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*Ole Schjødt-Osmo & Rune Engeset*

102

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# Remote sensing and snow monitoring: Application to flood forecasting

Ole Schjødt-Osmo & Rune Engeset
*Norwegian Water Resources and Energy Administration, Hydrological Department, Oslo, Norway*

ABSTRACT: The Norwegian Water Resources and Energy Administration (NVE) uses image data from the NOAA-AVHRR sensors to derive information on the changing distribution of snow during periods of accumulation and, in particular, ablation. The major objective of the classification is to separate water bodies, clouds, bare ground, and a set of snow cover classes. The classification of snow cover is based on the fractional percentage of snow cover within each pixel. A cloud detection algorithm is implemented and several images acquired close in time can be merged. In this manner, national scale snow cover estimates are produced at an improved temporal resolution. During the spring of 1995, major flooding occured in southern Norway, in some parts the largest since 1789. The snow monitoring system at NVE was used operationally prior to and during the flooding, and its specific application is presented and discussed.

## 1 INTRODUCTION

The Norwegian Water Resources and Energy Administration (NVE) is responsible for flood forecasting in Norway. In response to this, NVE has had a long-term involvement in the development of remote sensing methodology for monitoring of the snow resources (Østrem 1974, Andersen 1982). NVE uses image data from the NOAA-AVHRR (National Oceanic and Atmospheric Administartion - Advanced Very High Resolution Radiometer) sensors to derive information on the changing distribution of snow during the periods of accumulation and, in particular, ablation.

Approx. 50% of the annual precipitation is stored in the snow reservoir. The state of this snow pack during the melt period in spring is of prime importance for the development of flooding. The areal extent of the snow is one of the principal variables and the areal snow extent is directly related to the surge-type runoff potential.

NVE has developed an operational system for snow monitoring, NOSIS (NVE's Operational Snow Information System), based on remote sensing data. The system is mainly implemented within the GIS environment of Arc/Info®. During the spring of 1995, major flooding was experienced in the south-east parts of Norway. The snow cover prior to and during the flooding was studied in near real-time using the NOSIS snow monitoring system. NVE hosts an archive of AVHRR imagery (18 years) and hydrological data (aprox. 100 years). The data sets carry a potential as basis for analysis of floodings in combination with hydrological runoff models.

Satellite-derived snow information is also of interest as input to climatological and meteorological models, to the general public, and to hydropower companies.

## 2 BACKGROUND

Snow measurements from satellite are acquired by optical, and passive and active microwave sensors. For operational snow monitoring, data from the NOAA-AVHRR sensors (Table 1) provide a favourable cost/benefit trade-off.

Table 1. Description of the NOAA AVHRR sensor.

| Sensor parameter | Value |
|---|---|
| Band 1 interval | .58 - .68 µm |
| Band 2 interval | .725 - 1.10 µm |
| Band 3 interval | 3.55 - 3.93 µm |
| Band 4 interval | 10.30 - 11.30 µm |
| Band 5 interval | 11.50 - 12.50 µm |
| Spatial resolution | 1.1 km |
| Swath with | > 2600 km |

The spectral properties of snow-covered surfaces enable detection of snow, and estimation of the snow-cover fraction if the imaged scene is a mixture of snow-covered and bare ground. For this, measured radiation in the visible (band 1) and near-areas are used for the 100% snow cover fraction. A lower limit for the pixel values is found by using typical values for water bodies. Open water shows little variation in band 2 during the year. The land surface, on the contrary, shows large annual variation in band 2. This effect is caused by snow cover giving high reflectance values in the winter. Low reflectance values are found in late autumn and early spring, with increasing reflectance as leaf and vegetation develop during the summer season.

The linear relationship can also be established by examining the histogram for AVHRR band 2. One point for this relationship is found between values representing water and land, identified as a minimum between two peaks (water and land) at the lower end of the histogram. The other extreme for the linear relationship (100% snow-cover) can be recognized as the point where the slope increases for the upper values of the histogram. Using this procedure gives reproducible classification results, even though the classification includes subjective evaluation. The classification procedure separates 8 classes of increasing snow-cover fraction.

The classified snow cover images are subjected to hydrological analysis in the temporal and spatial domains. For example, in combination with the national digital elevation model (100m horizontal resolution), and distribution of drainage basins, the altitudinal distribution of snow within different drainage basins are investigated. Temporal studies include analysis of snow cover distribution and changes on scales of one to several years.

## 4 APPLICATION TO FLOOD FORECASTING

Operational use of NOSIS provided important information for NVE during the 1995 flooding of the Glomma-Lågen river. Seven AVHRR acquisitions were processed prior to and during the event. The images were partly corrupted by cloud cover. Therefore, multi-temporal image mosaics were established to frequently update the snow information from the large drainage basin.

Figure 2. Key map of the Glomma and Lågen river system.

The Glomma and Lågen rivers system (Figure 2) have a total catchment area of 41500 $km^2$. This is 13% of Norway's total land area, and equivalent in size to Denmark. The distance from north to south is 600 km, and the annual discharge is $2.2 \times 10^9$ $m^3$. The topography is fairly rugged, with 30% of the surface being situated more than 1000 m a.s.l. and 40% between 500 and 1000 m a.s.l. Annual precipitation ranges from 260 to 1050 mm.

The distribution of the snow cover at the onset of the flooding event is shown in the snow cover map in Figure 3.

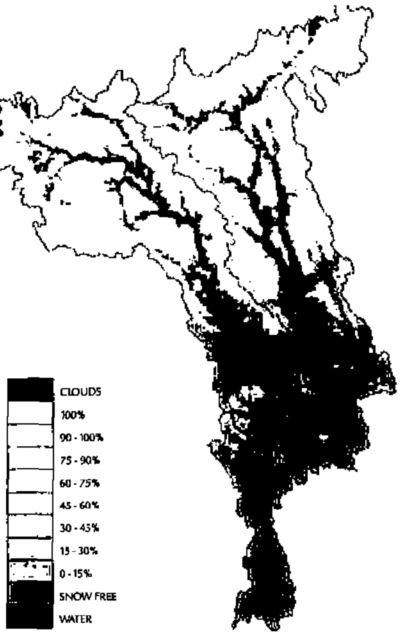


Figure 3. AVHRR-derived snow cover in the Glomma - Lågen catchment on 22 May 1995.

High snow cover fractions were found in the intermediate and higher elevations. In Figure 4, the fractional snow cover is shown as a function of elevation.

Figure 4 shows that the snow free line was at about 500 m a.s.l. on 22 May 1995. From this level up to the tree limit, the snow cover estimate is believed to be too low. This is because snow-free tree canopies constitute a fraction of the imaged scene, reducing the reflectance values represented by the pixel values. Despite this underestimation, areas with or without snow are separable. Above 1000 m a.s.l., the snow cover fraction exceeds 70%. Large areas had near 100% snow cover, an unusual situation at that time of the year. The fact that the snow cover is

1km ground surface covered by a pixel, are not adequately taken care of in the system. Methods which handle the effects of snow, bare ground, and vegetation mixing, need to be incorporated. Also effects caused by variations in terrain orientation and sun position need to be reduced.

Today, the information obtained from NOSIS are used separately as one of many sources of information in flood forcasting. Our current plan is to couple snow-characteristic and hydrological-runoff models, so that remotely sensed snow data can be fed back into the model to adjust the model variables.

Through the spring of 1995, the importance of derived snow cover information became obvious. Analysis of changes in snow cover, and comparison with historical situations will be further investigated. The NVE archive of AVHRR imagery, dating 18 years back in time, could be used to establish normalised index maps for the snow cover throughout the season.

## 6 CONCLUSION

The snow monitoring system based upon use of a GIS and remote sensing data (NOSIS), is a useful tool in flood forecasting. All though the methods used for deriving snow characteristics from satellite data are known to underestimate the snow cover under some conditions, the near real-time overview given by the system is of enormous help. The use of imagery during a melt period to examine the change in snow cover, shows more clearly trends in the situation as it develops.

We see a great potential for futher use and development, especially as new satellite sensors reduce the gaps in the data sets and also provide additional snow information. Combined with hydrological runoff models and new analysis methods, better understanding and monitoring of the snow pack characteristics critical to flood forcasting is possible.

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Norges vassdrags- og energidirektorat
Middelthunsgate 29
Postboks 5091 Majorstua
0301 Oslo

Telefon: 22 95 95 95
Telefaks: 22 95 90 00
Internett: www.nve.no