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EO data in hydrological models

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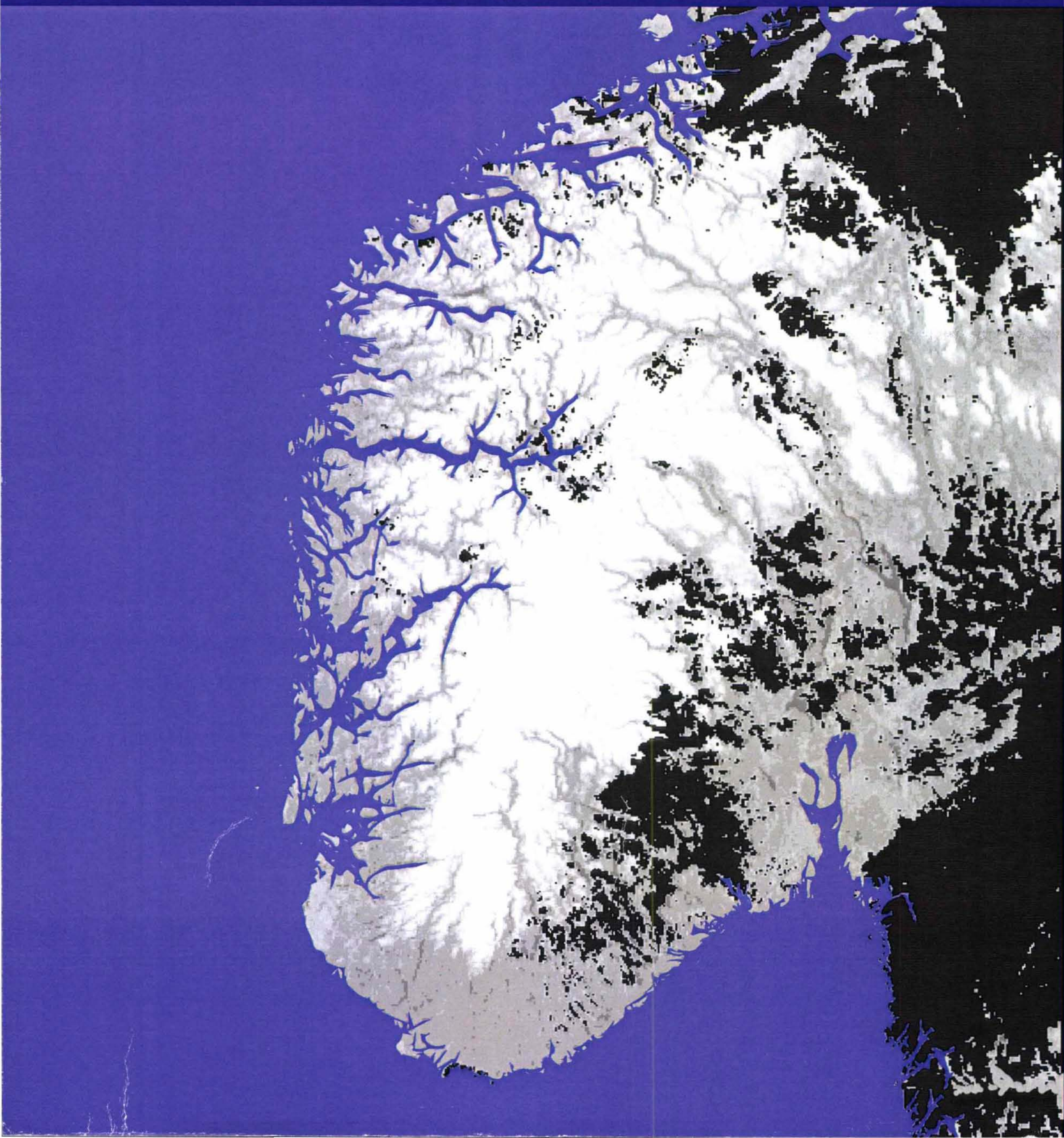
2001



REPORT

EO data in hydrological models

Requirements and operational concept

The Norwegian Water Resources and Energy Directorate

2001

Report nr 1

EO data in hydrological models

Published by: The Norwegian Water Resources and Energy Directorate

Editor: Hans-Christian Udnæs

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Print: NVE

Number printed: 25

Front page: Snow cover in southern Norway May 14th 2001. Based on NOAA-AVHRR satellite data.

ISBN: 82-410-0450-8

Abstract: This paper describes in brief the overall requirements in the SnowMan project and outlines the operational scenario of remotely sensed earth observation data (EO data) in hydrological models.

Key words: Snow monitoring, hydrology, remote sensing, HBV model, ECOMAG

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October 2001

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Preface

The research project SnowMan (Snow parameter retrieval from remote sensing data for improved monitoring and management of water resources) is funded by the Research Council of Norway (Project no: 143540/431) for the period 2001-2004. The goal of the SnowMan project is to improve methodology for remote sensing of snow parameters and the use of snow parameters in hydrological models in order to achieve better water management practices related to snow. This should result in improvement in flood prediction, river- and dam management and hydropower production planning.

The SnowMan partners are Norut IT (NORUT), Norwegian Computing Center (NR), Norwegian Water Resources and Energy Directorate (NVE) and the Department of Geophysics, University of Oslo (UiO).

In this project the satellite derived snow parameters will be integrated in the hydrological models HBV and ECOMAG, in order to investigate possible improvement in the hydrological modelling. NVEs role in the project is mainly integration of snow parameters in the HBV-model. Liss M. Andreassen is the project leader for NVE.

Oslo, October 2001

Kjell Repp
Director of the Hydrology Department

Liss M Andreassen

Liss M. Andreassen
Project leader

Abstract

This paper describes briefly the overall requirements of the Snowman project and outlines the operational scenario of remotely sensed earth observation data (EO data) in hydrological models. The EO data that will be used in the project are optical and synthetic aperture radar (SAR) data. Users of the data will be the National flood warning services at NVE and the Department of Geophysics, University of Oslo (UiO). For hydrological modelling NVE will use the HBV model and UiO will use the ECOMAG model.

The most important snow parameters are snow covered area (SCA) and snow volume wetness (SVW) for short time flood warning and snow water equivalent (SWE) for long term runoff prediction. SCA will be derived from radar and optical sensors. SWE and SVW is expected to be derived from radar sensors.

The users require snow data of spatial resolution 250-1000 m. This requirement is within the capabilities of the suggested sensors. The required temporal coverage is from daily to monthly, depending on the time of year, application and the rate of change in snow status.

For the SnowMan project a combination of optical and radar data will generate historical EO data approximately weekly in the melting periods in the years 1996-2000 for about five catchments covering selected areas. This satisfies the requirements for calibrating hydrological models for these catchments. For additional catchments, calibration of hydrological models will be done by optical data alone using longer calibration periods.

For the operational flood warning system at NVE a combination of optical data, covering the whole country, and radar data, covering essential regions, would realistically generate EO data at least monthly for the whole country and at least weekly for essential regions covered by data from radar sensors.

1. Background

A number of hydrological models for monitoring and runoff forecast are used throughout Europe, many of which, in principle, can be updated by earth observation data (Standley et al. 1998). Operational use of satellite derived snow parameters in the HBV model has not been reported and only a few authors have reported operational applications of remotely sensed snow parameters in other models (Rango and Shalaby, 1999). Automatic updating of the snow variables in the HBV model for a single catchment has been reported by Johansson et al. (2000). The results from this work showed that the simulations could be improved by integrating the snow covered area (SCA) derived from satellite images. A condition for this improvement appeared to be calibration of the model against SCA in addition to runoff. This condition is supported by the work of Lindström (2000) and Kolberg and Tøfte (2000) who show that reducing the calibration freedom, by validating the model to observed SCA, improves the simulation and reduces the uncertainty. However, how to correctly integrate spatially distributed information on snow parameters in the HBV model, has not yet been solved (Kolberg et al. 2000).

ECOMAG is a distributed "physically based" model developed by Motovilov and Belokurov (1997). This model was adapted for application to a regular grid (Gottschalk et al., 1998) and is used as a platform for model development at the University of Oslo. It has been applied within the inter-European multi-disciplinary project NOPEX (Northern hemisphere climate Process land surface EXperiment) (Halldin et al., 1998, 1999) and on an experimental basis to an area in the mountains in mid-eastern Norway around lake Aursunden (see Figure 2).

2. User requirements

2.1 Key snow parameters

Both the HBV and the ECOMAG models simulate daily values of SCA, snow water equivalent (SWE) and snow volume wetness (SVW). Some versions of the models simulate the albedo also. To adjust these variables by EO data, the models must be calibrated against the same type of data. Hence reliable EO data will be required.

Daily variation in runoff is strongly dependent on the size of the melting snow area. This makes the SCA and the SVW the most important parameters for short term flood warning. For larger catchments (>100 km^2) a resolution of 1 km should be suitable when the topography is not too rough. For smaller catchments and steep topography the resolution of the data should be higher, 0.25 – 1 km. A maximum accuracy of 10% is required.

The SWE will give information about the total melt water storage and is of most importance for long term runoff prediction. A maximum accuracy of 10% is required. Information about the SWE, SVW and snow surface wetness (SSW) distribution will also be valuable, especially for the ECOMAG model. This will give better spatial distribution of observed precipitation and melting parameters.

2.2 Temporal requirements

The need for temporal updates expressed by the Nordic hydrology users generally range from once or twice a week to monthly, emphasising the spring flood as the most critical period (Kolberg et al. 1997). Concerning the requirements for a Norwegian remote sensing snow product, there was an overall consensus that weekly data is needed during the melt season, while monthly data is sufficient throughout the winter. For spring flood forecasting, critical situations may require updating every 2-3 days. Special conditions in the autumn may also require data at very short notice, 2-3 days. If wetness data prove useful, more frequent deliverables may be considered.

For mountainous areas above the timberline, the melt season starts in April and ends in June or July, depending on latitude and altitude. Catchments and regions with a limited elevation interval experience considerably shorter melt seasons than areas with large elevation differences. In the Heimdalen area for example, used within the SnowTools project (Guneriussen et al. 2000), the melt season typically starts in late April or early May, and lasts throughout June. The elevation difference here is 800 meters.

2.3 Spatial requirements

At the national flood warning services in Norway (NVE), HBV models are run daily for 63 catchments (Figure 1). The catchments are evenly spaced around the country and they cover forested, non-forested and mixed areas. The size of the catchments varies between 6 and 15,000 km^2. However the majority (44) of the catchments are in the range ~100-1000 km^2. In the most northern parts of the country and in the mountainous areas in the south, the largest floods tend to be dominated by snow melting. In these regions there is no vegetation or it is sparsely forested. The hydrological models for flood warning and long term runoff prediction should benefit most from updating the snow variables in these regions. Suggested catchments, located in the mountainous areas in the south, in the SnowMan project are shown in Figure 2 as black polygons. The catchments N.Heimdalsvatn (6) and Aursunden (5) are the suggested catchments for field campaigns in the project.

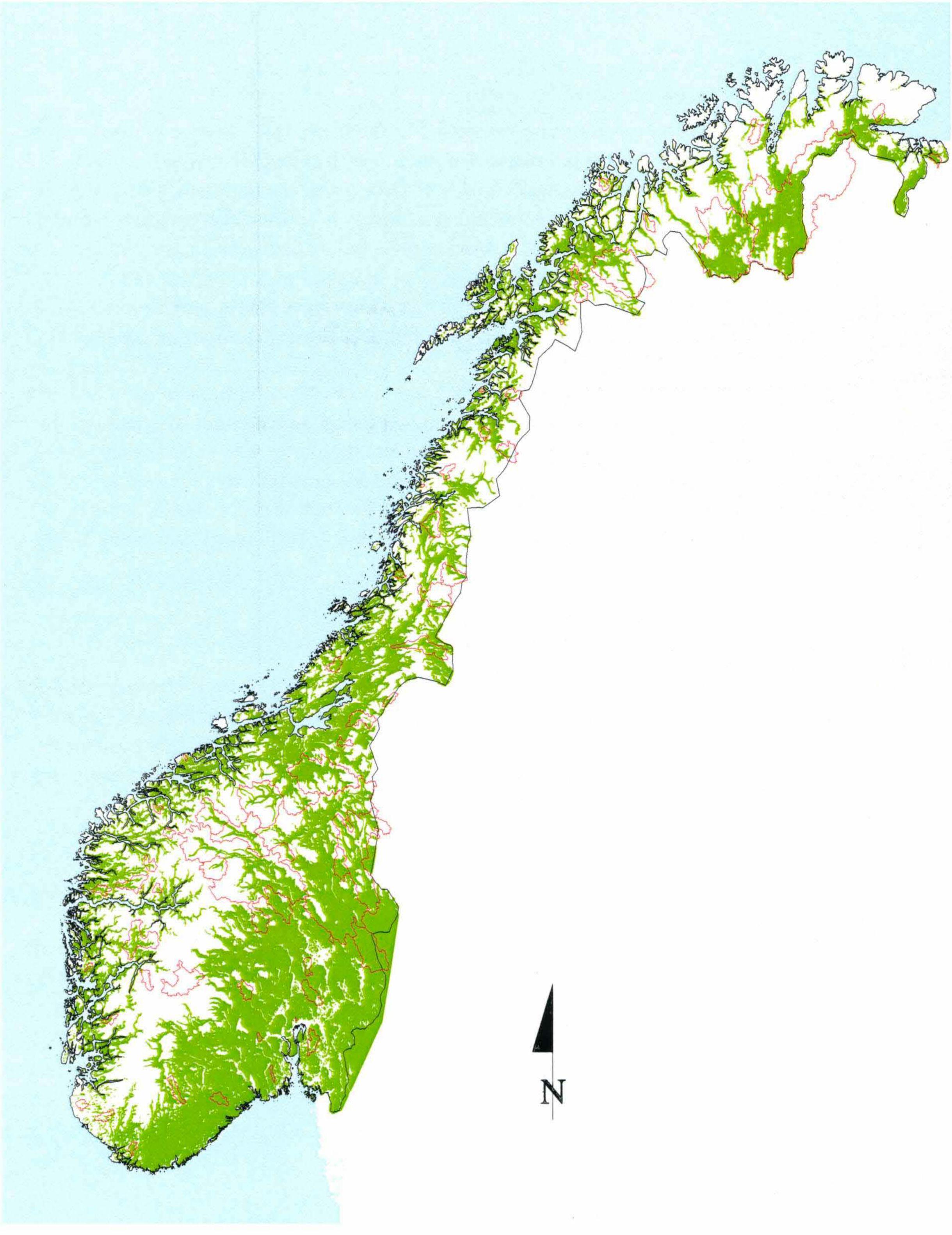

Figure 1. Operative HBV models (red polygons) at the national flood warning services at NVE. Forested areas are marked green.

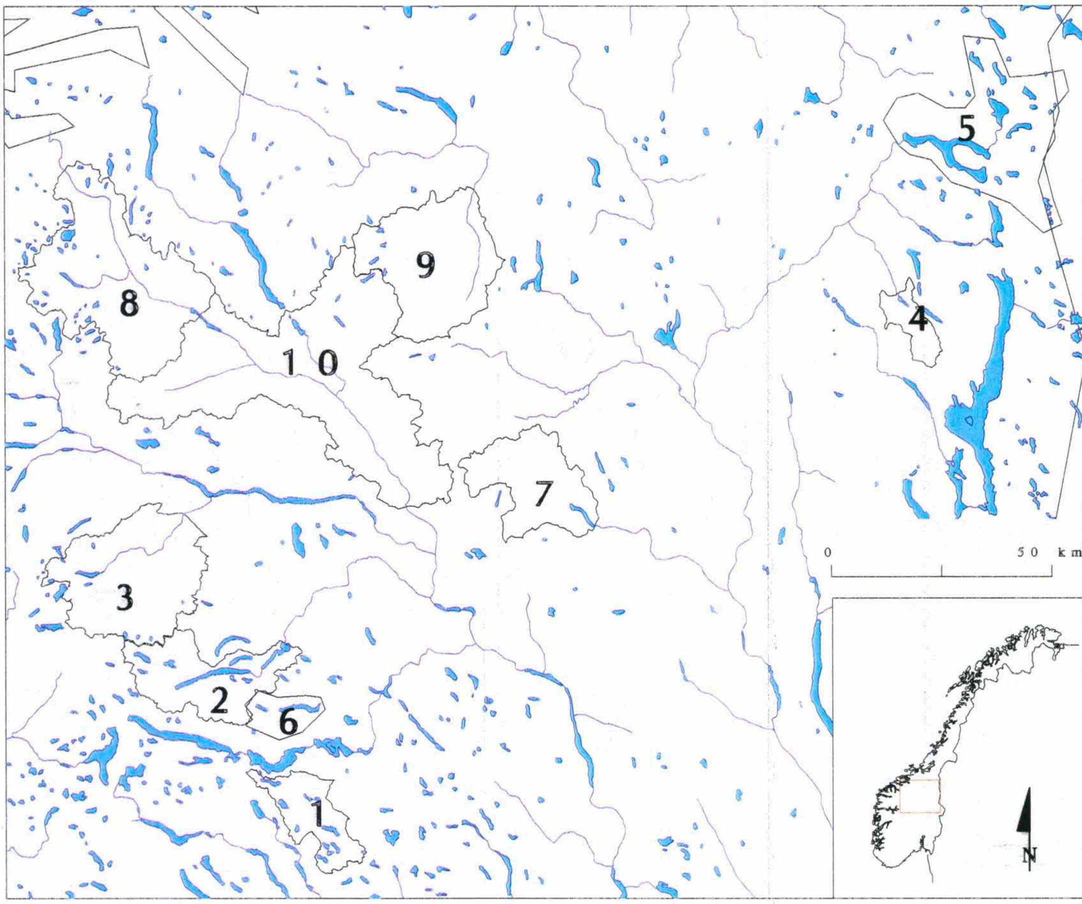

Figure 2. The suggested catchments, located in the mountainous areas in the south, in the SnowMan project. They are numbered according to priority where 1 is the highest priority. 1. Vindeelv. 2. Sjodalsvatn. 3. Akslen. 4. Narsjø. 5. Aursunden. 6. N. Heimdalsvatn. 7. Atnasjø. 8. Horgheim 9. Risefoss. 10. Rosten.

2.4 Summary of user requirements for EO product

Based on the key snow parameters, temporal and spatial requirements defined by the users (2.1-2.3), the requirements relevant for the pre-processing algorithms are summarised in Table 1.

Table 1. Summary of requirements relevant for the pre-processing algorithms.

Application	Parameter	Spatial Context	Spatial Resolution	Time Resolution	Time Delay	Precision
Long term runoff prediction	SWE	6-15,000 km^2	0.25-1 km	1-2 weeks	2-3 days	10%
Flood forecasting	SCA, SVW SSW	6-15,000 km^2	0.25-1 km	2-3 days	<= 1 day	10%

The requirements for EO products in hydrological models and flood prediction are shown in Table 2. The requirements in Table 1 and 2 are generally consistent with the snow products available now and in the near future (Table 3), as outlined by Solberg et al. (1997).

Table 2. Requirements for EO products in hydrological models and flood prediction.

Model	Purpose	Spatial resolution (m)	Temporal resolution
HBV	Winter Snow melt runoff Spring flood	250-1000 250-1000 250-1000	Monthly Weekly (April-July) 2-3 days (April-July)
ECOMAG	Winter Snow melt runoff Spring flood	1000 1000 1000	Monthly Weekly 2-3 days

Table 3. Primary map snow products (from Solberg et al. 1997).

Name	Parameter	Application	Spatial Resolution	Temporal resolution	Delivery time	Precision	Accuracy
SCA-HDAY	SCA	C&M	500 m	1/2 day	2 hours	10 cls.	80%
SCA-DAY	SCA	WRM/FRF	250 m	1 day	0.5 day	10 cls.	80%
SCA-WEEK	SCA	WRM/FRF	250 m	1 week	1 day	10 cls.	80%
SCA-MONTH	SCA	WRM/FRF	250 m	1 month	1 week	10 cls.	80%
SWE-DAY	SWE	WRM/FRF/C&M	250 m	1 day	0.5 day	100 mm	50 mm
SWE-WEEK	SWE	WRM/FRF/C&M	250 m	1 week	1 day	100 mm	50 mm
SSA-DAY	SSA	C&M	500 m	1 day	2 hours	10 cls.	80%
SVW-DAY	SVW	WRM/FRF	500 m	1 day	0.5 day	binary	80%

SCA = Snow Covered Area
SWE = Snow Water Equivalent
SSA = Snow Surface Albedo
SD = Snow Depth
SST = Snow Surface Temperature
SVW = Snow Volume Wetness
SSW = Snow Surface Wetness

C&M = Climatology and Meteorology
WRF = Water Resource Management
FRF = Flood Risk Forecasting
ARF = Avalanche Risk Forecasting

3. Snow parameters from EO sensors

The types of sensors of interest for deriving snow parameters are optical, radar and passive microwave radiometers (PMR). The Norwegian users require data with a spatial resolution of 250-1000 m. This requirement is met by the optical and radar sensors, but not the PMR. The required temporal coverage is in the range of one day to one month, depending on the time of year, application and rate of change in snow conditions. In the melting season, most users require coverage every one to a several days (Kolberg et al. 1997). This limits the applicability of using satellite/sensor combinations such as Landsat TM, SPOT HRV and ERS SAR.

Optical sensors covering the right frequencies and with appropriate spectral resolution provides information on snow covered area (SCA), snow surface albedo (SSA), snow surface wetness (SSW) and snow surface temperature (SST). Data from optical sensors are limited by cloud cover.

A Synthetic Aperture Radar (SAR) with the right frequencies, polarisation and incidence angle can contribute to information on SCA, snow water equivalent (SWE) and snow volume wetness (SVW). Short wavelengths are required for SCA, where the discrimination between snow and bare ground is based on different surface roughness characteristics. SAR sensors are best for wet snow mapping and it is assumed that snow coverage is close to 100% above the melting zone.

The present relatively high cost of some EO products is also a limiting factor for full utilisation of EO derived information in hydrology. However, large changes are taking place within the EO industry which will affect future data policy, including price and availability. In order to improve methodology for remote sensing of snow parameters and the use of snow parameters in hydrological models the future EO data policy must be taken into consideration.

4. Scenarios

The scenarios for using EO data in hydrological models include snow parameters derived from both optical and SAR sensors. The low cost, good coverage and the high frequency available with optical data makes it possible to use these data as a basis for updating the hydrological models. However, long periods of cloudy weather require additional use of radar data that provide guaranteed repeat coverage.

4.1 Operational scenarios

For the national flood warning service a combination of optical data, covering the whole country, and radar data, covering essential regions, would realistically generate EO data at least monthly for the whole country and at least weekly for the radar regions. Updating the models by EO data weekly from April to July would satisfy the requirements for most situations. However, certain critical situations in spring and autumn, when it is important to know whether the new fallen precipitation has come as rain or snow, requires more frequent updating. The combination of the cost of these data and the user requirements will possibly make operational use of radar data reasonable for catchments or regions up to ~10.000 km^2. Four important regions, each covering ~10.000 km^2, are identified and shown in Figure 3. Each region covers areas where snowmelt contributes significantly to the largest floods in the major river systems in southern Norway. Region 1 covers the upper part of Glomma, Orkla and Gaula. Region 2 covers the upper parts of Gudbrandsdalslågen, Driva and Rauma. Region 3 covers the upper parts of Drammensvassdraget, while region 4 covers the upper parts of Skiensvassdraget and Numedalslågen.

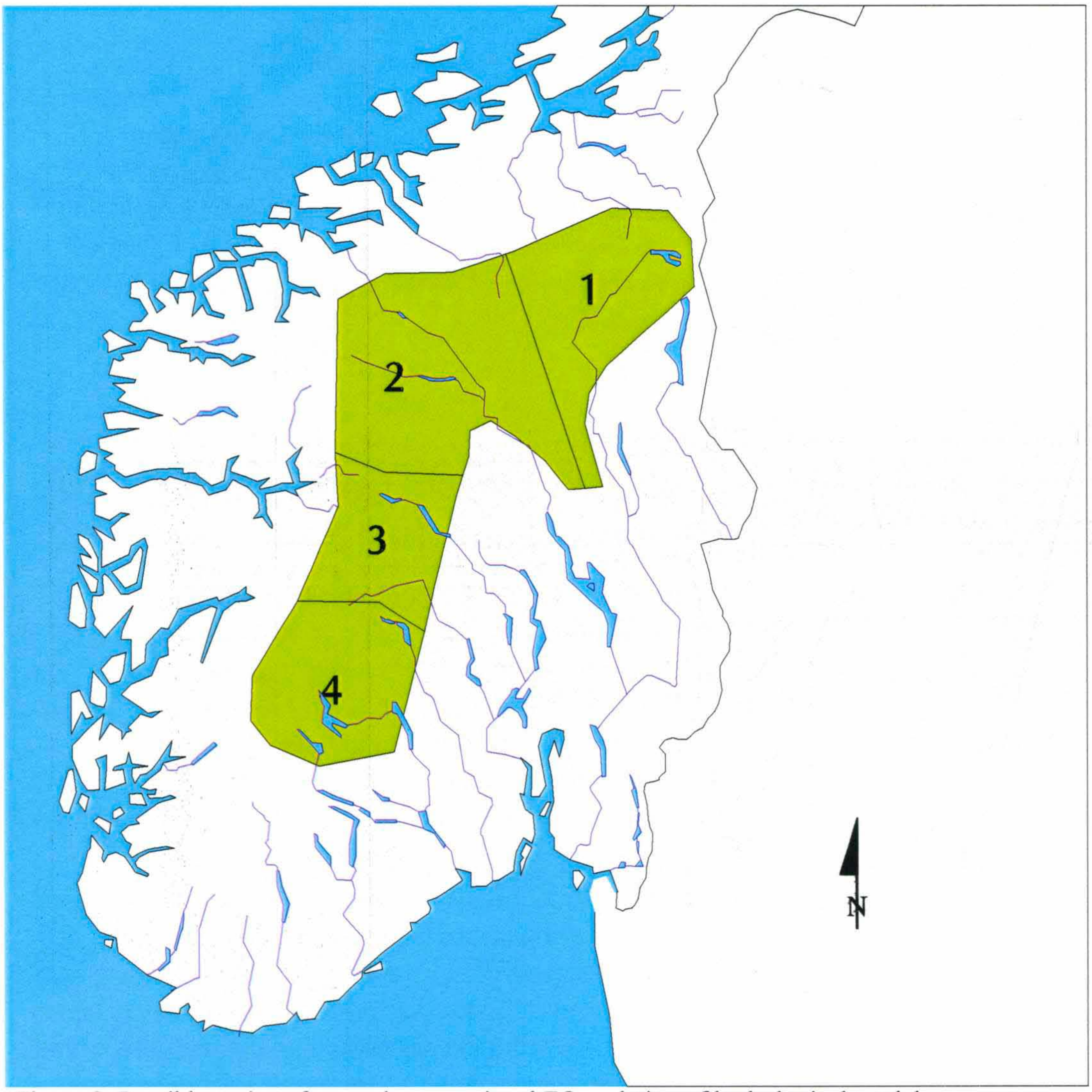

Figure 3. Possible regions for regular operational EO updating of hydrological models.

The optimal scenario, ignoring the costs, would be regular EO updating at least weekly in October-December and April-July for all operational hydrological models used by the flood warning services at NVE. These models will cover watersheds over the whole country. In addition, EO data should be available at short notice (~ 1 day) when critical situations occurs. This would lead to better forecasts for the whole country, both with respect to the quantitative simulation of discharge in the rivers and to the qualitative description of regions affected by snow melting.

A more realistic scenario would be regular EO updating at least monthly in October-December and April-July for all the operational models, and at least weekly in the same periods for the models in one or more of the four regions (Figure 3), depending on the cost of EO data. This would give better forecasts and information about the snow conditions in remote areas in the river systems themselves.

4.2 Experimental scenarios

For an experimental project a combination of optical data and radar data will realistically generate historical EO data approximately weekly for the period 1996-2000 for the catchments shown in Figure 2. This should satisfy the requirements for calibrating HBV models for these catchments. The Aursunden catchment, where the ECOMAG model is run, has a shorter period (1998-2000) of hydrological data (except for runoff) and will possibly require more frequent EO data in the model calibration. However the snow module of the model can be calibrated for the whole period.

For the N. Heimdalen and Aursunden catchment, radar scenes from 1996-2000 are available about twice a month in the melting period. The scenes covering Heimdalen also cover most of the Sjodalsvatn and Vindeelv catchments (see Figure 2). Approximately 60 radar scenes and 60 optical scenes, a total of 12 scenes per year for each catchment, will be required for the model calibration of these catchments.

The optimal experimental scenario will be a combination of weekly optical and radar data used in the model calibration of at least ten HBV catchments in different regions including at least two catchments for the ECOMAG model. The potential improvements from snow updating should be analysed concerning catchment area, type of region, type of terrain and time of year. Due to the cost of radar data a more realistic scenario would be to focus on at least five clustered catchments (see Figure 2) covered by the same radar scenes for model calibration against radar data. Maximum five catchments, in other parts of the country, should be calibrated against optical data. The frequency of available optical data will probably be less than once a week, but longer calibration periods, say 10 years, will reduce this problem. A calibration of the ECOMAG model for more than one catchment is unlikely in the SnowMan project due to the data demands of this model.

5. Conclusion

For hydrological modelling with the HBV and the ECOMAG models the most important snow parameters are snow covered area, snow water equivalent and snow volume wetness. These parameters are required with a resolution of 0.25-1 km^2 for the actual catchment scales in the SnowMan project and for operational flood warning at NVE.

A combination of optical data and radar data will realistically generate historical EO data approximately weekly for the suggested experimental catchments. This should satisfy the requirements for calibrating the hydrological models for these catchments. The cost of the radar data reduces the size of the region from which radar data and optical data can be used in experimental modelling. However, longer calibration periods can be achieved by using optical data alone, which makes the use of other regions possible. The most realistic experimental scenario is thus using a combination of radar and optical data in the calibration of hydrological models for at least five relatively close catchments in essential areas. Maximum five other catchments, distributed around the country, will be calibrated against optical data alone.

For operational flood warning the most realistic scenario is monthly updating of the operative hydrological models by optical data. For models in essential areas weekly updating (radar or optical data) is expectable in the critical periods of October-December and April-July.

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This series is published by Norwegian Water Resources and Energy Directorate (NVE)

Published in the Report series 2001:

No 1 EO data in hydrological models: Hans-Christian Udnæs (Ed.), Lars Gottschalk, Tore Guneriussen (16 pp.)

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