

## Comparison of MODIS and *SnowStar* Snow Maps in Scandinavia

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### ABSTRACT

In this study, we look at the melt season in the spring of 2004 in the southern part of the Fenoscandia region, which includes Finland, Sweden and Norway, to determine the relative accuracy of the Moderate-Resolution Imaging Spectroradiometer (MODIS) snow maps as compared to the maps which employ a modified *SnowStar* algorithm. *SnowStar* is an operational snow-mapping system developed in Norway for mapping snow in Scandinavia. The *SnowStar* maps use 250-m MODIS data as input and a cloud mask which is tuned to the Fenoscandia region. Snow maps from MODIS produce global, daily maps using an automated algorithm which is not tuned to any particular land cover or set of cloud conditions. For the four dates studied, the preliminary assessment is that the regionally tuned cloud mask of the *SnowStar* maps accounts for most of the difference in amount of snow mapped between map products.

### INTRODUCTION

Algorithms have been developed using data from Earth Observing System (EOS) sensors to create geophysical products that are needed for modeling and monitoring studies. The Moderate-Resolution Imaging Spectroradiometer (MODIS) sensors on the Terra and Aqua satellites provide global-scale geophysical products such as land cover, albedo, snow and sea ice cover. The algorithms are designed to be automated and many of the resulting products have been validated (see Justice and Townshend, 2002).

The MODIS global snow-map products (<http://modis-snow-ice.gsfc.nasa.gov>) are available at different spatial resolutions to serve different user groups (Hall et al., 2002) and are archived and distributed through the National Snow and Ice Data Center (NSIDC) (Scharfen et al. 2000). The *SnowStar* map products may be produced in an automated or semi-automated mode using Advanced Very High Frequency Radiometer (AVHRR) data. A new version of the algorithm utilizes 250-m resolution MODIS data.

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Validation of new snow maps can be accomplished by comparing snow maps with operational maps and with point measurements (i.e., from meteorological station data). Intercomparison of snow maps can be problematic because it is often difficult to determine which map is more accurate, nevertheless it provides a great deal of information on the viability and limitations of different mapping techniques.

The MODIS daily snow maps compare well with existing NOAA daily or near-daily snow maps such as the NOAA National Environmental Satellite Data and Information Service (NESDIS) and NOAA National Operational Hydrologic Remote Sensing Center (NOHRSC) maps, however most of these studies have been done in North America (see, for example, Bittner et al., 2002; Klein and Barnett, 2003; Maurer et al., 2003; Simic et al., 2003) which may or may not be representative of the rest of the world.

Both the *SnowStar* maps and MODIS products provide fractional (sub-pixel) snow cover, and it is anticipated that interesting comparisons will be made comparing sub-pixel snow classes between the products in future work. However, in this paper, binary snow-map products from MODIS at 500-m resolution, are compared with the 100% snow category of snow maps produced using *SnowStar* algorithms, derived from 250-m Level 1B resolution data, are compared digitally.

## BACKGROUND

***MODIS snow-map products.*** The MODIS snow maps provide daily, global coverage. Swath and daily products are available at 500-m resolution, while the climate-modeling grid (CMG) products are provided at 0.05° resolution (~5.6-km resolution at the Equator). Fractional snow cover is currently available in the CMG products, and in the future, it will be provided in the 500-m products based on an algorithm developed by Salomonson and Appel (2004). Details about the MODIS snow products may be found in the Snow Products User Guide (Riggs et al., 2003) and elsewhere (see Hall et al., 2002).

A land/water mask is used by algorithms to determine if a pixel is land or ocean for processing in the algorithms. Processing within the algorithms is based on the 1-km resolution United States Geological Survey (USGS) global land/water mask stored in the MODIS geolocation product (Wolfe et al., 2002). The algorithms that generate products used as input in the snow and sea ice algorithms also use that land/water mask. However, a new land/water mask, developed at Boston University, will be implemented in the future and will be available with the MODIS snow maps in Collection 5, with reprocessing tentatively set to begin in early 2005.

A challenging problem in snow detection is the discrimination of snow from clouds (Ackerman et al., 1998 and Riggs and Hall, this volume). The “cloud-conservative” algorithm used with the MODIS snow map products decreases the errors of commission, globally, but because it tends to map some snow as clouds, and thus often underestimates the amount of snow cover.

***SnowStar-derived maps from MODIS.*** An operational snow-cover monitoring system using satellite imagery is run by the Norwegian Energy Corporation (Statkraft) for the monitoring of snow resources in the snowmelt season (April–July). The system can be run in both an automated and a semi-automated mode and is based on the use of NOAA Advanced Very High Resolution Radiometer (AVHRR) data (Solberg and Andersen, 1994). The classification algorithm is based on an empirical reflectance-to-snow-cover model (Andersen, 1982), and presents snow cover as snow-cover fraction. The model is calibrated by providing two points of a linear function, corresponding to maximum and minimum reflectance for 0–100% snow cover. The calibration is usually done automatically using calibration areas. The algorithm was integrated by the Norwegian Computing Center (NR) into a snow-cover monitoring system called *SnowSat*, which was run operationally by Statkraft since the beginning of the 1990s.

The approach was improved and implemented by NR in a new system called *SnowStar* run by Statkraft and later also implemented in a snow algorithm experiment environment, *SnowLab*, run by NR. There are two versions of the algorithm currently, one for NOAA AVHRR data and another for Terra MODIS data. The MODIS version generates 250-m snow maps based on MODIS band 1.

A particular problem for practical use of the snow algorithm has been cloud detection. NR has experimented with several approaches, and the current best cloud detection algorithm is based on K Nearest Neighbor (KNN) classification of MODIS data. In a KNN classifier a pixel is assigned the class which is dominating among the K nearest classified pixel vectors in the corresponding feature space generated from the training data. A KNN classifier is an asymptotically optimum (maximum likelihood) classifier as the size of the reference set increases.

The classifier has been trained based on a set of partially cloudy images acquired through a melt season. Reference vectors are extracted using a manually controlled spectral-distance based region-growing procedure. The procedure enables an accurate positioning of the spectral transition between different classes by utilizing the operator's ability to interpret both the pixel context and the pixel color. The pixel "color" in this case is the RGB image obtained through a transform of each pixel vector. A tool is developed to ease the manual labeling of scenes, a procedure which typically takes a couple of hours. The final reference set size is reduced to a manageable size using standard vector-quantization (K-Means). In our initial reference set we used the following classes: cloud, land, ocean and snow/ice. A total of 500 representation vectors was used for each class. The method is still under development and has not yet been published.

## **METHODOLOGY**

The MODIS snow maps, and the modified *SnowStar* maps were compared for four different dates in the melt season of 2004 (April 12, 21, 24, and May 1) in the Fenoscandia region. Because the *SnowStar* maps employ the 250-m resolution MODIS Level 1B data, are tuned specifically to the region, and the cloud mask is manually prepared, we are considering the *SnowStar* maps to be closer to the actual snow conditions than are the MODIS snow-map products.

In order to compare the extent of snow mapped on the *SnowStar* and MOD10\_L2 snow maps, the MOD10\_L2 product was resized from 500-m to 250-m resolution (to match the resolution of the *SnowStar* product). Additionally, the cloud mapped on each product was combined to form a single cloud mask for each data pair, and the inland water mapped on the MOD10\_L2 maps was overlaid on the *SnowStar* map.

## **RESULTS**

A comparison of the *SnowStar* and MODIS maps for 12 April 2004 is shown in Figure 1. The *SnowStar* map shows that 24.7% of the scene is snow covered, while the MODIS map shows that 19.2% of the scene is snow covered. If we employ the same cloud mask on both maps (cloud masks from both the MODIS map product and from the *SnowStar* map) and inland water from the MODIS product, using the *SnowStar* land/water mask on both maps, the *SnowStar* map shows somewhat less snow as compared to the MODIS map product—15.62% of the scene is snow covered while the MODIS product shows that 17.75% of the scene is snow covered (Figure 2). Figure 3 shows the results for each of the four dates studied. Results for the four dates using the overlays on both the *SnowStar* maps and MODIS map products are summarized in Figure 4. These preliminary results show that the amount of snow mapped is similar when the cloud mask, land/water mask and inland water mask are the same on both maps.

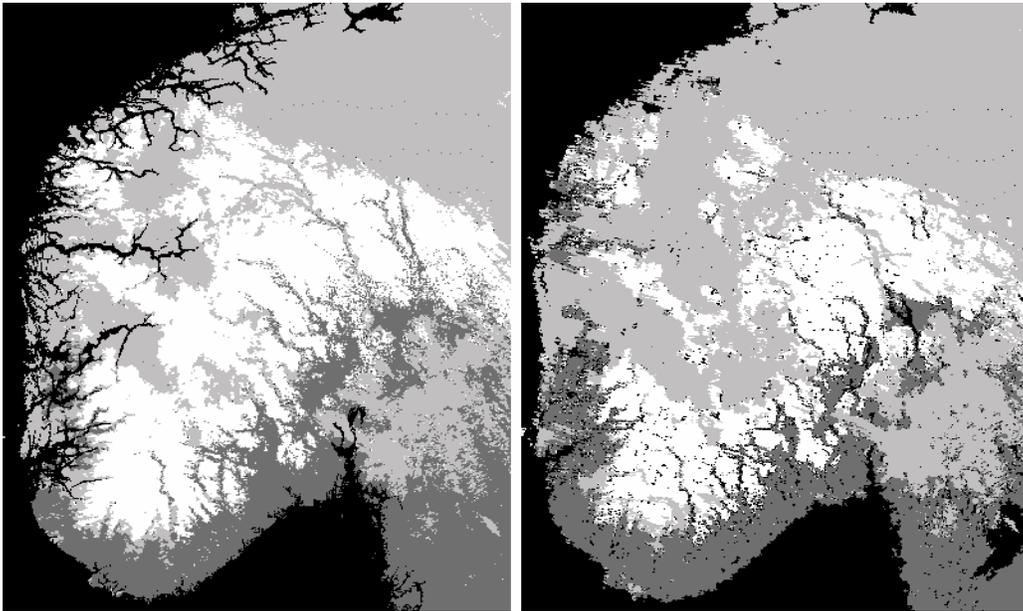


Figure 1. Comparison of *SnowStar* and MODIS snow maps—April 12, 2004—(*SnowStar* on left, MOD10\_L2 on right). Note the difference in the cloud masks.

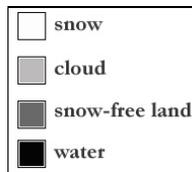
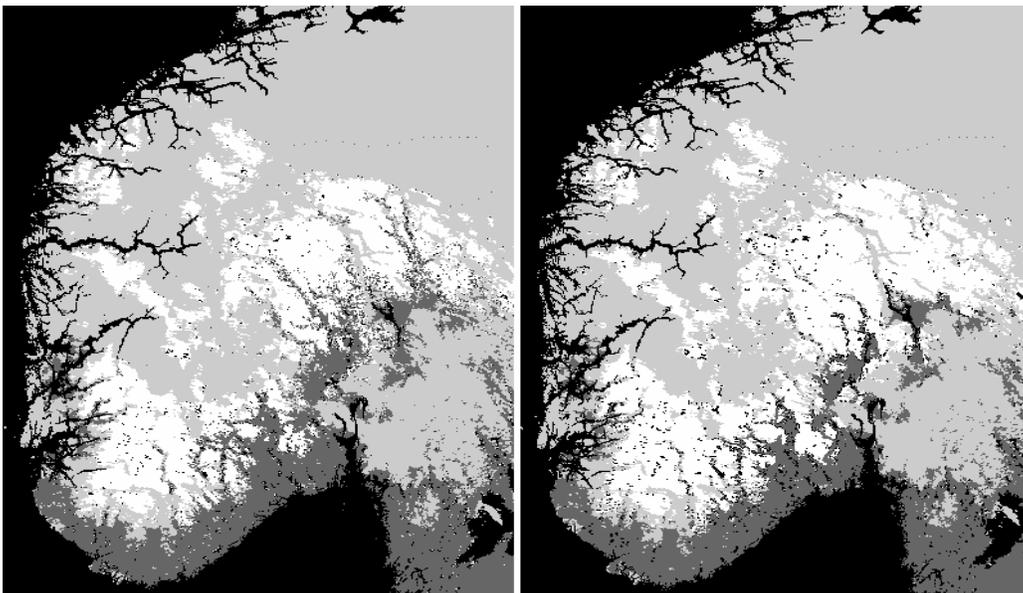


Figure 2. Comparison of *SnowStar* and MODIS snow maps—April 12, 2004—(*SnowStar* on left, MOD10\_L2 on right). The MODIS cloud mask is overlain on the *SnowStar* map, and the *SnowStar* coastline is overlain on the MODIS map.

Based on this preliminary data and the very small sample shown herein, the improvement in the “raw” maps, relative to the MODIS product, seems to come mainly from the regionally tuned cloud mask and land/water boundary of the *SnowStar* maps. While the MODIS 500-m resolution, daily snow-map products provide a product for use in global models, they tend to underestimate actual snow cover due mainly to the conservative nature of the cloud mask, thus errors of commission are minimized.

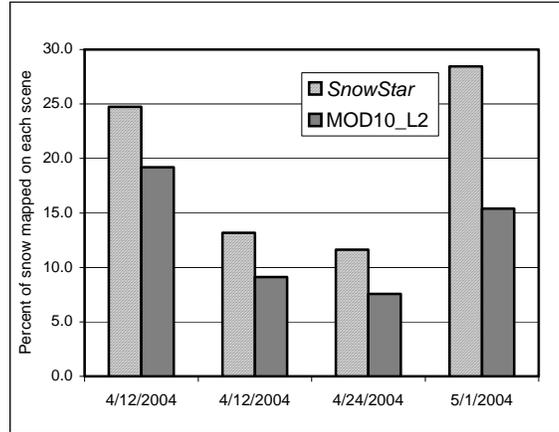


Figure 3. Percent of snow mapped using the snow maps as they are produced.

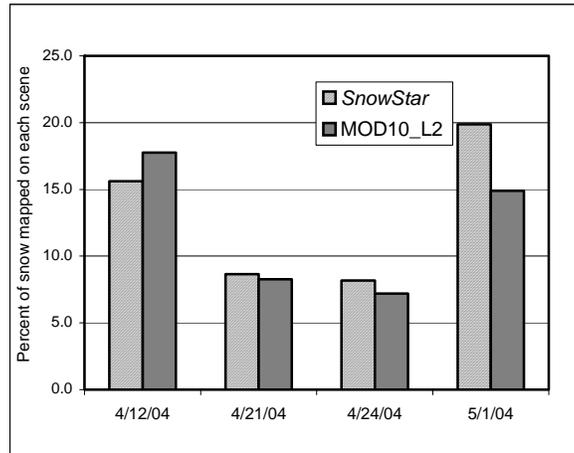


Figure 4. Percent of snow mapped using the MODIS cloud mask, and the *SnowStar* coastline on both maps.

## DISCUSSION AND CONCLUSIONS

Algorithms designed for use globally, such as those developed to map snow and clouds using MODIS products, have limitations when using them at the local and regional scales. For example the cloud-conservative nature of the MODIS cloud mask (Ackerman et al., 1998) that is used with the MODIS snow products, may permit less actual snow to be mapped, but is useful for decreasing the errors of commission in global snow mapping. Also, the land/water mask, developed for global application, is not as detailed as is possible to develop for a local area, such as the land/water mask used with the *SnowStar* maps. This lack of detail in the current land/water mask contributes to errors in snow mapping, at least in Version 4 of the MODIS snow maps, though an improved land/water mask, developed at Boston University, will be implemented in the next MODIS reprocessing, known as Collection 5 (also Version 5).

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