EVALUATION OF SATELLITE IMAGES OF SNOW COVER AREAS FOR IMPROVING SPRING FLOOD IN THE HBV-MODEL

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ABSTRACT

For the hydro power companies it is of major importance to know the magnitude of the spring flood. Hence, the amount of snow is crucial for forecast modelling. In mountainous areas with plenty of snow, the meteorological network is often sparse, and they lack direct observations of the snow pack. Therefore, if it is possible to combine satellite snow cover area information with a hydrologic model, it would enhance the quality of the forecasts. In this project, financed by ELFORSK, a comparison is made between snow covered area (SCA) from satellite processed images and the HBV-model. The satellite processed images are based on data from Terra/Modis and Envisat/SAR. The images are produced in near real-time by NORUT and Kongsberg Satellite Services AS, for a project called Nordic Mountain Snow Hydrology (GSE) supported by European Space Agency (ESA). The HBV-model was calibrated without the use of snow observations. The evaluation has been made for mountainous catchments with less than 30 % forest cover. In most catchments there is a consistency between the difference in observed and simulated SCA and the error in simulated runoff. During spring 2008 updates of the HBV-model will be made in real-time.

INTRODUCTION

The HBV-model is used for spring flood forecasts in Sweden. The amount of snow in a drainage area is calculated by the model from measurements of precipitation and temperature. Hence, there is an uncertainty in the estimated snow pack. This is partly due to few measurements in the most mountainous areas and partly due to the fact that the HBV-model does not consider other weather parameters. There have been several efforts to use snow observations to improve the HBV simulations (Brandt and Bergström, 1994, Johansson et al., 2001, Johansson et al., 2003, Engeset et al., 2003, Malnes et al., 2005, Boresjö Bronge et al., 2006). The results have varied, but still, no result has led to recommendations for operational use.

In this project, financed by ELFORSK, a new attempt is made to improve the estimated snow pack in the HBV-model by the use of satellite observations. The SCA products are based on a multi-sensor time-series algorithm combining snow maps retrieved from Terra/MODIS and Envisat/ASAR. The images are produced in near real-time by NORUT and Kongsberg Satellite Services AS, for a project called Nordic Mountain Snow Hydrology (GSE) supported by European Space Agency (ESA). From the Terra MODIS and Envisat ASAR images a composite or multi-sensor (MS) product is created (Figure 1). In addition to data from two satellites, the composite uses data from several days to provide a complete picture.

PURPOSE

The purpose for this project is to evaluate the possible contribution of the MS product for enhancing the SCA in already existing and calibrated drainage areas in the HBV-model. The project is concentrated on years with difficult weather situations and where less than 30 % of the total drainage area is covered by forest. The aim is to find criteria for when a problematic area in the HBV-model should be updated with data from MS product and what kind of corrections has to be made before the data from the MS product can be used in the HBV-model.

In the project data from spring 2006 and 2007 have been evaluated. There will be a try with real-time data during spring 2008. The aim is to answer these questions

- Are the data from the MS product reliable?
- Is there coherence or incoherence between snow cover data from the MS product and the HBV-model when there are large errors in simulated springflood data?
- What difference must there be between observed and simulated SCA to start update the simulated SCA with data from MS product?
- To what extent shall the simulated SCAs be corrected based on MS product?

METHODS

Satellite images, multi-sensor (MS) product

The Polar View Nordic Snow Service provides an operational SCA monitoring service and is based on the snow mapping algorithms and software developed by Norut and Norwegian Computing Center (NR). The service provides daily snow maps over Norway, most of Finland and Sweden. MODIS data is processed daily; ASAR data is used whenever available, but at least with a weekly coverage in the mountainous areas.

The optical MODIS snow cover algorithm is based on an empirical reflectance-to-snow-cover model originally proposed for NOAA AVHRR in Andersen (1982) and later refined in Solberg and Andersen (1994). The algorithm, also know as the Norwegian Linear Reflectance-to-snow-cover (NLR) algorithm retrieves the Fractional Snow Cover (FSC) for each pixel. The model is calibrated by providing two points of a linear function relating observed reflectance (or radiance) to fractional snow cover. The calibration is carried out automatically by the use of calibration areas. Statistics from the calibration areas is then used to compute the calibration points for the linear relationship.

The snow service use satellite data from the Advanced Synthetic Aperture Radar (ASAR) onboard Envisat, ESA's environmental satellite that was launched in 2003. We use the wide swath imaging mode, which covers a swath of approximately 400 km and has 100 m spatial resolution. The snow processing line use the standard Level 1B satellite products as input, and performs automatical geocoding to correct for topographical effects using a digital elevation model (Lauknes and Malnes, 2004). The geocoded SAR images are subsequently compared against geocoded reference images from dry snow conditions. Due to the strong absorption of radar waves in wet snow, there is a significant decrease in the radar backscattering when the snow becomes wet. By comparing the current SAR image with the reference image, we establish areas containing wet snow using a 3 dB threshold (Nagler and Rott, 2000). By using the digital elevation model, dry snow is subsequently inferred by postulating that the snow above the local wet snow height is dry (Storvold et al., 2006).

Optical remote sensing algorithms are able to map snow cover quite accurately, but are limited by clouds. SAR sensors penetrate the clouds, but current algorithms for satellite-borne sensors are only able to map wet snow accurately. The sensor fusion approach is to analyse each image individually and combine them into a product showing the current, most likely SCA situation. The multi-sensor product should then represent the most likely status of the monitored variable. More information about the fusion approach can be found in Solberg et al. (2004a, 2004b and 2005).

Correspond satellite data to data from the HBV-model

HBV_Sverige is a HBV-model covering entire Sweden with a thousand sub basins and is run daily at the forecast and warning centre at SMHI. The model has been calibrated regionally. Every sub basin has one value for SCA which means that an average value must be calculated for each sub basin from the MS product. This was done with a combination with the MS product, sub basin areas and land use map. Due to the poor accuracy in forested areas, these were not included in the average value. 15 sub basins were evaluated, mainly situated in the north-western mountainous areas in Sweden. The locations can be seen in Figure 2.

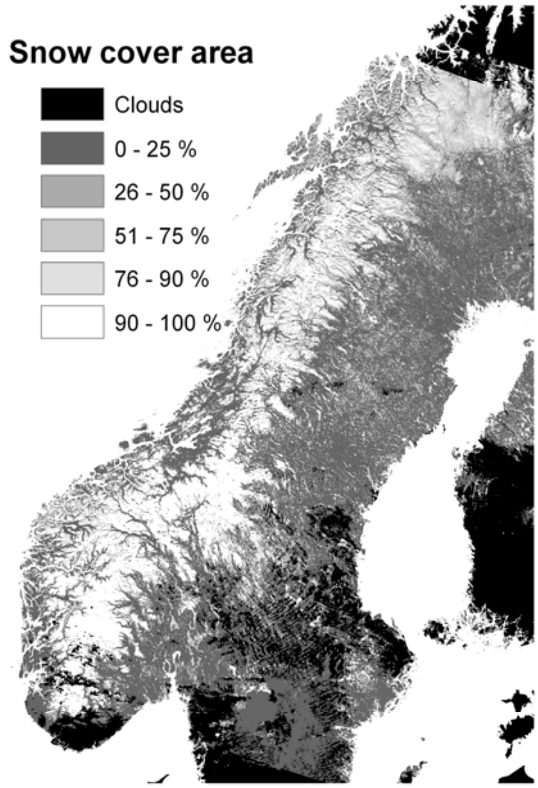

Figure 1. A multi-sensor (MS) product over Scandinavia 8th April 2006.

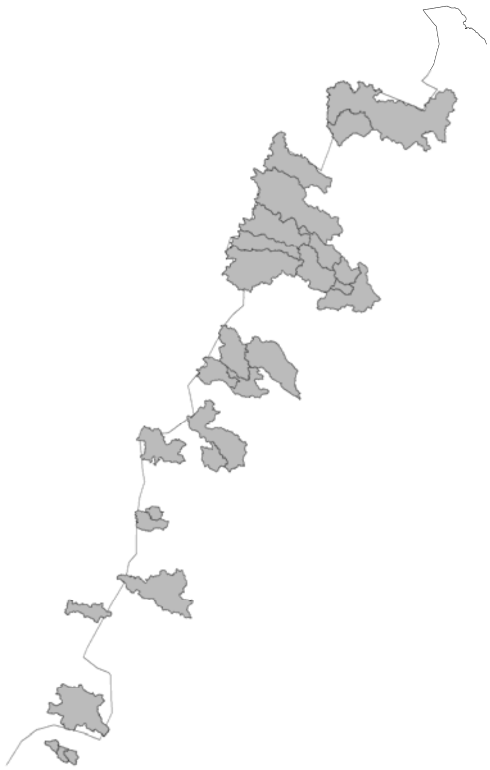

Figure 2. Areas of interest are situated close to the Swedish-Norwegian border in the northern Scandinavia. The major areas are 15, however some areas are divided in sub basins for the HBV-model.

Adjust the HBV-model

The first results show that it is not possible to compare data from the MS product directly with data from the HBV-model without any correction. It could be many factors that contributes to these differences some of them could be shadows on northern slopes (see discussion chapter) or in fact the HBV-model itself. A simple equation to adjust the satellite data was developed within the project.

RESULTS

A comparison between the simulated HBV snow cover and the satellite image indicates the usefulness of the satellite data. A high snow covered area in HBV, as compared to the satellite image, generally corresponds to an overestimation of the simulated spring flood volume and vice versa (Figure 3a). With those positive results the project continued to the next step, to update the HBV-model with corrected values from the MS product. Updates were made when the difference between observed and modelled SCA were at least 10 percentage points. No updates should be done if new snow comes during the melting period and places a thin layer of snow over the majority of the sub basin area. The simulated snow pack was updated by approximately 70 % of the difference between the observed and the simulated.

The results are unambiguous for 2007 (Figure 3b). In areas with extreme spring flood volume errors according to inflow (>20 %) during spring flood, an update of the SCA gives a significant decrease of volume errors from the middle of May and onward during the spring flood. For areas with large volume errors (10-20 %) an update results in a decrease of volume error, however a bit later in the season, June and onward. For areas with minor volume errors the update has no negative effects.

DISCUSSION

The results for 2006 were not as good as 2007 after updating the HBV-model with observed SCA. One explanation could be that data from MODIS were more frequent during spring 2007. In 2006 several days at a time were cloudy for some sub basins. During spring 2007 there were also very little precipitation which led to minor variation on SCA except for melting.

It would be useful if an update could be made for areas with 10-15 % error in the simulated spring flood volume. Even though the results are not as stunning as for areas with major errors (>20 %), an update is easily made and not time consuming. During 2008 the project will continue to find a system for a real-time update with some automation for the different steps.

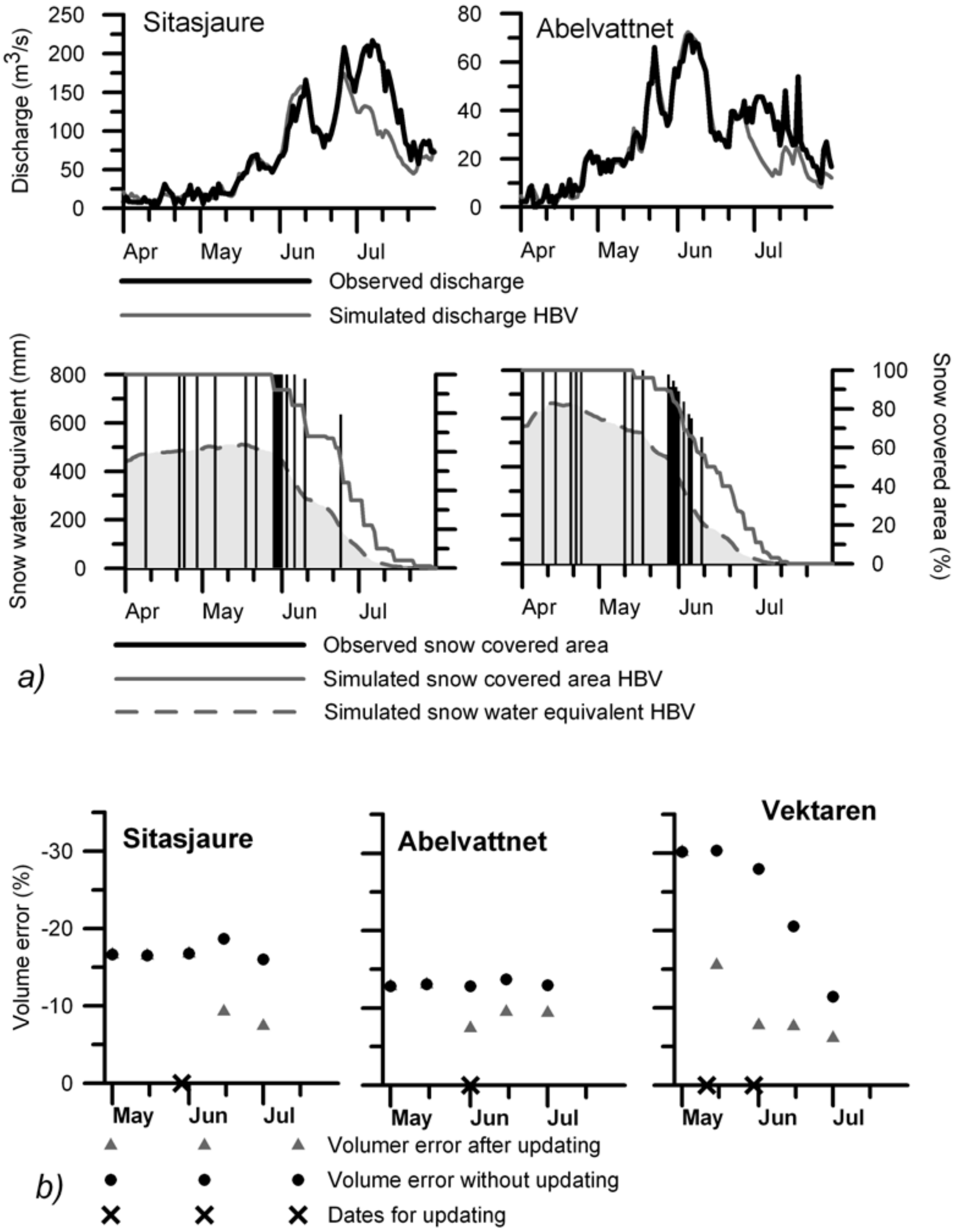

Figure 3. a) Examples of observed and simulated runoff and snow covered area (2007). An underestimation of the snow covered area also gives an underestimation of the simulated runoff.
b) Examples of volume error in simulated runoff with and without updating (2007). Every dot represents the volume error from the actual date to the end of the melt season (0731). Error expressed in % of total spring flood volume (0401-0731). In the examples updating leads to decreasing volume errors.

The NLR algorithm for Terra/MODIS SCA retrieval has been applied and evaluated in several projects. The general experience is that the algorithm typically underestimates the SCA somewhat. However, it is hard to conclude quantitatively, from experiments comparing SCA retrieved from MODIS images using NLR with SCA maps based on Landsat TM and ETM+, exactly how large the underestimation is. The underestimation is especially noticed in mountainous regions. In winter and early spring, there will be shadows because of the low sun. There will also be underestimation of snow in slopes facing northerly. These errors will decrease as the sun rises higher. The best results are obtained in April and May before significant fragmentation and pollution of the snow occurs. In this period the algorithm gives satisfying results with accuracy of 80-90%. Towards the summer the underestimation will increase because of dirty snow.

Norwegian Computing Center's cloud algorithm has been found to work quite well over Norway, and generally better than NASA's algorithm for the MOD35_L2 MODIS cloud mask product. There are small differences in general, but the main difference lies in detection of clouds over and at the borders of snow-covered areas. MOD35 frequently shows clouds along most of the edges of the snow covered area. In cases with cold weather and dry snow, the MOD35 product could show clouds over large snow-covered areas when there are no clouds. NR's cloud algorithm is sometimes not able to detect clouds over snow-free land and classify these pixels as snow. Cloud shadows can also reduce the estimated SCA value.

Radar waves are partially absorbed in forests. This results in less sensitivity towards wet snow in forests. Researchers in Finland (Luojus et al., 2007) have tested methods to compensate for the local forest stem volume with some success. The current service have not made any attempt to implement forest compensation due to the significantly more complex algorithm needed. In addition, the necessary forest stem volume inventory needed as auxiliary data for such method is currently not available for the areas we cover. Future improvements of the service should, however, focus on this issue.

SMHI observed in 2006 several examples where the snow depletion curve for several drainage areas indicated snowfall in the middle of the melting season. The ability to detect such snowfalls with the snow monitoring service depends somewhat on if it is detected by SAR or optical sensors. If only SAR has coverage during the lifetime of the newly fallen snow, chances are large that it remains undetected since a thin snow cover with little liquid content probably does not reduce the radar backscatter sufficiently to be detected as wet snow.

ESA and EU have through the GMES initiative made SAR data basically free for the GMES services. This will in the next years probably guarantee improved SAR coverage. KSAT is going to improve the operational aspects of the service. Improved experience in running the service and improved software will mean a more reliable service that provide near real time users with high quality data.

The multi-sensor time-series approach has proven to give significantly better coverage in space and time than using a single-sensor approach. The current confidence-based approach has been tested for a few snowmelt seasons and thereby demonstrated to work very well with respect to coverage in space and time. This is the only way of providing close-to-daily snow cover maps throughout the whole snowmelt season. However, there is still a lack of harmonization of the results coming from optical and SAR sensors. The two sensor types observe different geophysical phenomena and, therefore, cannot be expected to give fully consistent results. A new fusion model combining data closer to the physical retrieval process level is currently under development by Norwegian Computing Center and Norut.

CONCLUSION

The MS product from the satellite images has such good quality that they are applicable to compare and to update the HBV-model for a sub basin with large volume errors. Although a fixed constant has to be added to the data from the MS product.

Despite usage of a MS product there could be long periods of time without reliable observation e.g. clouds.

The MS product could be used to indicate overestimated or underestimated amounts of snow in the HBV-model.

An update of the HBV-model with data from the MS product enhances the accuracy of the HBV-model.

Evaluation was made for the spring melting seasons of 2006 and 2007. The results after updating the HBV-model with SCA data were more effective for values during 2007. Most probably due to more favourable weather conditions for satellite images.

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