USING ENVISAT ASAR WIDESWATH DATA TO RETRIEVE SNOW COVERED AREA IN MOUNTAINOUS REGIONS

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ABSTRACT

It has previously been shown that wet snow can be detected using ERS SAR repeat pass imagery where a reference image is captured during cold dry snow conditions and subtracted from the image to be classified. We have extended and validated this technique for retrieving snow-covered areas (SCA) using repeat pass Envisat ASAR wide swath data (500 by 500 km^2 swath coverage, 100 m resolution), covering the mountainous regions of Southern Norway. The algorithm has also been extended to postulate dry snow above areas with wet snow, thus giving a total snow-covered area that is comparable to SCA from optical sensors. A sliding window technique has been applied to facilitate the dry snow classification. The method has been implemented in a near-real time environment and has been run pre-operationally in Norway in 2004. The relatively large coverage allows SAR to become an operational tool for snow monitoring, as opposed to standard modes used in previous works. In order to improve snow classification we have used air temperature data from the Norwegian meteorological station network to create high-resolution surface air temperature maps. These maps are used to filter wet snow from reference images and prevent incorrect classification of dry snow. Snow-covered area maps for South Norway have been derived for the spring melt season with a one-week temporal resolution. The results are validated against optical sensor retrievals (MODIS, Landsat) and high accuracy field measurements.

Keywords: Snow covered area, hydrology, ASAR wideswath

INTRODUCTION

Snow properties such as Snow-Covered Area (SCA) and Snow Surface Wetness (SSW) and ultimately Snow Water Equivalence (SWE) are important input parameters for hydrological models especially in northern and mountainous regions. In these regions snow run-off may account for more than 50% of the annual run-off. Precise retrieval of snow parameters is vital for prediction of flooding and run off forecasting. The Norwegian Water and Energy Directorate (NVE) uses optical remote sensing (NOAA-AVHRR) data operationally in their flood forecast. By assimilating SCA in their modelling, considerable improvements have been shown in the forecast (T1). The use of optical remote sensing is, however, unreliable in the rough and clouded climate in the Norwegian mountains. Periods of 1-2 weeks without coverage due to clouds are frequent in the important spring season. Use of weather and light-independent Synthetic Aperture Radar (SAR) data is very attractive in this respect. Snow-covered area mapping has been demonstrated in several papers before (2,3,4), but only for high resolution (30 m) data with limited coverage (100 by 100 km^2). In several European projects (Envisnow, EuroClim and SnowMan) we have demonstrated the use of Advanced Synthetic Aperture Radar (ASAR) Wide Swath (WS) data for SCA retrieval. ASAR WS allows regular coverage of both high spatial (100 m) and temporal (up to every day in Scandinavia) resolution and is independent of weather and light and is therefore a valuable supplement to optically based retrievals.

METHODS

Wet Snow Cover Detection.

Detection of wet snow by means of multitemporal Synthetic Aperture Radar data from the ERS and Radarsat standard modes (100 km coverage, 30 m resolution) has been demonstrated by several groups (2,3,4).These algorithms use the absorption dependency of the radar signal on the liquid water content of the snow to set a threshold on the differential backscatter between the actual scene and corresponding repeat pass scenes taken under dry snow or snow-free conditions. These algorithms have proved to perform well in identifying wet snow pixels over these limited areas. When using ASAR WS mode data (500 km coverage, 100 m resolution) one will encounter some problems due to the large range of view angles and the natural spatial variations in climate within such a large area. The fact that a single swath will cover regions of different climate and weather conditions implies that one would rarely find a single reference scene working well over the entire area. To accommodate this problem we use temperature fields derived from data from the Norwegian meteorological station network. These data has been used to create temperature maps corresponding in time with the ASAR passes and the corresponding reference scenes as well. A Digital Elevation Model (DEM) and a constant lapse rate of 6°C/km was used to interpolate the surface air temperature between the weather stations weighted by the distance from the stations in the surrounding area within a 70 km radius. In this manner we filter out areas from the reference scene where the surface temperature is above freezing and is likely to contain wet snow. The met station density and an example of derived temperature fields and the resulting masked reference image are shown in Figure 1.

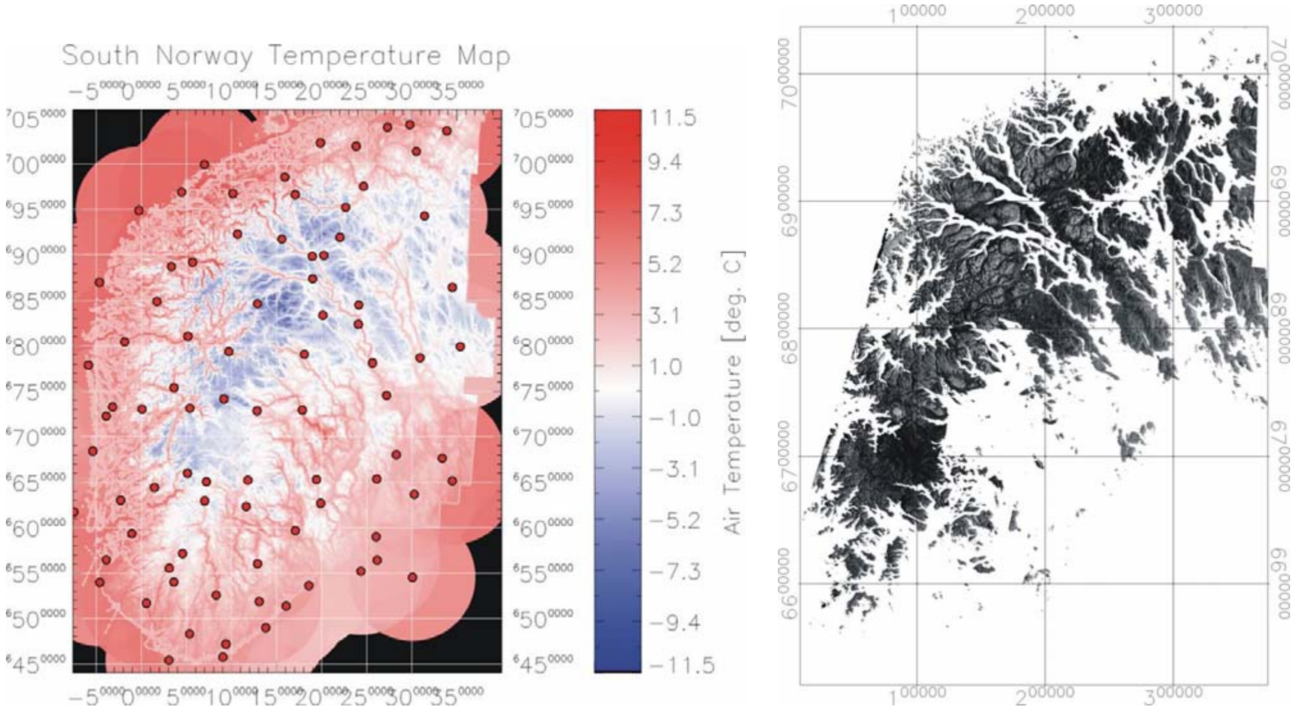

Figure 1: Left: Distribution of weather stations in South Norway used together with a 100 m resolution DEM and a constant lapse rate of 6°C/km to construct an air temperature field map for March 10, 2003 at 10 am. Right: SAR backscatter reference image covering South Norway from the same day with above 0°C pixels masked out. Using reference scenes containing wet snow would lead to underestimation of the snow cover. As more reference scenes with the same geometry are obtained one can improve the coverage and statistics by averaging (to reduce effect of speckling). Confidence maps are generated for the reference image based on the temperature map, hence on the probability for dry snow.

Inferring Dry Snow Cover

Since dry snow cannot be derived directly from the backscatter intensity difference between the SAR scene and the reference scene, the dry snow mapping is based on the probability of dry snow under the given circumstances. The current algorithm, which is a refinement of the method suggested in (5), prescribes snow in areas fulfilling the following requirements:

1) the pixel is above the mean altitude of all identified wet pixels within a sliding 20x20 km^2 box centred at the pixel;
2) Derived air temperature in °C for the pixel has to be negative;

3) At least 2% of the pixels in the sliding box must contain wet snow. The use of temperature data prevents erroneous prescription of dry snow at higher elevations late in the season.

Confidence Flags

In addition to a SCA map, our algorithm produces a confidence flag image. The flags give a confidence value for each image pixel. This flag is a percentage probability of the pixel being correctly classified. For wet snow pixels the value is based on the difference between threshold value and satellite geometry and on the confidence value of the reference image which is based on the air temperature. For dry snow and no snow pixels, the elevation difference between the wet snow mean altitude and the air temperature contributes to the determination of the confidence value as well. Each factor is treated independently based on and tuned to empirical data, and the final flag value is the product of all the individual factors. These flags are used later on when the SAR-based SCA products from different sensors are merged with optically based SCA products to optimize spatial and temporal coverage.

RESULTS

We have established a production line for near real time automated geocoding and SCA classification of ASAR WS images. The steps involved in retrieving SCA maps are outlined in the diagram describing the production line shown Figure 2.

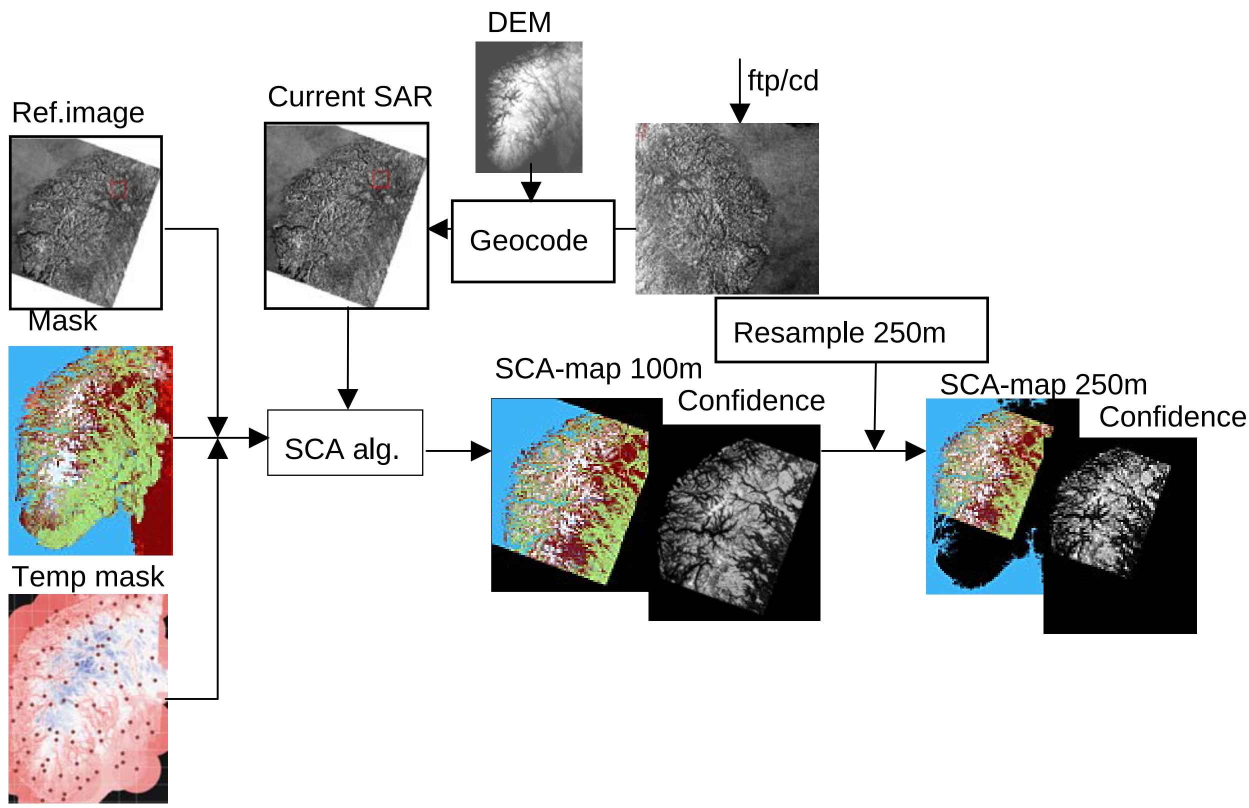

Figure 2: Diagram showing the steps involved in producing SCA maps from repeat pass ASAR WS data.

A 100 m resolution classification map for May 3rd 2004 is shown in Figure 3, where we have classified wet snow pixels using the threshold algorithm (2) with a -3dB threshold.

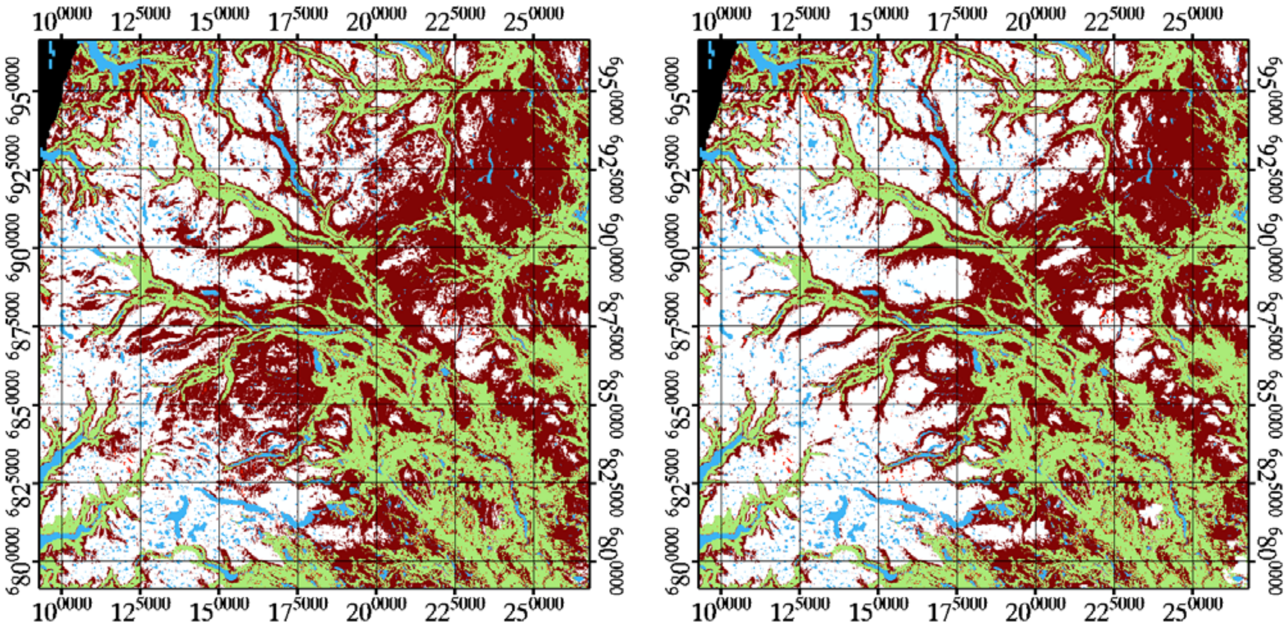

Figure 3: Left: Wet snow map (white pixels) for May 3rd 2004. Higher elevation in the central and eastern side of the mountains has dry snow which is transparent to the C-band radar (brown pixels). Right: Snow-covered area map for May 3rd 2004, now assuming dry snow at elevations higher than the wet snow elevation within 20 km of the pixel. Green and blue colour masks forested areas and water bodies, respectively. Red pixels are no data due to overlay and shadowing.

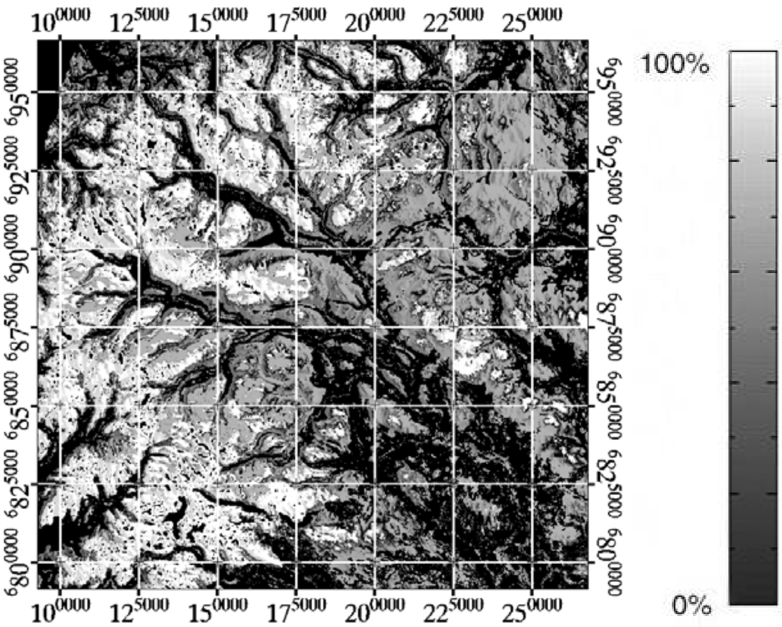

Figure 4: Confidence map for the May 3rd 2004 SCA image of dry and wet snow and bare ground. Areas that are masked out due to water, forest, shadowing or folding have confidence 0 (black), The confidence flags are in the range 0-100% (black to white)

The most problematic situations to map are the early spring scenes. In these scenes we are likely to have large areas of dry snow which causes the dry snow algorithm to fail due to the lack of wet snow which is needed to predict dry snow at higher elevations. This causes the algorithm to erroneously predict bare ground in these instances. An example is shown in the northeastern corner of Figure 5. The corresponding temperature map shows that this area is uniformly below freezing. Since this area would normally melt out late in May, it is most likely covered with dry snow during this time (late in April). Without temperature fields to remove dry snow predictions for above freezing temperatures, the algorithm will have problems in late spring by overprediction of dry snow areas. This is caused by the winter wind redistributing snow in the mountainous areas which causes snow at the exposed higher elevations to melt out earlier than in the lower and less exposed areas.

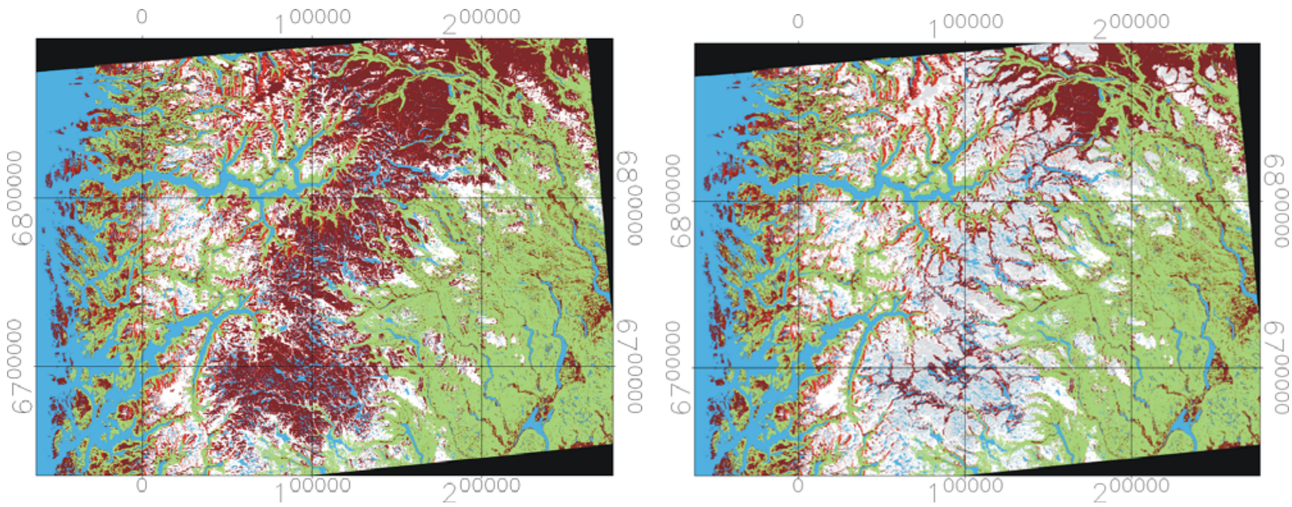

Figure 5: Left: Wet snow map for April 24th 2003. Right: Same date also including dry snow. Temperature maps for this day show that it was cold enough for dry snow also in the northeast corner of the image, but lack of wet snow in the vicinity caused the dry snow algorithm to fail.

Comparison with MODIS

For comparison with optical imagery (MODIS) we have resampled the ASAR data to the same grid and resolution (250 m) as the MODIS SCA images provided to us by the Norwegian Computing Center (NR). NR has developed a state-of-the-art algorithm (6) for snow cover classification based on 250 m radiometrically calibrated MODIS data. The snow cover is given as percent of pixel covered by snow. The 100 m resolution ASAR-based classification gives a binary snow or no snow for each pixel, while the 250 m resampled product gives the average of the 100 m pixels covered.

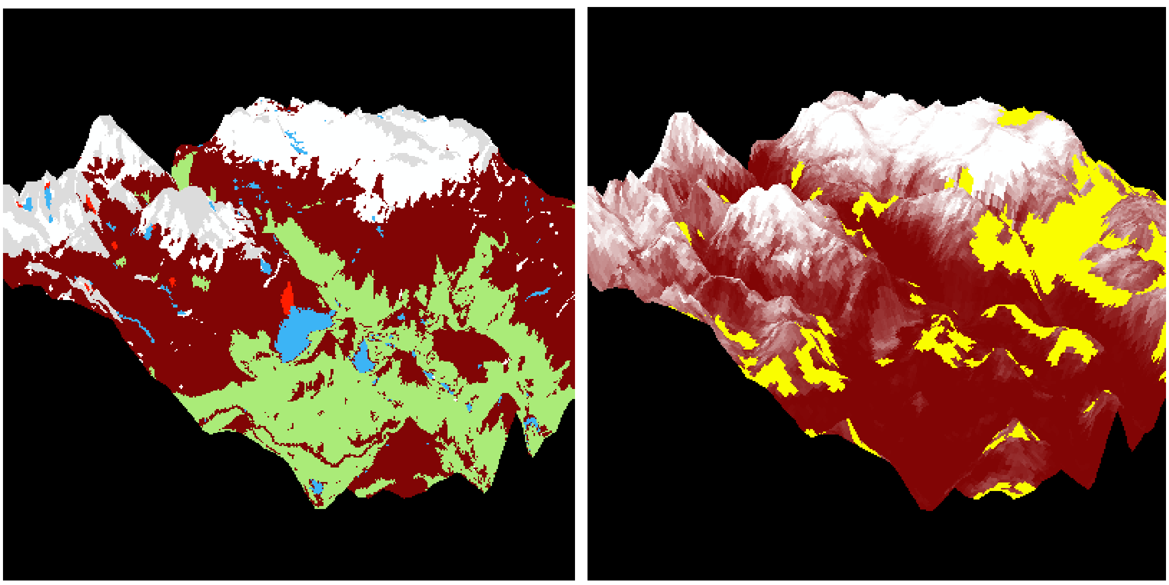

Figure 6: Left: Snow cover area map from Envisat ASAR draped on DEM. White denotes wet snow, grey denotes dry snow. Right: Corresponding drape of SCA map derived from Modis data. Yellow colour denotes clouds.

We have produced a difference map between the radar and optically based classification shown in Figure 7, which also shows the statistical differences of the classifications. There is a much higher frequency of partial snow cover pixels in the optical classification than in the ASAR classification due to the binary nature of the ASAR SCA algorithm.

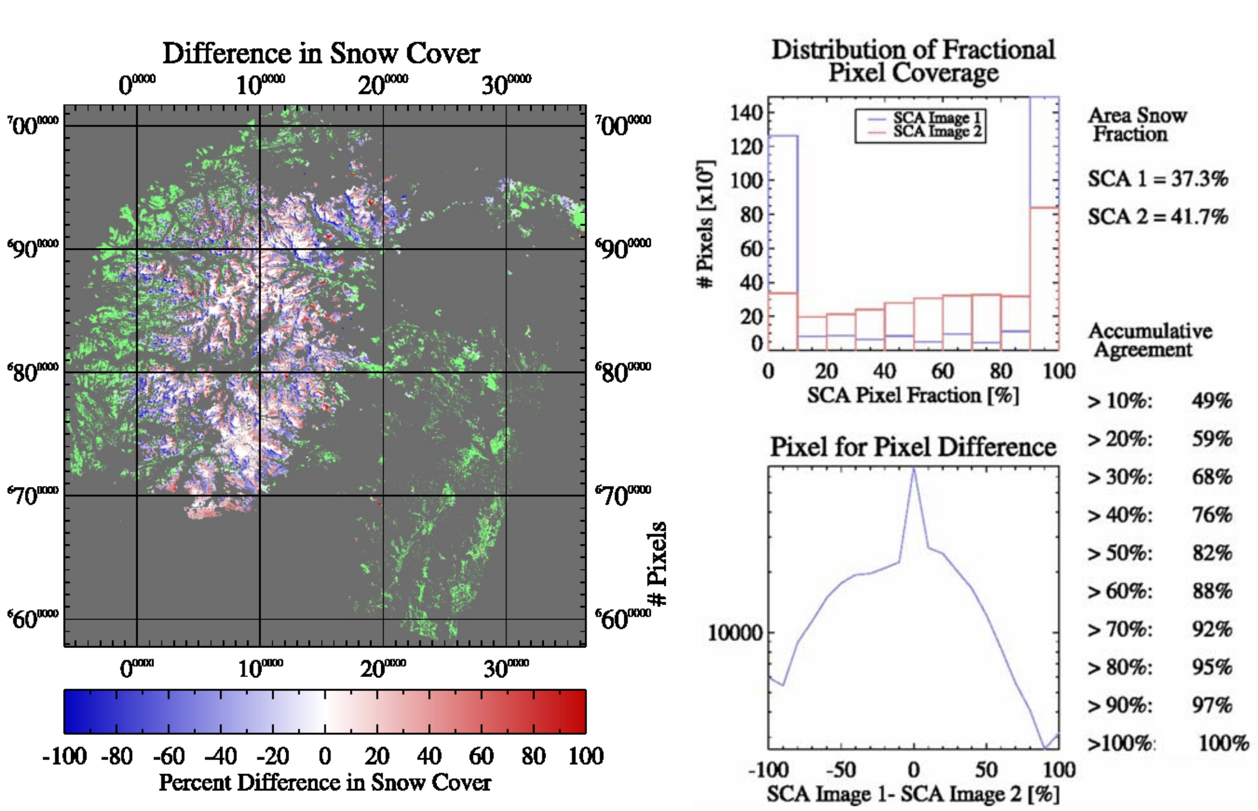

Figure 7: Difference between radar and optical snow cover estimate. White is no difference. Towards dark green, optical pixel has larger snow fraction than radar pixel. Towards dark red, radar pixel has a larger snow fraction than the optical. Grey is masked area due to clouds, forest, water, or no data. The histogram shows the fraction distribution of the SCA image pixels for both the radar and optical image acquired on May 9th 2004. The pixel for pixel difference in the SCA classifications is shown in the lower right panel, where the MODIS derived SCA image (SCA 2) is subtracted from the ASAR SCA image (SCA 1). The accumulative agreement shows the percentage of pixels agreeing to 100% within 10% point difference.

CONCLUSIONS

There are several problems that can cause errors in the SCA classification. This is mostly mirrored by the values of the flags in the confidence maps. It is instrumental that the geocoding (7,8) is accurate. Otherwise offset between the images will create false signals and erroneous classifications. Strong sensitivity to vegetation and bare spots causes partly covered pixels to be classified as snow free by the radar SCA algorithm. With improved vegetation maps one could tune the algorithm to deal with some vegetation like in (3). From Figures 6 and 7 we observe that most of the differences are in areas bordering the forest mask and in hillsides down towards the valley floors. These are areas that are likely to have vegetation not covered by the snow. Low solar angles are known to create problems for north sloping hillsides early in the year for the optical algorithm and we see some evidence of this as well in Figure 7. The overall agreement is very good, around 90% and we see from the accumulative agreement shown in Figure 7 that for the single pixels the partial errors are less than 20 % for most of the pixels. Though, as mentioned earlier, the radar algorithm is based on the high absorption of the radar signal by wet snow which during early season cold periods is likely to classify dry snow as bare ground. Further, it is very important to ensure that the reference images indeed are taken under cold dry conditions, and if necessary to mask out regions of the reference that do not fulfil this condition. Access to temperature data is very important for the performance of the dry snow algorithm. More work is needed to tune the algorithm optimally, particularly in connection with estimating confidence map values. Better vegetation maps should also be used to investigate whether thresholds can be adjusted to work in moderately vegetated areas.

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