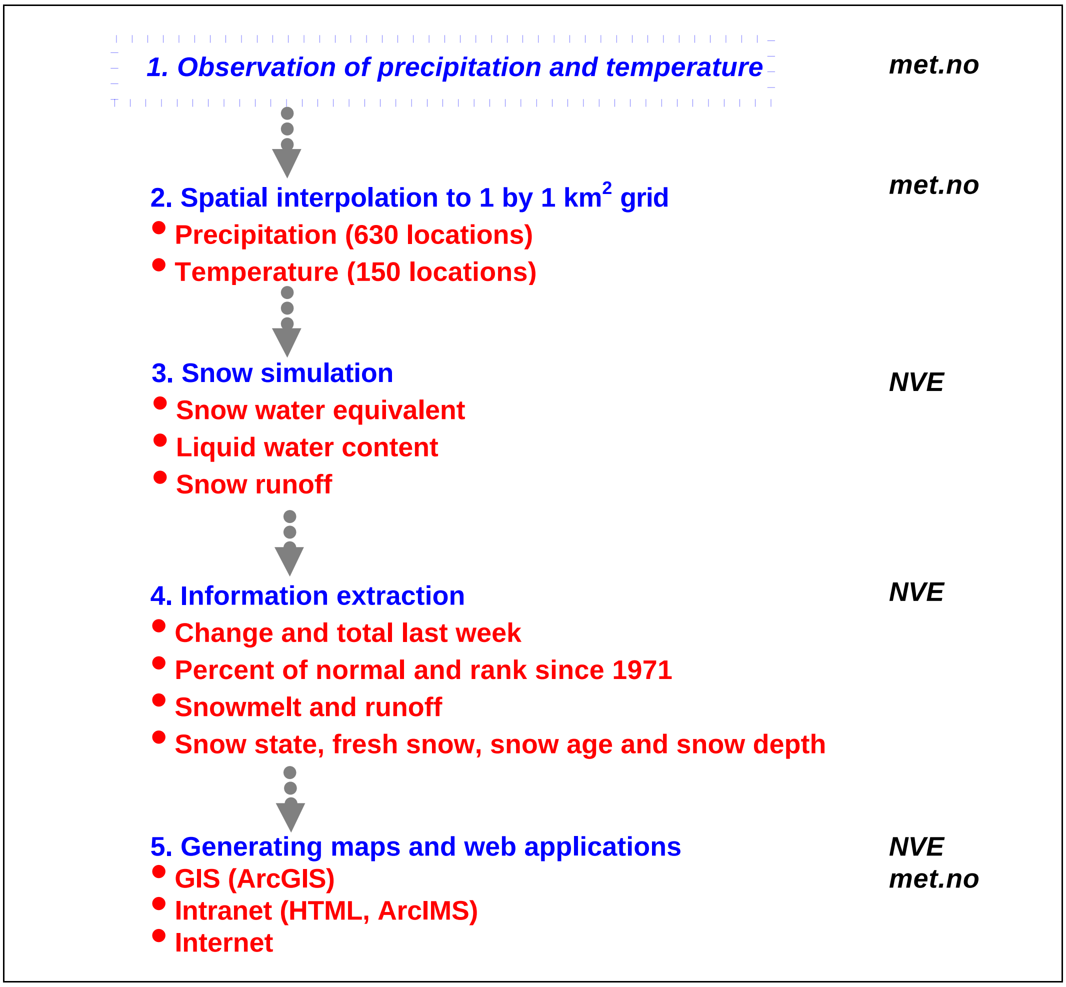

Figure 1. Data processing elements in the snow map system. Left column shows the five processes and right column shows responsible/implementing institution.

Historical archive

A historical archive of daily gridded data from the winter 1962 to the winter 2004 is established using the system. 8-bit or 16-bit binary grids are produced for the variables precipitation (RR), temperature (TM), snow water equivalent (SWE), liquid water content (LWC), fresh snow (FSW), snowmelt (QSW), runoff (QTT) and snow age (AGE). Maps are produced from the winter 1962: in total 43 years, about 16,000 days and more than 300,000 maps.

Updating

Weekly dispatches of the latest meteorological data are used for model updating throughout the winter. Observations for a 14-days period are retrieved every Tuesday afternoon: the most recent observation day being proceeding Friday. A two-week period is updated, as the observation set for the last week is typically containing 50-70 % of all observations: the remaining observations are entered in the database over the next few days. However, weekly updates are done Tuesdays in order to correspond in time with the publishing of the water reservoir filling rates in the Nordic countries.

Navigation and presentation

The snow map archive is disseminated at three channels: HTML-based Intranet and Internet navigation services, and an Internet Map Server (IMS) service on the Intranet. The Intranet services are currently available for NVE and *met.no* users only. A thematic-temporal subset of the snow map service will be available on the Internet. HTML in combination with web-scripting and PNG map images are used. ArcIMS from ESRI and HTML/JavaScript are used for the IMS service.

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. Requires a user-specified density, since the snow density not simulated in the present model.
- 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.

WHERE WERE THE MAPS WHEN NEEDED?

Shortage hydropower production

A sever situation occurred during the winter 1996. Very cold and dry weather triggered a risk of shortage of electricity production. The hydropower reservoirs were at a minimum, and knowledge of the size of the snow reservoir was important in order to manage the risk of electricity shortage. So, was the snow reservoir in 1996 in particular small in Norway? The answer is both yes and now, which is shown in the snow map system. The winter was very dry and cold. The public and the Government were worried about the very low water levels in the reservoirs. The situation was extreme. As shown in Fig. 2, the 1996 winter had the lowest snow quantity in southern Norway and the largest snow quantity in northern Norway during the entire period 1971-1996. E.g., the reservoirs of Nordmarka which serve as water-supply for Oslo were at a historic low. The annual discharge of the river Glomma (at Elverum) had never been lower during the entire observation period from 1872. In the North, on the other hand, snow was in abundance, and a large snowmelt-related flood was observed in the river Tana.

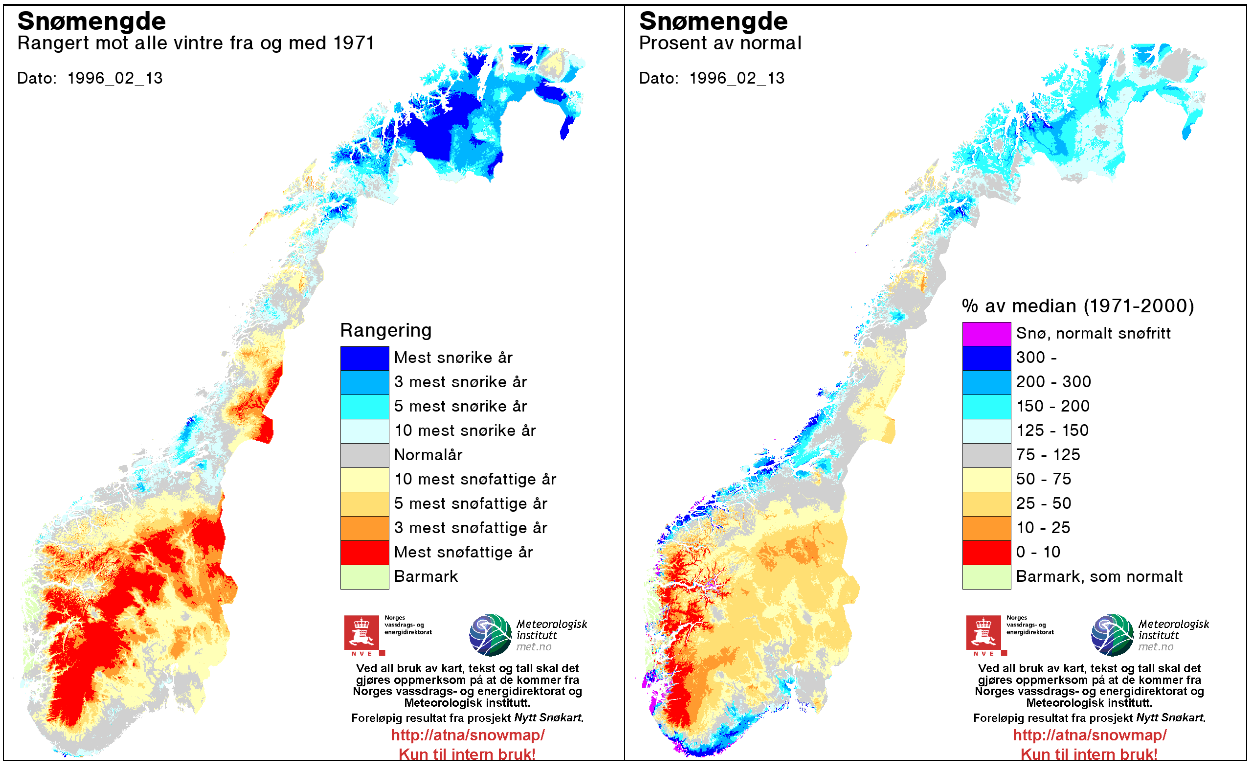

Figure 2. Two maps showing the unusual snow conditions during the winter of 1996: significantly less snow than normal in South-Norway and much more than normal in North-Norway. Left map shows amounts compared to all winters from 1971. Right map shows amounts compared to median for 1971-2000.

Floods

In Norway, large floods in the spring are often fed by intense snowmelt events. Did the snow contribute to the large "Vesle-Ofsen" flood in south-east Norway in

1995? The amount of snow was above normal, but not unusually large during most of the winter 1995. In southern Norway, the spring was cold and snowmelt less intense than normal. 24 May, prior to "Vesle-Ofsen", the maps show very large amounts of snow and an extended snow cover in areas normally not covered by snow at this time of the year (Fig. 3, right map). Using the snow map system it is possible to track the development of the flood and the contributions from snow and precipitation prior and during the flood: Fig. 3 (left map) shows where and how much fresh snow came the week ahead of 24 May. Fig. 4 shows clearly the areas where snowmelt contributed to the flood during the following week.

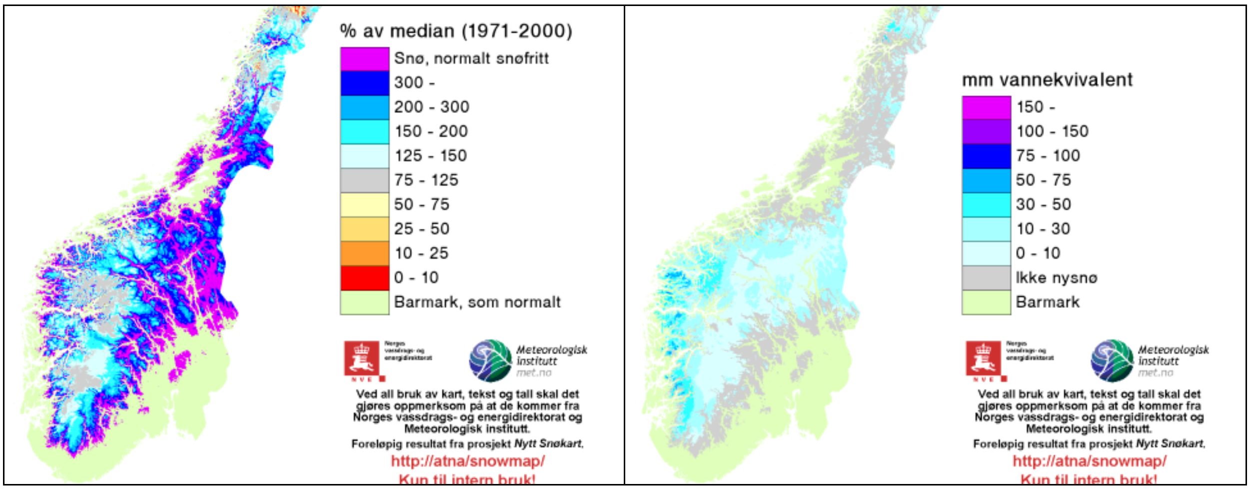

Figure 3. Unusual large amounts of snow and snow extent (class "Snø, normalt snøfritt") ahead of the flood in South-East Norway spring 1995: left map shows 24 May and right map shows amount and extent of fresh snow the week before.

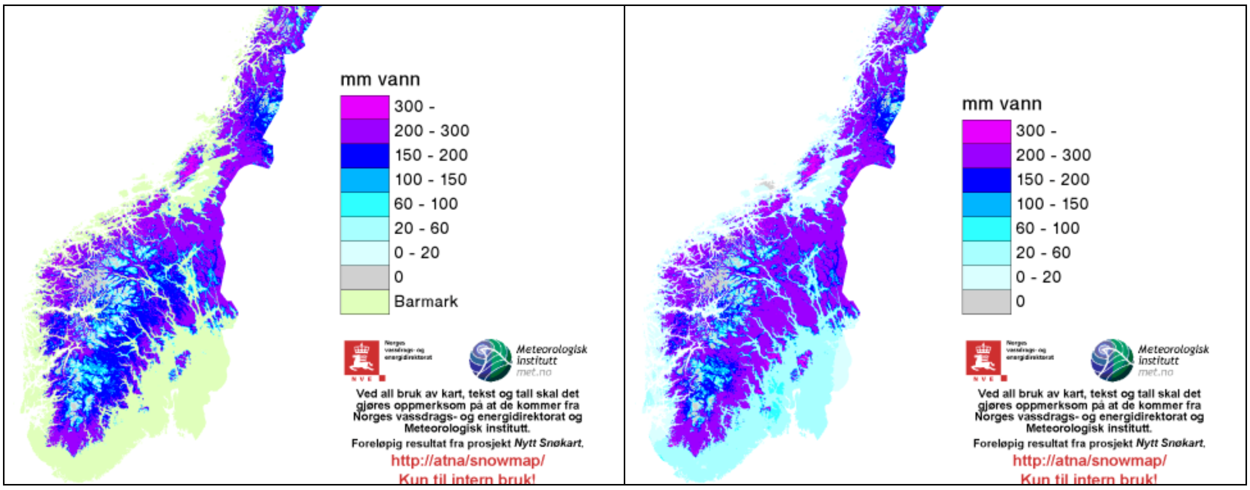

Figure 4. Maps showing the contribution from snowmelt (left) and snowmelt and rain (right) during the flood "Vesle-Ofsen" the last week of May 1995.

Recreation

The Olympics were hosted at Lillehammer in south-eastern Norway during the fortnight from 12 February 1994. The games were a success partly due to stable cold winter conditions and abundant dry snow (Fig. 5). The temperature remained low and kept the amount of snow along the ski tracks above average.

The snow map system shows what a “catastrophe” the Olympics could have been snow-wise if hosted for example in 1984 or 1992, and not 1994 (Fig. 6). Tromsø, a possible candidate for the 2014 games would have been a better candidate in these years, snow-wise. Snow maps produced from weather prognosis for the coming few days will provide skiers and others a great planning basis for activities apart from documenting historic events, and this will be implemented in the near future.

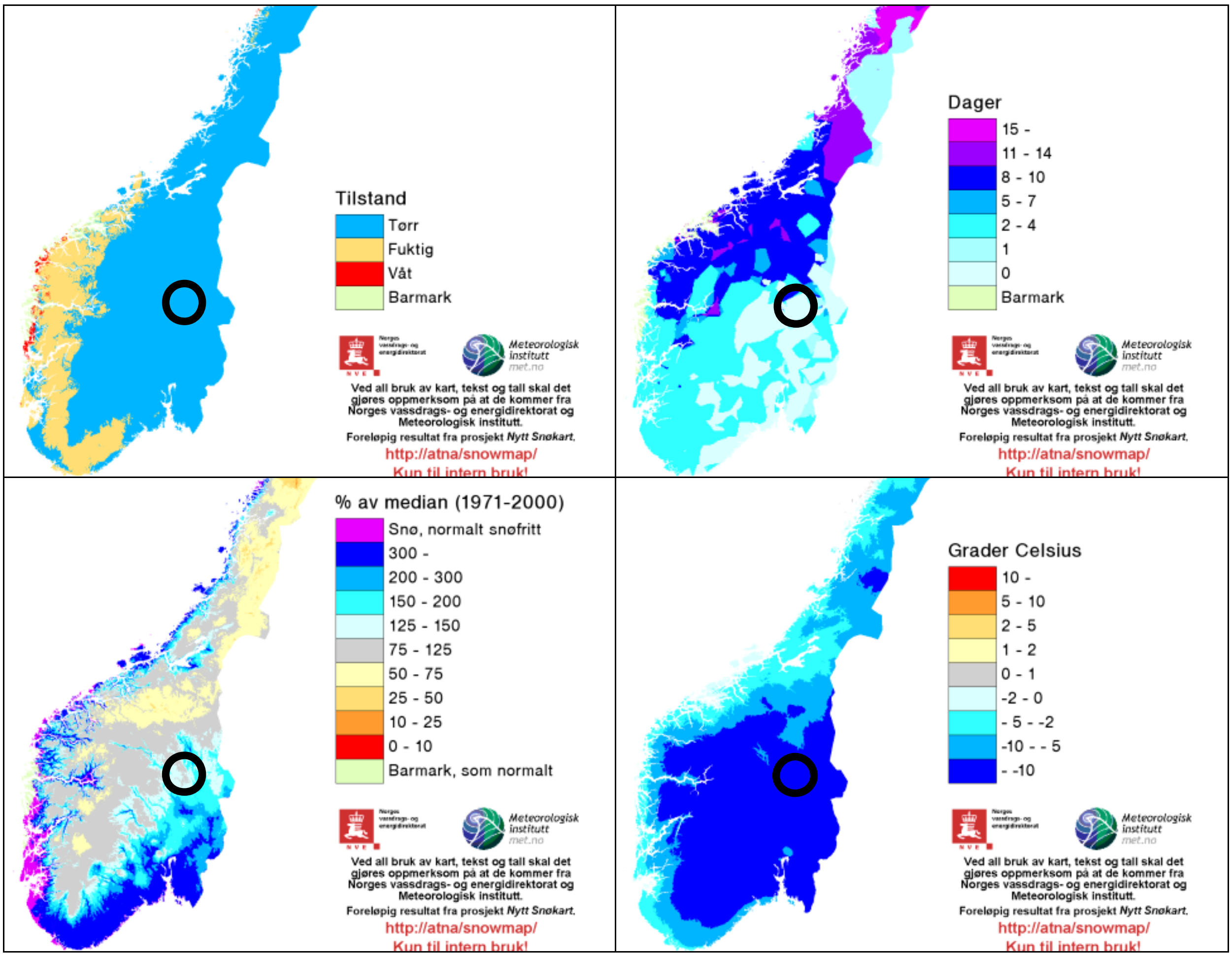

Figure 5. Top row maps show snow conditions at the opening of the Olympics at Lillehammer in 1994: Snow wetness (left) and days since last snowfall (right). Bottom row maps show amount of snow compared to normal and the air temperature (typical of the games). A circle shows location of Lillehammer.

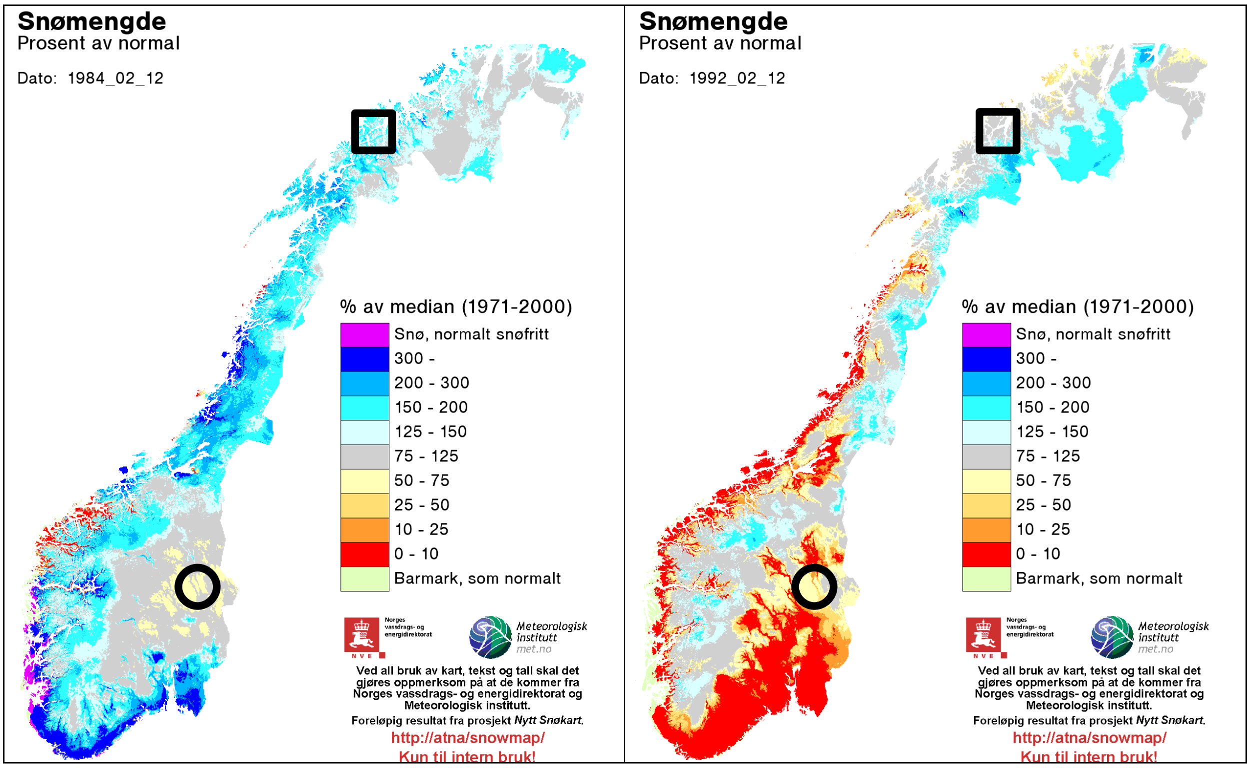

Figure 6. Snow conditions at Lillehammer in 1984 (left) and 1992 (right). Location of Lillehammer and Tromsø is indicated by a circle and a box.

CONCLUSIONS

Development and implementation of methods preparing snow maps for Norway provide national and local stakeholders tools for assessing a suite of snow-related risks and opportunities in a new way. A series of about 20 maps are available for each day in an archive from 1962, totalling more than 300,000 maps, and complemented weekly. Production of georeferenced image maps in web- and GIS-based applications provides quick and easy-to-use navigation in temporal and spatial domains.

Further work focuses on: 1. Make the snow map system available on the Internet; 2. Offer spatial navigation and GIS functionality; 3. Improve spatial estimation of precipitation; 4. Improve snow prognosis maps based on weather forecasts; and 5. Simulate the energy content of snow based on Norwegian hydropower catchments in order to provided better knowledge of risk of hydropower shortages during the winter and the summer.

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