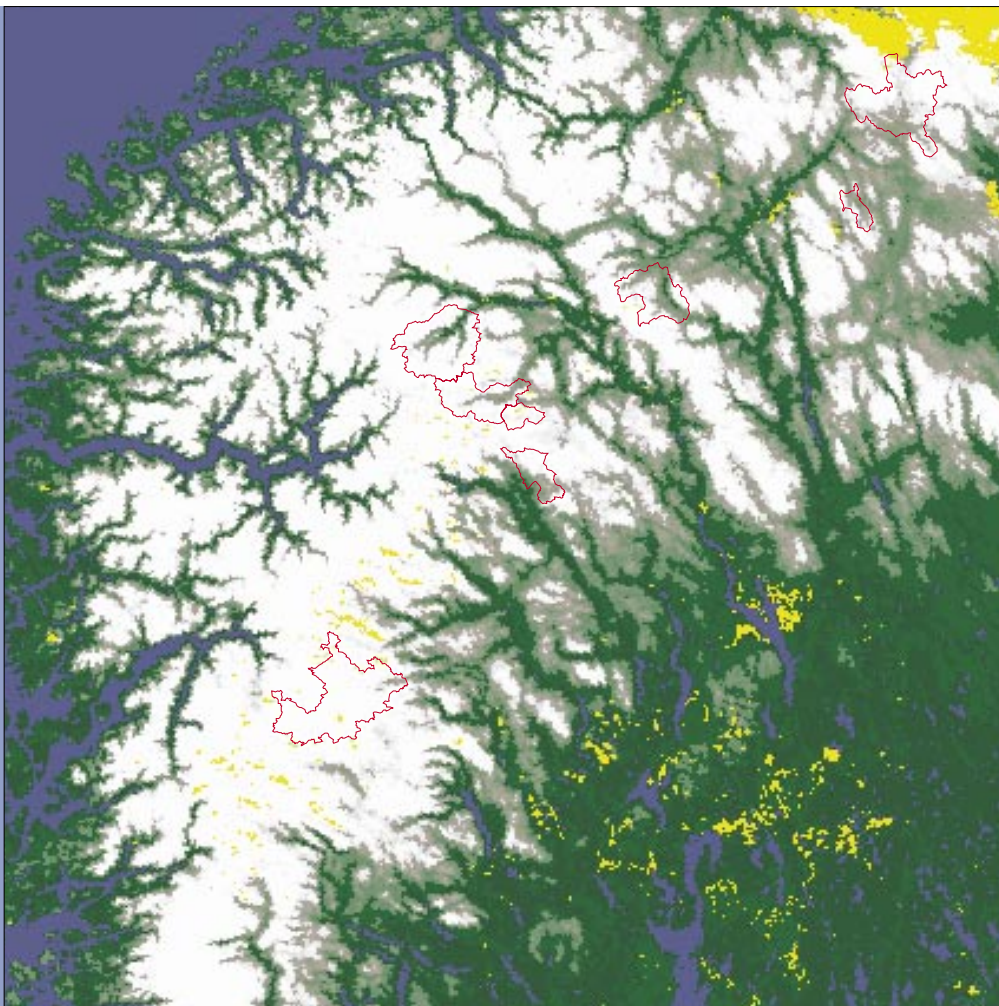




# Real time demonstration of satellite-observed snow covered area in the HBV model Spring 2004

*Hans-Christian Udnæs*

6  
2005



OPDRAGSRAPPORT A

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## Report No. 6-2005

### Real time demonstration of satellite-observed snow covered area in the HBV-model Spring 2004

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**Front page:** Snow covered area in southern Norway 7<sup>th</sup> May 1999 based on a satellite image from NOAA AVHRR. The test catchments are marked with red boundaries

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**Abstract:** During spring and summer 2004 the national flood warning services at the Norwegian Water Resources and Energy Directorate demonstrated in real time how satellite observed snow covered area could be included in the models. Use of observed snow covered area led to three corrections of the simulations. One of these resulted in a successful change of a flood warning.

**Keyword:** snow; runoff simulations; satellite derived snow covered area; hydrology; remote sensing;

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# Preface

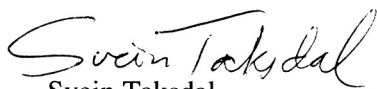
This report is a deliverable in the research project SnowMan - Snow Parameter Retrieval from Remote Sensing data for Improved Monitoring and Management of Water Resources. SnowMan is supported by the Research Council of Norway under the programme "Overvåking av marine/terrestriske systemer" (project No. 143540/431).

The main objective of SnowMan 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.

The partners in SnowMan are NORUT IT (co-ordinator), the Norwegian Computing Center (NR), the University of Oslo and the Norwegian Water Resources and Energy Directorate (NVE). The project is divided into five workpackages (WP). This report sums up the demonstration in 2004 carried out by NVE in WP5 -Verification and demonstration.

The report has been written by Hans-Christian Udnæs with contributions from Eli Alfnes and Liss M. Andreassen. Project partners NR and Norut IT processed satellite SCA data.

Oslo, February 2005



Svein Taksdal

Acting Director of the Hydrology Department



Liss M. Andreassen

Project Leader

# Summary

During spring and summer 2004 a demonstration using satellite derived snow covered area operationally in the national flood warning services at the Norwegian Water Resources and Energy Directorate was carried out. Data from optical sensors (NOAA AVHRR and Terra MODIS) and radar sensors (Envisat ASAR) were used to evaluate the simulated snow covered area for ten catchments. In general the simulated and observed SCA harmonised well with the optical data. For three of the catchments comparisons of simulated and observed snow covered area led to corrections of the simulations. One of these corrections resulted in a successful change of a flood warning.

# 1 Introduction

At the Norwegian Water Resources and Energy Directorate (NVE) HBV models for more than 80 catchments in Norway are used for daily runoff forecasting and flood warning. The models are also used for predicting inflow to the hydropower reservoirs. During spring and summer 2004 another ten HBV models were run operationally for the SnowMan test catchments. The test catchments represent different scales and regions in Norway. The models were calibrated on satellite derived SCA in addition to runoff in order to update the simulations whenever SCA observations were available. The calibrations and model validations are described in a separate report (Alfnes and Udnæs 2004).

The objective of this study was to demonstrate operational inclusion of satellite derived SCA in the national flood warning services.

## 2 Methods

### 2.1 Satellite observed SCA

Snow covered area was calculated in near real time based on optical satellite data from NOAA AVHRR and Terra MODIS and radar data from Envisat ASAR. The spatial resolution of the SCA products was 1 kilometer for the AVHRR data and 250 meters for the MODIS and ASAR data. The AVHRR images were processed by NVE according to the "NVE method" (Schjødt-Osmo and Engeset, 1997). The MODIS images were processed by the Norwegian Computing Center using the Norwegian-Linear-Reflectance (NLR) method (Solberg and Andersen, 1994). The optical SCA data were transformed linearly to harmonise with the HBV simulations, covering the entire interval from 100 % to 0 % SCA during the melting season (Engeset et al 2003). The ASAR data were processed by Norut IT using the Nagler algorithm for detecting wet snow (Nagler and Rott 2000, Malnes and Guneriussen 2002). Dry snow was classified using an algorithm of Malnes et al (2004). During the demonstration, from the end of April to the beginning of July, 42 SCA maps were processed (16 MODIS, 16 AVHRR and 10 ASAR).

### 2.2 Hydrological modelling

The Nordic HBV model (Sælthun, 1996) used by the flood warning services is a modified version of the HBV model (Bergström, 1992). The operational models are updated every morning by inputs from observed precipitation and temperature. The simulations for the six days forecast period are based on precipitation- and temperature-forecasts as inputs to the models. The main output from the simulations is runoff, but SCA for each elevation interval is also simulated. Hence observed and simulated SCA is compared for each catchment in order to evaluate if additional updating is needed. During the demonstration an update was triggered by either a deviation between observed and simulated SCA greater than 15 % at a single occasion or three succeeding deviations of at least 10 % within 10 days. In such cases the model input was updated with a) a percentage change of

the winter precipitation and/or b) temperature modifications immediately ahead of and during the melt season or c) correction of single events.

### 3 Test sites

The ten demonstration catchments represent different altitude ranges, area sizes and geographical location (Fig. 1 and Tab. 1). For all catchments the snow melt flood in spring and summer is usually the dominating flood each year. In order to achieve reliable SCA data from satellites, only catchments with non forested or sparse forested areas were chosen.

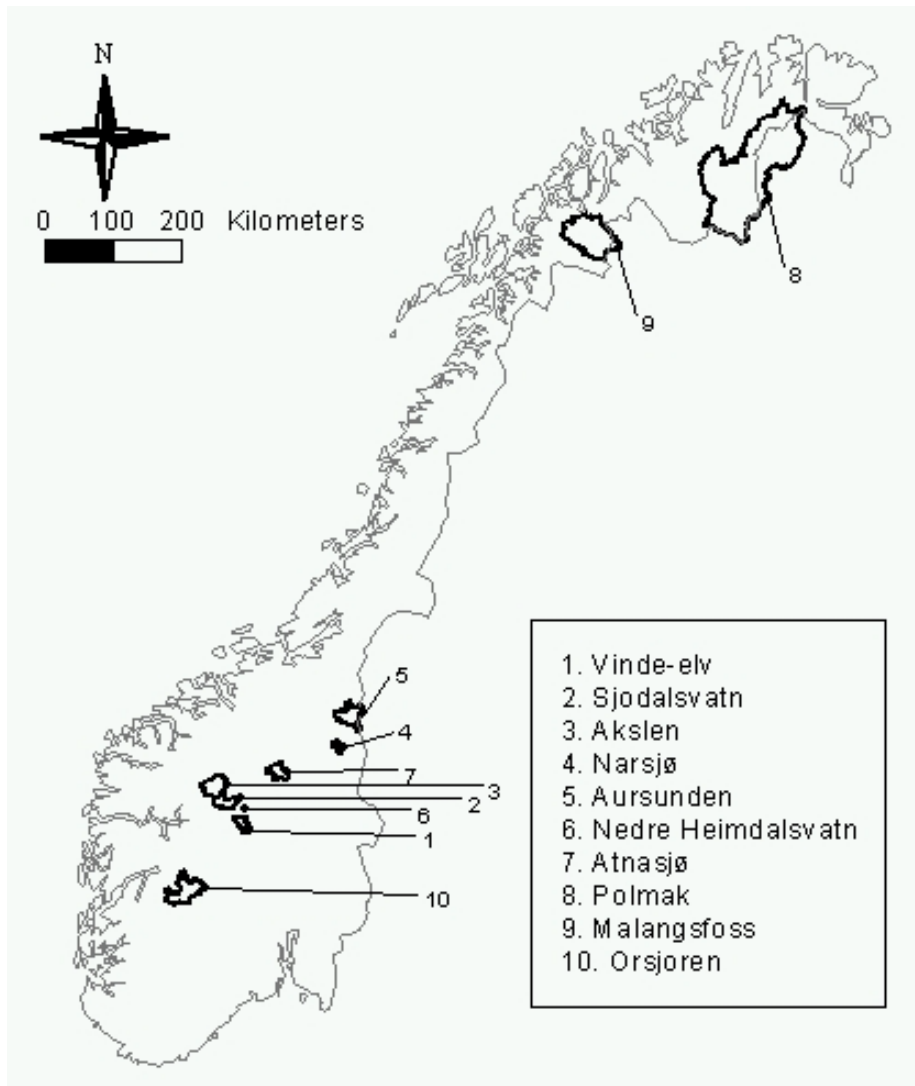


Figure 1 Location map of the ten catchments in Norway used in the demonstration.



**Table 1** Description of the ten test catchments used in the HBV simulations. The catchments are sorted by decreasing median altitude.

Catchment	No. in map (Fig. 1)	Annual runoff (mm)	Area (km <sup>2</sup> )	Altitude median-max-min (m a.s.l.)			Alpine (%)	Forest (%)
				median	max	min		
Akslen	3	966	791	1476	2472	480	84	16
Sjodalsvatn	2	1257	474	1465	2400	940	100	0
Nedre Heimdalsvatn*	6	875	130	1303	1843	1053	96	4
Orsjoren	10	840	1192	1231	1531	951	98	2
Atnasjø	7	671	465	1186	2114	701	78	22
Vinde-elv	1	487	268	985	1686	560	59	41
Narsjø	4	575	119	934	1595	737	66	34
Aursunden*	5	764	835	840	1553	690	59	41
Malangsfoss	9	847	3118	719	1677	20	70	30
Polmak	8	384	14165	355	1067	20	51	49

\* Catchment where runoff is calculated as reservoir inflow.

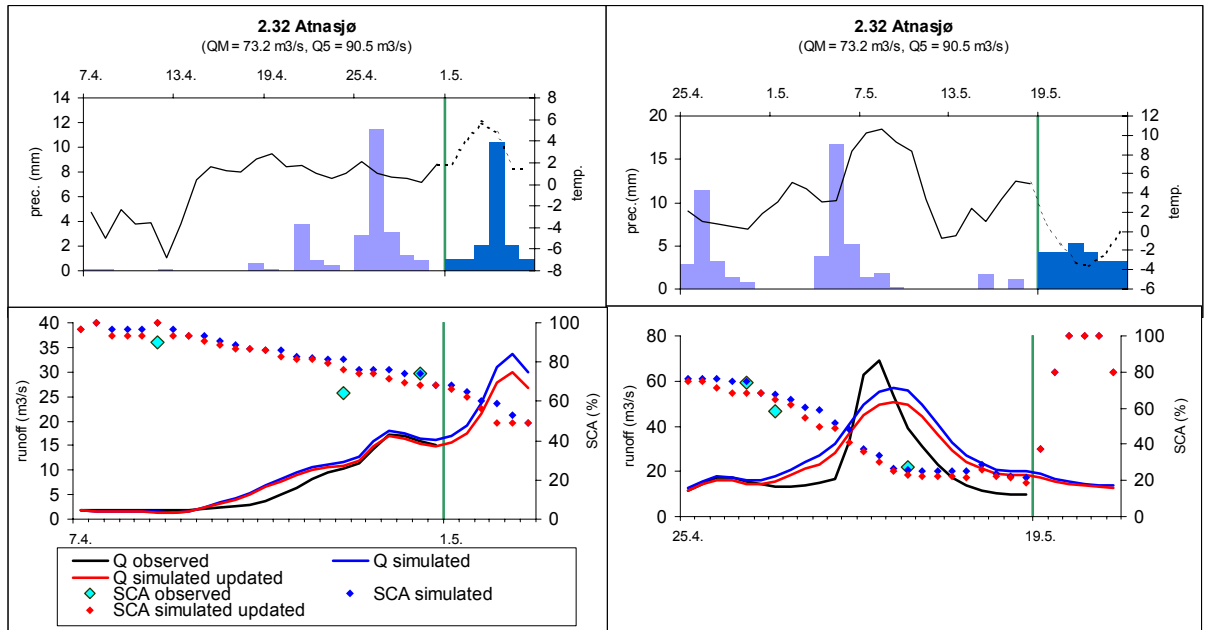
## 4 Results and discussion

### 4.1 Real-time demonstration

The demonstration started in the end of April 2004 and ended in the beginning of July. SCA derived from NOAA AVHRR, Terra MODIS and Envisat ASAR was compared to the simulated SCA from day to day. The comparisons were used for evaluating and updating of the models. During the demonstration 2004 three out of ten HBV models were updated, two of them without any consequences with respect to runoff forecasts and flood warnings.

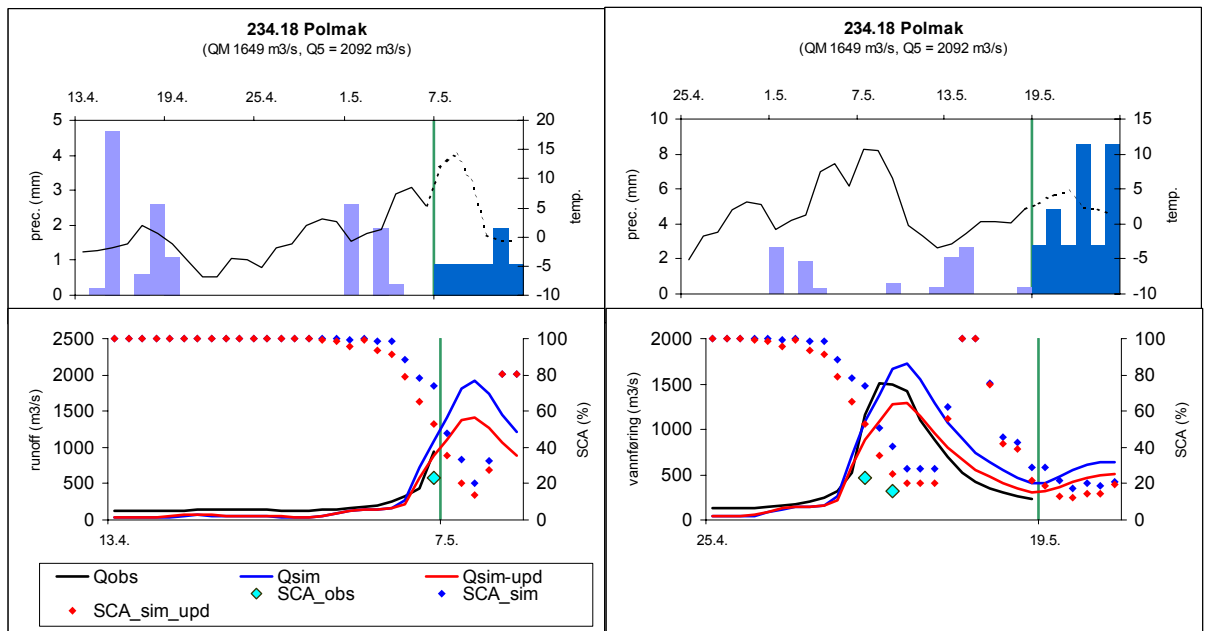
Figure 2 illustrates the situation in one of the updated catchments, Atnasjø, before and after the spring flood. On April 24<sup>th</sup> simulated and observed SCA deviated with more than 15%. Still the runoff this day and the following days was well simulated. In the updated simulations we reduced the input precipitation until the simulated runoff was even more correct and the SCA was within ~10% deviance from the observed. This led to a more than 10% reduction in the simulated runoff culmination in the forecast period. On May 18<sup>th</sup>, after the culmination, calculations showed that the total runoff during the flood period was better simulated by the updated model than by the uncorrected. Nevertheless, the uncorrected model simulated the culmination better on May 8<sup>th</sup>.

For northern Norway a flood warning was changed based on updated simulations for Polmak in the Tana river (Figure 3). On May 5<sup>th</sup> a flood warning was sent to the Finnmark county because we expected floods exceeding the 5-year flood. On May 6<sup>th</sup> the observed SCA deviated considerably from the simulated and a correction of the input data was required. By inspection of data from other meteorological stations and snow pillows, we revealed that one precipitation event in the early winter had probably given to much snow in our simulations. The observed precipitation this date was therefore reduced considerably in the updated simulations.



**Figure 2** Real-time simulations and forecasts from April 30<sup>th</sup> and May 18<sup>th</sup> with and without updating of the model inputs. In this example the winter precipitation was reduced until the triggering SCA observation on April 24<sup>th</sup>. QM is the annual mean flood. Q5 is the five-year flood. The green vertical lines indicate the limit between observation- and forecast-period.

The effect of the correction is clearly shown in Figure 3. On May 6<sup>th</sup> we simulated a reduction of approximately 25 % in the flood culmination forecasted for May 9<sup>th</sup>, and in NVEs following flood warning the Tana river was excluded from the area where 5-years flood was expected. Afterwards, on May 18<sup>th</sup>, we concluded that this decision was correct.

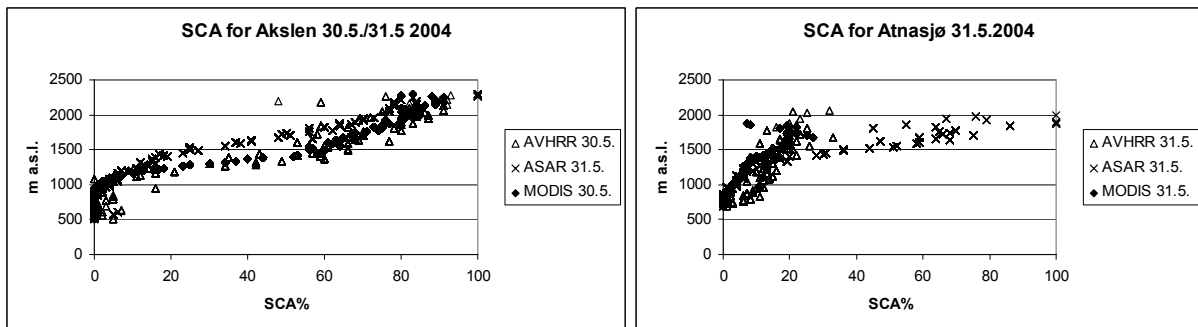


**Figure 3** Real-time simulations and forecasts from May 6<sup>th</sup> and May 18<sup>th</sup> with and without updating of the model inputs. In this example a winter precipitation event was reduced to get simulated SCA more in accordance with observed SCA on May 6<sup>th</sup>. QM is the annual mean flood. Q5 is the five-year flood. The green vertical lines indicate the limit between observation- and forecast-period.

Even if the flood turned out to be larger than in our updated simulations, the observed culmination was approximately 25% less than the 5-year flood. Colder weather than forecasted contributed to a reduction in the flood peak in addition to the smaller amount of snow available for snow melt. Accumulated over the flooding period from May 4<sup>th</sup> to May 18<sup>th</sup> the corrected model simulated the total runoff much better (98 % of observed runoff) than the uncorrected model (129 % of observed runoff).

## 4.2 SCA observations

During the demonstration only AVHRR data were used operationally since the spring flood started before an operational system for other EO data was established. MODIS was used as control data afterwards giving SCA values very similar to the AVHRR derived SCA. The SCA from ASAR was considerably different than SCA from MODIS and AVHRR (Figure 4). Figure 4 illustrates two effects that caused problems in harmonising SCA from ASAR to the optical data. For the Akslen catchment large areas with mixed pixels (snow and bare ground) are mainly classified as bare ground in the ASAR product. Hence the calculated SCA mean value is too low for these areas. For the Atnasjø area, with little remaining snow, the dry snow algorithm causes an overestimation of SCA in the upper area. Due to these effects ASAR data was not used for evaluating the hydrological models, since they were calibrated against AVHRR data. A comparison of the simulated and observed SCA from the different sensors for all the eight catchments in southern Norway showed that the difference between observed and simulated SCA was less than 10 % (Figure 5). For calibrations and simulations in the demonstration SCA from optical sensors was transformed to harmonise with the HBV simulations. A similar transformation on the ASAR data may lead to better results compared to the simulations. Still the effects demonstrated in Figure 4 indicate that differences between optical and radar SCA cannot be solved by one specific linear transformation for all the different stages in the melt season. ASAR seems to give higher SCA values than optical data in some areas and lower in other areas, depending on the amount of remaining snow.



**Figure 4** Comparisons of SCA from different satellite sensors (AVHRR, MODIS and ASAR) for the catchments Akslen and Atnasjø. The calculated values are mean values for each 20 meter elevation interval in the catchment.

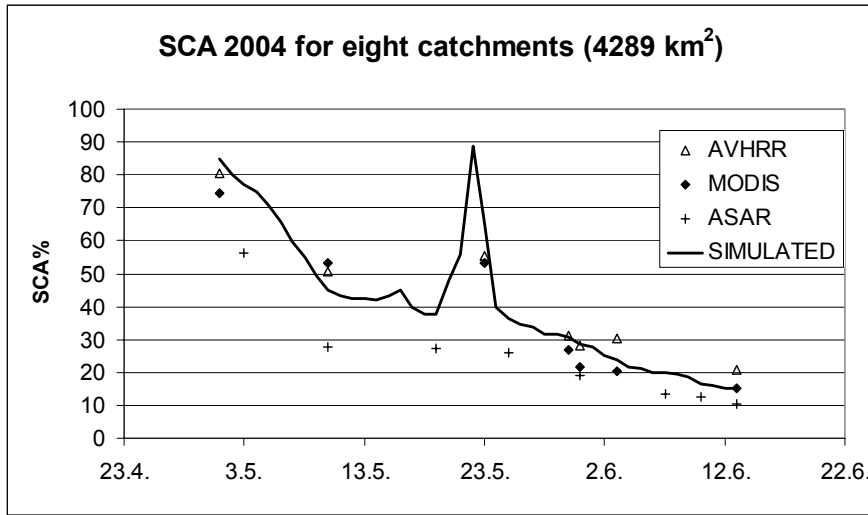


Figure 5 Comparisons of simulated SCA and observed SCA from different satellite sensors (AVHRR, MODIS and ASAR) for the eight demonstration catchments in southern Norway. SCA based on MODIS and AVHRR is transformed in the same way as in the model calibrations to harmonise with the HBV simulations.

## 5 Conclusions

The demonstration showed that operational updating of the HBV-model by satellite observed SCA was useful for the national flood warning services. One flood warning was successfully changed due to the information from the satellite data. Still the results from the demonstration were diverging. At some events the updating lead to less precision in the simulations. Nevertheless no forecasts or warnings were changed based on these simulations.

It was also shown that the HBV models in general simulated the SCA in good accordance with the observed SCA from the optical sensors during the melting period. The simulated SCA was not in accordance with the observed SCA from the radar sensor. A harmonisation of the radar and the optical SCA products is required before the radar data can be used operationally in the HBV simulations.

However, careful considerations of the uncertainty in the satellite SCA are needed, both for the optical and the radar sensors, before updating the operational runoff models.

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