MULTI-POLARISATION MEASUREMENTS OF SNOW SIGNATURES WITH AIR- AND SATELLITEBORNE SAR

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ABSTRACT

In 2003 an extensive campaign was carried out in the mountainous parts of southern Norway to measure snow signatures with multi-polarisation SAR using ESAR. Field campaigns were carried out to support the measurements. Airborne orthophotos and Radarsat imagery was also acquired in the period. Unfortunately, Envisat ASAR was not available at the time due to malfunction. In this paper we will present some of the results from the campaign, specifically multi-polarisation signatures for snow and bare soil will be derived. The results from using the multi-polarisation data to derive snow covered area maps will also be presented, using standard classification schemes. The classified results are compared with the orthophoto to assess the overall agreement. Snow cover will also be derived from Radarsat imagery, and compared with orthophoto. Near simultaneous imagery from single polarisation Radarsat imagery (HH-polarisation) will be compared to ESAR data to evaluate the potential of satelliteborne polarimetry to study snow parameters. Issues related to multi-scale observations of fractional snow covers will be discussed.

Keywords: SAR, snow covered area, snow monitoring, polarimetry.

INTRODUCTION

Retrieval of snow parameters from single polarimetric SAR (both VV and HH) has been studied widely for airborne as well as satelliteborne SAR sensors (1,2). Pre-operational systems for the retrieval of snow-covered areas have recently been implemented and demonstrated within the framework of the EU project Envisnow. Multi-polarisation SAR gives the potential to include more information into the equation, and hence potentially more information for retrieval algorithms for snow parameter retrieval. This paper discusses the potential for using multiple polarisations for snow parameter retrieval. Shi and Dozier (3) used polarimetric space shuttle borne SIR-C data to derive snow wetness by inverting a first order backscatter model (surface and volume scattering). By measuring three components (σ^{vv}, σ^{hh} and $\sigma^{vvhh}=\mathrm{Re}[VV\,HH^*]$) they were able to minimise effects from volume scattering and surface roughness (i.e. reduce the dimensionality of the inversion problem) to estimate snow permittivity, which subsequently are related to snow wetness. The algorithm has a limited parameter regime, but yields quite high accuracy. The algorithm is promising, but since there is not any spaceborne platform yet which has full polarimetry, it is currently not applicable. Data from Envisat ASAR alternating polarisation mode are not applicable for the current algorithm. ESAR data are neither useable since the polarisations cannot be measured simultaneously. The aircraft has to perform two passes for covering the same stripe with all polarisations. Hence, the full cross-polarisation matrix cannot be formed. The objectives of the study are: first, to assess if ESAR multi-polarisation data can improve classification of snow; second, we want to investigate how multi-scale SAR data affect the classification of snow. In the current study, we show how multi-scale SAR and optical data can be applied to classify snow-covered areas. The fine resolution datasets from ESAR and orthophoto are able to map the patchiness of a partial snow cover in a much better way than medium resolution SAR data (Radarsat). It appears that medium resolution data fail to derive a snow-covered area when the patchiness has a similar scale as SAR data. The resulting effect is an underestimation of snow cover due to the fact that snow has much lower scattering cross-section than bare ground. Strategies to compensate for this lack of sensitivity are discussed in the conclusion part of the paper.

METHODS

The current paper describes a dataset that was collected in the EC EE SD FP 5 project Envisnow. The main data set is a multi-polarisation airborne ESAR acquisition from May 28, 2003. In combination with this dataset both satelliteborne Radarsat scenes and airborne orthophotos were acquired in the same period. *In situ* measurements of snow properties were also carried out.

Area

The experiment was carried out in Heimdalen, a small valley in the Jotunheimen mountain range in southern Norway. Heimdalen is a well-developed test site for EO studies of snow parameter retrieval, and has been used as a test site several years for this purpose. We have available high-resolution digital elevation models (5 m resolution) for the area. We also have access to meteorology stations and time-series of EO data from the area. The area was appointed the main study area in Norway within the Envisnow project. In 2003, which was the main field campaign season for the Envisnow project, totally 6 field campaigns were carried out in the area. Heimdalen also contains a hydropower station owned by GLB (Glommen and Laagens Brugseier forening) and is well regulated with hydrological models. The area has an altitude range from 1100 to 1800 m.
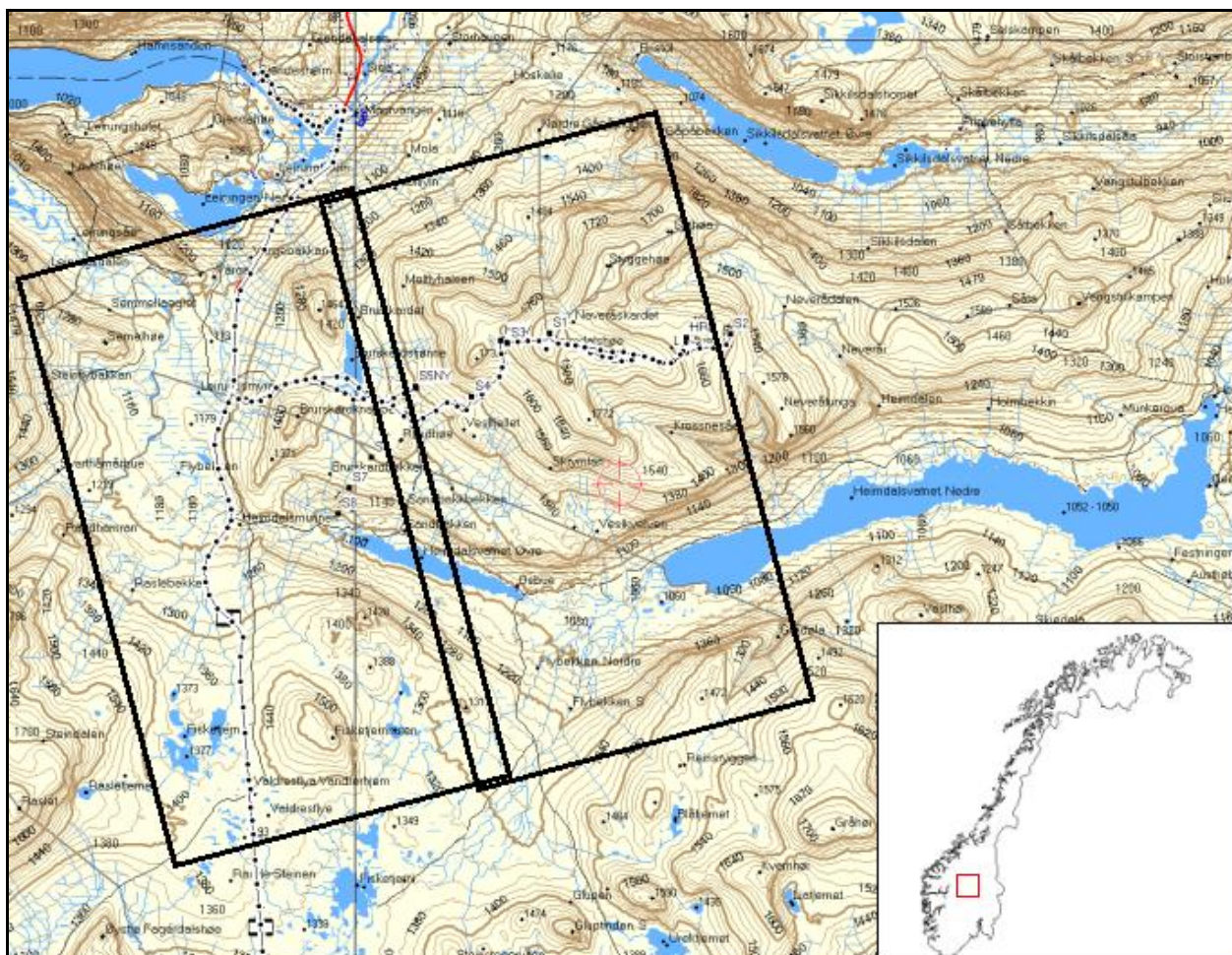

Figure 1: Map for the Heimdalen test site and its position in southern Norway. The approximate positions for the two ESAR stripes are indicated. The GPS track log and the different positions for snow pit measurements are also shown.

ESAR data

An airborne SAR campaign took place on May 28, 2003. The airborne SAR measurements were carried out by DLR with their ESAR sensor on a Dornier aircraft (Figure 2). The dataset was geocoded and calibrated by DLR using a high-resolution digital elevation model. The results are two

stripes of multi-polarisation data (HH, HV, VH and VV at 5.3 GHz, angle range from 25 to 60 degrees for narrow swath). In conjunction with the campaign, *in situ* measurements of snow properties were carried out. Corner reflectors were deployed in the field and GPS measurements were also carried out to assure proper geocoding and calibration of the ESAR data.

Figure 2, Left: ESAR aircraft. Right: Corner reflectors and GPS equipment for accurate differential GPS measurements.

Field measurements

In the field campaign snow-pits were dug, and the snow parameters density, temperature and wetness were measured at 20 cm depth intervals. Roughness, correlation length, grain size, snow depth and air temperature were also measured. A total of six snow-pits was properly documented in an altitude transect covering altitudes from 1100 to 1800 m.

On the day of the ESAR acquisition the air temperature was ranging from 2-8°C depending on the time of the day and the altitude. The snow depths also varied a lot in the test area ranging from no snow to three metres in some places. The snow density was on average 240 g/cm^3. The snow was, however, wet all over. The snow wetness ranged from 2-5%, and in general, the snow pack was totally wet. This proved to be advantageous for the snow cover area algorithm since there is a large overall correspondence between the optical and the radar imagery. The most prominent differences can probably be explained due to the retreat of snow from the ESAR to the optical acquisition taken four days later.

Auxiliary dataset

In addition to the ESAR dataset, we also acquired a high-resolution orthophoto on June 2, 2003. Originally the optical acquisition was planned on the same day as ESAR, but could not be arranged due to overcast. Due to the four-day delay, there might have been some retreat in the snow cover from May 28, 2003 ESAR acquisition. Visual inspection of the two datasets, show some retreat, but this is not a predominant feature.

From meteorological stations in the vicinity of Heimdalen we observed that the daily mean air temperature increased from 0 to 10°C at Bitihorn (1607 m.a.s.l.) and 8 to 18°C at Bygdin (1050 m.a.s.l.) in the period of May 28 to June 2, 2003. This also indicates that there should be some retreat of the snow between the two airborne acquisitions.

We also acquired two Radarsat ScanSAR Narrow beam scenes from May 28 and June 22, 2003 to allow comparison with satelliteborne SAR data. The two scenes originated from the same repeat pass (25 days separation). The scenes were acquired in the near range (NSA) mode with incidence angles ranging from 20 to 39 degrees. Radarsat uses HH-polarisation and transmits at C-band frequencies (5.3 GHz). Although not ideal, we have used the latest Radarsat scene as dry soil reference in the classification scheme for wet snow cover.

Envisat ASAR was not available due to system malfunction. This was very unfortunate since the Envisnow project aims at studying Envisat ASAR data in detail and its applicability to snow parameter retrieval. The ESAR campaign coincided with a major system failure of ASAR that lasted for more than a month. There were no data available over the area from May 6 to June 20, 2003.

Image processing methods

The geocoding of the ESAR images was performed by DLR, using a high precision DEM (5 meters), while the calibration was executed by means of indications provided by DLR. The Radarsat and orthophoto images were geocoded and calibrated using in-house Norut software (4). The classification of the snow cover area was performed using a minimum distance classifier for ESAR and orthophoto, while the Nagler algorithm (2) was applied for Radarsat data.
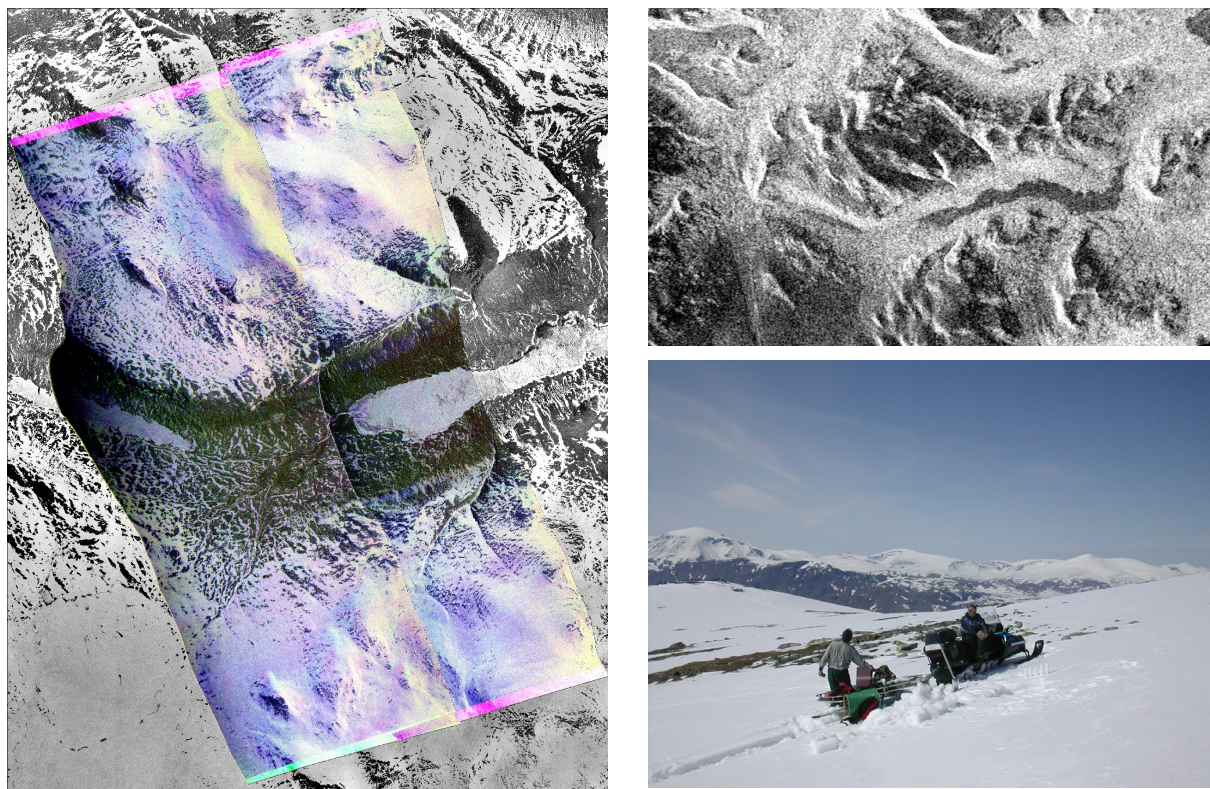

Figure 3, Left: Aerial photo over Heimdalen with the two ESAR (colour composite of HH,VV and HV) strips superposed. Upper right: Radarsat-1 imagery over Heimdalen on May 28, 2003. Lower right: Imagery from the in situ *field campaign in Heimdalen on May 28, 2003.*

RESULTS

The overall correspondence between ESAR data and orthophoto is good in non-vegetated terrain (Figure 3). By using RGB-composite of the VV, HV and HH backscatter coefficients with inverted colour tables, we were able to reproduce the snow coverage very accurately (visual inspection). For the most part, the minor differences noticeable in the two images can be explained by the retreat of snow from May 28 to June 2. There are, however, some partly forested areas at low altitudes, where the ESAR data cannot be interpreted easily. Figure 4 shows the same area for optical and ESAR data. The overall agreement between the two data sets is good. The value of using such high spatial resolution for classification of snow data is evident.

Backscattering signatures for multi-polarisation ESAR data

The ESAR data have been studied with respect to variability in incidence angles. In Figure 5 we show the variation of the backscatter cross-section as a function of incidence angle for the four polarisations. The data have been averaged in 1-degree intervals, and show a smooth dependency between incidence angle and backscatter cross-section. We classified the orthophoto and used the classification as snow mask to separate snow and soil pixels in the ESAR imagery.

In Figure 5 we observe that the difference between backscattering from soil and snow is fairly constant 6-7 dB for all incidence angles and polarisations. We also observe that VV backscatter is consistently lower than HH. This is inconsistent with what we should expect from theory. Oh *et al.*

(5) state that VV should be larger than HH for all incidence angles, roughness conditions and moisture contents. The inconsistency could be explained by poor calibration of the ESAR instrument, but we lack evidence to support this assumption.
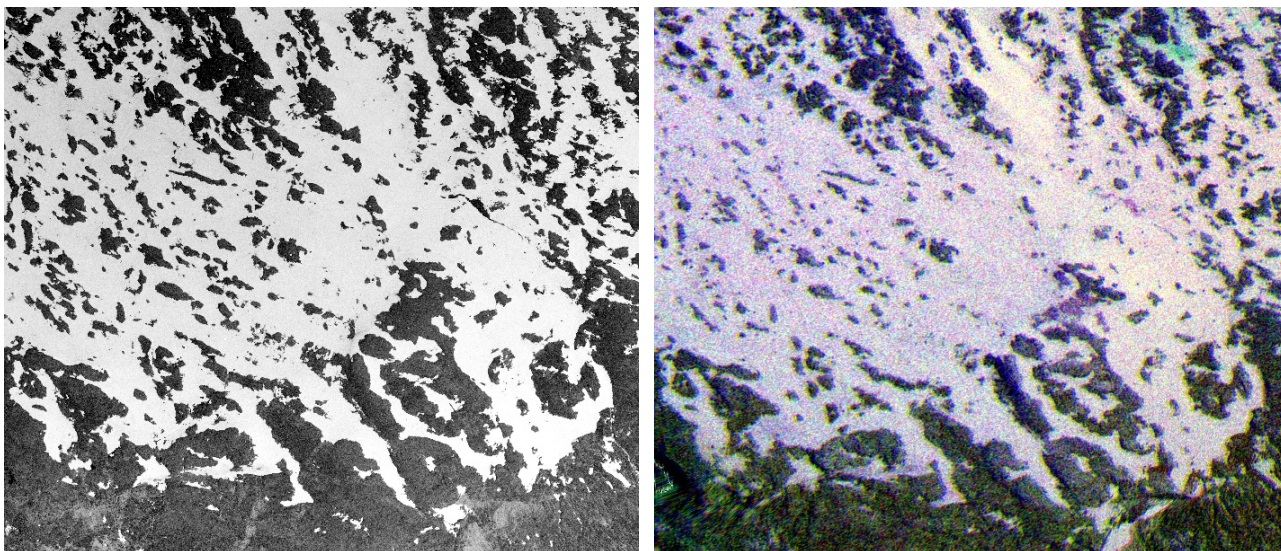

Figure 4, Left: Aerial orthophoto from Heimdalen from June 2, 2003. Right: Inverted colour composite of ESAR multi-polarisation data (Red:HH, Green:HV, Blue:VV) from May 28, 2003.
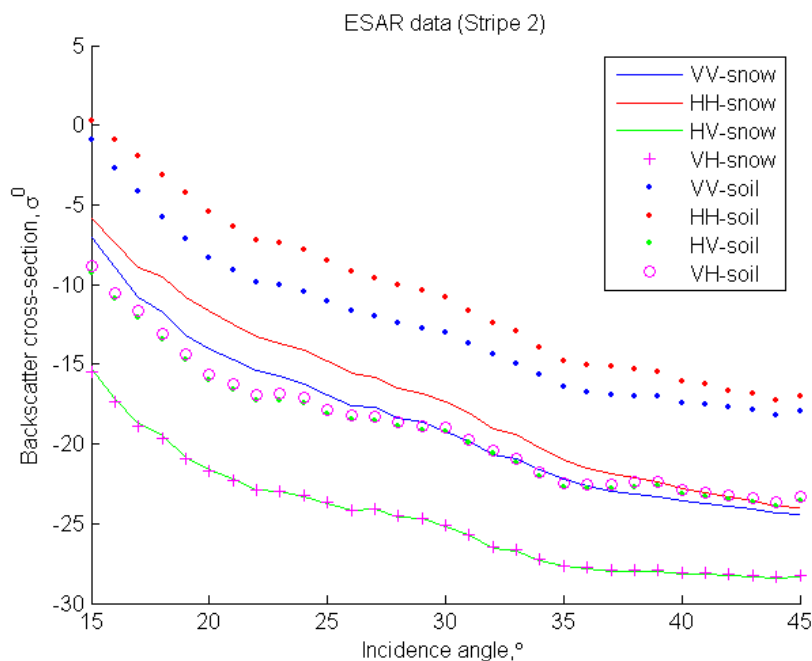

Figure 5: Average backscatter cross-section vs. incidence angle for wet snow and bare soil. The optical imagery was used to classify pixels. Backscattering was averaged in 1-degree intervals.

Classification of ESAR data

Different classification schemes have been tried out to study the ability of the multi-polarisation SAR to classify wet snow. As a first step the ESAR images have been speckle-filtered using a gamma filter with a 3×3 window. A simple minimum distance classifier was applied using two classes (snow and no snow). The classifier calculates the Euclidean distance from each unknown pixel to the mean of each vector class selected. The use of the four polarisations has been tested in order to verify if improvements of the accuracy could be achieved.

The snow map from ESAR data has been generated, considering the minimum distance classifier working in all the four polarisations available. Subsequently, the corresponding snow map has been generated from orthophotos to serve as reference for the ESAR snow map. The classification errors are presented in Table 1 that shows that the use of four polarisations gives the best result, while it seems that there are no great differences in performance between the single polarisations, although the cross-polarisation bands present a lower error than the co-polar bands. The result of the classification is shown in Figure 6, and it is possible to verify the agreement between ortho-photo and ESAR data. The snow maps are generated considering the classified orthophoto as 'ground-truth'. In a final step, the areas where the snow is present in the ESAR image, but not in the orthophoto have been studied. Most of the differences can be explained with the fact that the orthophoto data were acquired a few days after the ESAR images, and some snow may have melted before the ESAR acquisition.

Table 1: Percentage of snow erroneously classified as bare soil in ESAR images, using the classi-fied orthophoto as ground truth. The values refer to Figure 6a and b.

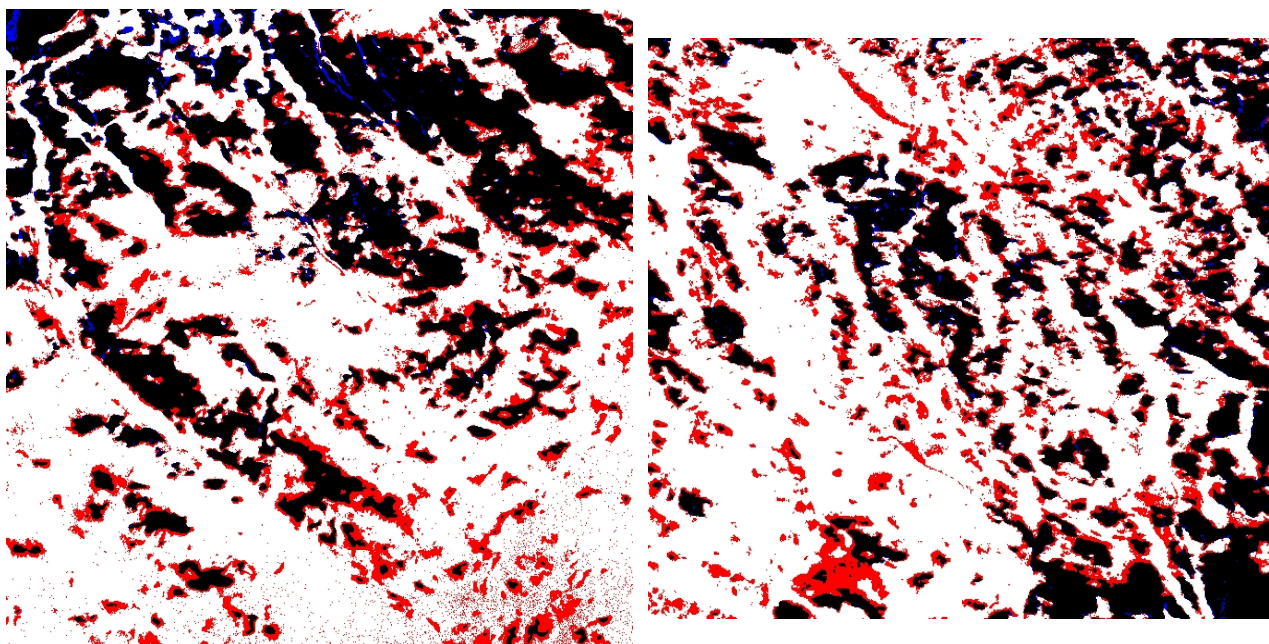| Area	All pol.	VV	VH	HV	HH
Figure 6a	1.06	2.62	1.37	1.15	2.69
Figure 6b	0.85	2.94	1.07	1.46	3.23

Figure 6a,b: Snow maps of two areas generated using all the polarisation. White denotes the snow detected correctly by ESAR and orthophotos, blue indicates snow detected in the orthophoto but not in the ESAR image, red shows the snow detected by ESAR but not in orthophotos. Most of the red areas are consistent with a snow retreat due to melting between the two acquisitions.

Radarsat data

The two Radarsat scenes from May 28 and June 22, 2003 have been geocoded and calibrated using in-house Norut software (4) and a high precision digital elevation model, and projected to UTM WGS-84 zone N33 on a 25 m x 25 m grid. Visual inspection of the scene from June 22 shows no evidence of snow in the relevant area. Classified Terra MODIS imagery was also inspected. Although clouds were a problem in this period, we found no evidence of snow. We have used the Nagler and Rott method (2) to threshold the snow in the image of May 29. Figure 7 below shows the snow cover area classified in the image.
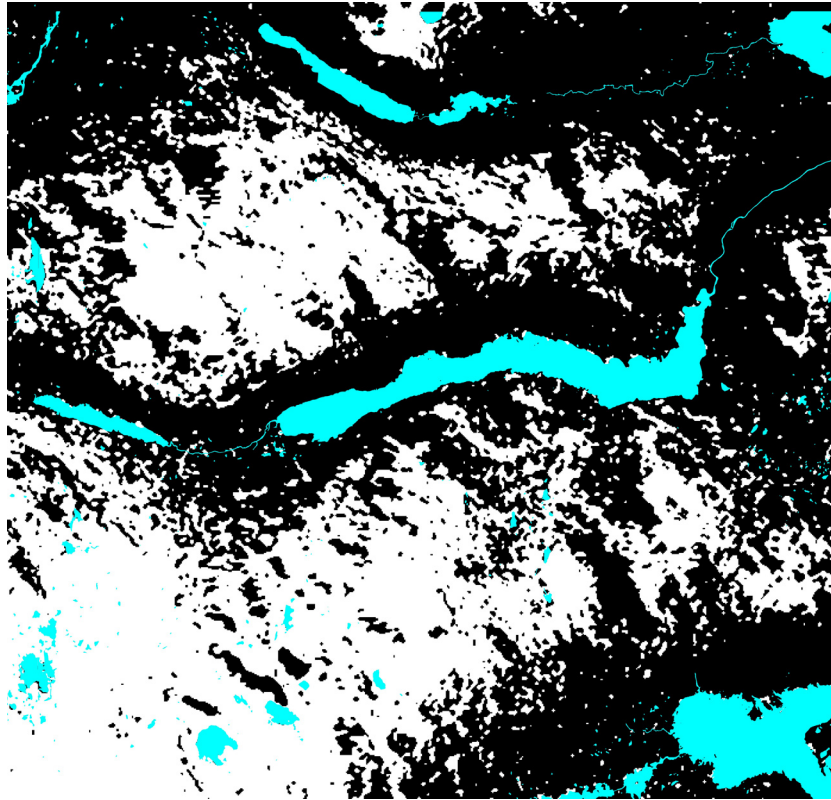
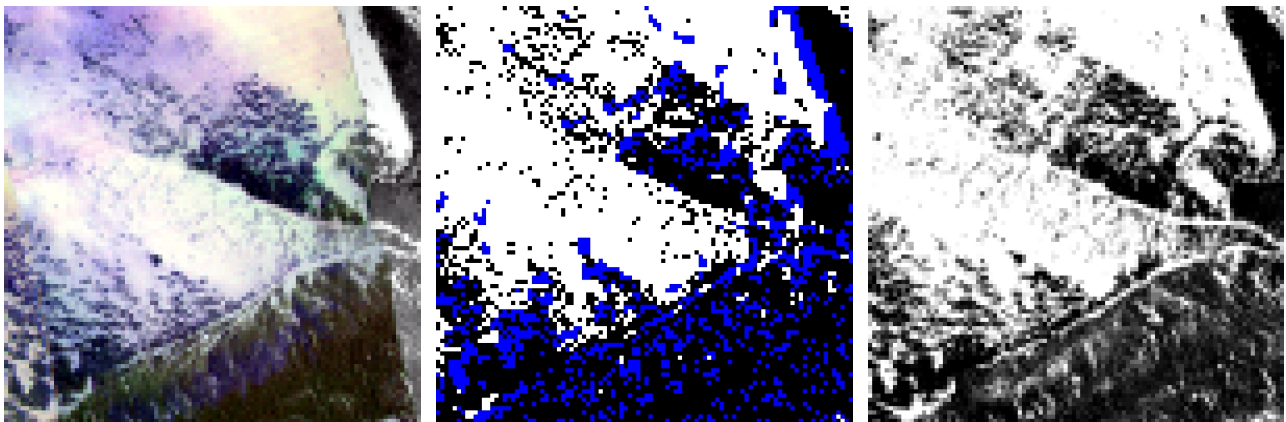*Figure 7: Classified snow cover in Radarsat scene from May 28, 2003. Lakes are masked with cyan colour.*

Figure 8: Same area shown by three different sensors. Left: ESAR colour composite, May 28. Middle: Classified Radarsat imagery, May 28. Right: Orthophoto, June 2. The Radarsat imagery has 25 m resolution, resulting in far less accurate classification (blue is misclassification). 14.0% of the pixels were misclassified when we used the orthophoto (resampled to 25 metres resolution) as ground truth.

In Figure 8 we show a comparison between airborne SAR, orthophoto and satelliteborne SAR. The correspondence is good between ESAR and optical imagery, but somewhat poorer with respect to Radarsat imagery. Some overall features can, however, be recognised. The reason for the poor correspondence is probably mainly due to the large difference in resolution. Another source of errors in the classification of Radarsat data might be any remaining snow cover in the reference scene from June 22, 2003, even if we did not find any indications. The effect caused by poor resolution vs. snow patchiness is well understood. Medium resolution SAR data tend to underestimate the snow cover for partial snow cover, since the scattering from soil is much higher and tends to dominate even for small fractions of bare soil. The patchiness observed in the ESAR and orthophoto datasets is not visible in the Radarsat data since the scale of the patches is smaller than the

resolution of the Radarsat data (25 m), while it is more in line with the high resolution datasets. The overall misclassification in the Radarsat data is 14%, when we compare against the orthophoto. This accuracy is close to the overall agreement reported by Nagler and Rott (2) when they compared Radarsat and Landsat derived SCA maps.

DISCUSSION

Current algorithms for mapping snow-covered areas by SAR are mainly based on the works by (2) for mountainous areas and by (6) for boreal forests. Means for improving the snow cover maps with inferred dry snow have been suggested by (7) for mountainous areas. During 2003, 2004 and 2005 near real time demonstrations of pre-operational multisensor snow cover mapping using Envisat ASAR wide swath data (sampled to 100 m resolution) and Terra Modis data (250 m resolution) were performed in Southern Norway (8). Fractional SCA was obtained from SAR data by re-sampling to 250 m resolution. A major problem in these demonstrations has been to harmonize the fractional SCA from SAR with fractional SCA from optical sensors, since SAR data underestimate the snow coverage.

Different strategies to avoid the underestimation of wet snow should be studied in the future. This is a key issue in the research towards operational SAR algorithms for detecting snow, since it is of major importance that the data are in line with optical fractional snow cover algorithms (9). This is not an easy task since the signal in a SAR image pixel contains the mixed contribution from all single scatterers within the pixel. When the pixel is partially covered by wet snow and partially covered by bare soil, there is too little sensitivity left in the single backscatter cross-section measurement from a single polarisation SAR to separate various degrees of snow wetness from the relatively strong signal from bare soil. Multiple polarisation data from e.g. Radarsat-2 could be used to expand the parameter space, and hence allow correct retrieval of the snow cover fraction within the pixel. We believe, however, that operational SAR, which presently is within reach with Radarsat-2 and ESA Sentinell-1, will have to rely on single frequency and single polarisation wide swath data to provide operational snow cover monitoring. In that respect, it is very interesting if SAR data can provide higher accuracy for snow mapping.

Present algorithms use a –3 dB threshold to separate between wet snow and dry snow/bare soil. A more fine-tuned thresholding could be applied if the vegetation cover is known (10) and a variable threshold can be applied. A different strategy would be to use a backscatter model in combination with both the differential backscattering and the absolute backscatter, to quantify the snow cover fraction directly as opposed to a binary classification into snow/no snow per pixel. Means to obtain this should be studied.

CONCLUSIONS

The current paper describes data from a campaign performed in Jotunheimen, Norway in May-June 2003. The campaign involved multi-polarisation high resolution ESAR data and near simultaneous optical orthophotos. Radarsat data were also acquired in the same period. Field measurements of snow properties were also obtained.

The signatures of the ESAR data have been studied with respect to polarisation and incidence angle variation. The data have also been compared with the orthophotos with overall very good correspondence.

Automatic classification of the ESAR data did give good results for every polarisation used, and the combination of all polarisations did improve the accuracy.

The final part of the paper compares the classified snow maps from the Radarsat data set with the high-resolution data. The overall classification accuracy is not impressive for medium resolution SAR since fractional snow cover is poorly estimated. The paper also discusses means for improving the classification accuracy, and for how a resulting improved SAR algorithm may be of big importance for future operational snow cover monitoring.

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