Area 3 was used for investigation of the classification results. The results are shown in Table 2. The table shows that clustering of VV data gave the best results with an error rate of 7.2%. The least good results were obtained for cross-polarization with an error rate of 12.2%.

ERS DATA

ERS-1 SAR PRI datasets from 29 March, 6 June, 11 July and 12 July have been calibrated and processed into terrain corrected images in Universal Transverse Mercator (UTM) map projection by applying high resolution (5m x5m) DEM data and geocoding software [4]. The DEM is derived from airphoto. A 3x3 Lee filter was applied to the data before conversion to dB.

In Fig. 3 the mean ERS-1 SAR backscattering coefficient for from, 29 March, 6 June, 11 July and 12 July, respectively, are shown for two areas close to the previously defined areas are used. A decrease of 4 dB in backscattering coefficient is observed for the high mountainous area between 29 March to 6 July. This change is related to the change in snow properties. In 29 March the area is covered with dry snow while in June the area is covered with wet snow. We clearly observe a change between the ascending 11 July and descending 12 July ERS pass. This is caused by the difference in viewing geometry giving rise to different local incidence angle.

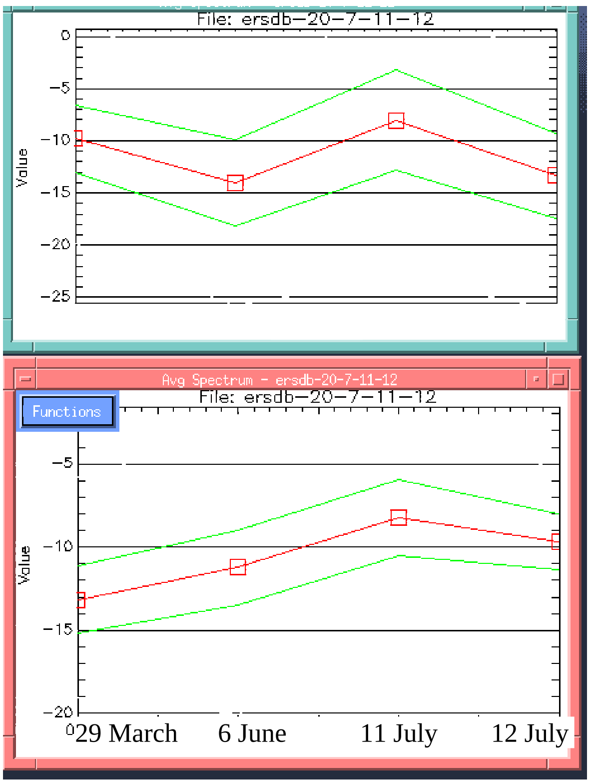

Figure 3. ERS mean backscattering coefficient from two areas for March 29, June 6, July 11 and July 12, respectively. The standard deviation is also shown.

DISCUSSION AND CONCLUSIONS

The backscatter statistics of two areas with an elevation difference of about 450 m was studied. The difference of the mean of the class snow between the two areas were largest for co-polarization with about 4.4 dB. Correspondingly, it was 1.8 dB for cross-polarization. For bare ground, the corresponding numbers were less than 1.0 and 1.3 dB. Since the ground conditions for snow were very similar in the two areas, the main reason for the change of the backscatter level is probably the incidence angle. For the purpose of classification, a preliminary conclusion is that local classstatistics must be applied. If the reason for variation is mainly due to the incidence angle parametrized class models may be designed. A classification test using K-means clustering showed best results with an error rate of 7.2% for VV polarization. All error rates were between 7.2 and 12.2. An investigation of a larger area is necessary in order to draw more clear conclusions.

EMISAR C-band polarization responses from wet snow correspond to theoretical responses from smooth surfaces. The polarization response at L-band show a higher degree of diffuse scattering than C-band.

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The ground measurements include measurements of snow density, snow grain size, snow liquid water content and surface roughness. Air- and snow temperature data are also available. Several trihedral corner reflectors were deployed within the field for calibration and georeferencing purposes. The field measurements are georeferenced using GPS. One aerial photo of the test site was taken July 14. The field was completely covered with snow on March 22 and on May 1-3, while in July the field was nearly snowfree.

The calibration of the EMISAR data have been verified using the radar cross section and the polarization responses from a 0.7 and 1m trihedral corner reflectors deployed within the area.

CLASSIFICATION EXPERIMENT

One experiment using the EMISAR C-band data from July 1995 data set is presented here. Data was extracted from three test areas, two areas for investigation of snow and bare ground backscatter statistics.
Area 1 is located about 550 m.a.s.l., while Area 2 is located about 1000 m.a.s.l. The aerial photo was co-registered with Area 3 EMISAR data using a second-degree control-point transformation. An accurate snow cover mask was extracted from the aerial image based on thresholding.

In Fig. 2 the Co-polarization responses from snow covered areas are shown for C- and L-band, extracted from two different range positions. The C-band polarization responses correspond to theoretical smooth surface scattering responses. No range variation are observed. The polarization response at L-band have a higher pedestal, i.e a show a higher degree of diffuse scattering than at C-band. This is explained by the higher penetration depth of the L- band resulting in scattering contribution from within the snow volume We clearly observe a range difference.
For the statistical investigation, “safe” snow and bare areas were selected. Due to the uncertainty in the co-registration, the areas defined were all well within the border of each snow and bare ground area. The statistics are shown in Table 1. For Area 1, we see that the difference between the mean values of the two classes (between-class distance) is of the order 1.0-1.5 standard deviations. For Area 2, the between-class distance is about 2.0 standard deviations. This means that the two classes should be well separable in a classification for Area 2, but less separable for Area 1. Comparing the two areas for snow for each class, we see that the backscatter level is about 4.4 dB higher in Area 2 for co-polarization and 1.8 higher for cross-polarization. For bare ground, there is a change of less than 1 dB for co-polarization and about 1.3 dB for cross-polarization. The ground truth measurements of snow show that water contents and surface roughness are almost equal for the two areas. For bare ground, the type of vegetation cover is different and may influence on the backscatter level. However, both areas have only low alpine vegetation. It is more likely that the main differences in backscatter levels are due to the variations in local incidence angle. The angle was about 45 for Area 1 and 55 for Area 2.

Table 1: Backscatter statistics for Area 1 and 2. The values are given in dB.

	Area 1	Area 1	Area 2	Area 2
Class	**Mean**	**St. dev.**	**Mean**	**St. dev.**
Snow HH	-15.8	2.8	-20.1	3.1
Bare gr.HH	-12.7	3.0	-13.6	3.4
Snow VV	-15.1	2.8	-19.6	3.1
Bare gr. VV	-12.6	3.0	-12.5	3.3
Snow HV	-21.4	2.9	-23.2	2.8
Bare gr. HV	-16.5	3.1	-18.0	3.1
Snow VH	-21.2	2.9	-23.0	2.9
Bare gr. VH	-16.4	3.1	-17.7	3.1

To obtain a more accurate investigation of the discrimination which could be expected for Area-2 conditions, Area 3 was investigated further. A K-means clustering algorithm [7] was applied. Data from the entire West Profile, including Area 1 and 2, were speckle filtered by a 3 $\times$ 3 mean filter and applied for the clustering.

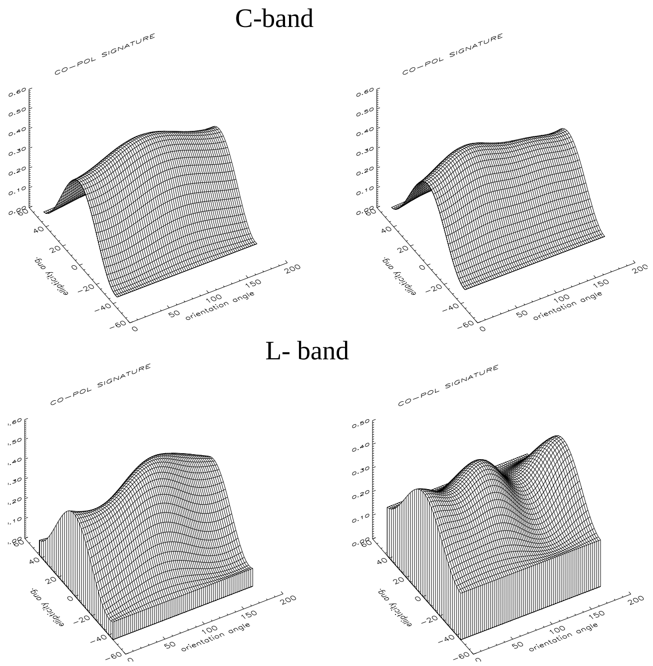

Figure 2. Snow Co-polarization responses for C- and L-band. Left) near range, right) far range.

Snow Monitoring Using EMISAR and ERS-1 Data within the European Multi-sensor Airborne Campaign EMAC-95

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ABSTRACT

Results from analysis of data obtained in the Snow and Ice experiment within the European Multi-sensor Airborne Campaign (EMAC'95) [2] are presented in this paper. The study area is located in Norway, 66^o N, 14^o E.

Fully polarimetric C- and L-band SAR data from EMISAR, a airborne instrument operated by the Danish Centre for Remote Sensing, combined with ERS SAR, airborne photos and field data were analyzed in order to determine the capabilities for snow parameter estimation in mountainous areas. The backscatter statistics of EMISAR C-band data from two areas partly covered with wet snow was studied. There was a difference in mean values between the two areas of up to 4.4 dB for snow and up to 1.3 dB for bare ground. For the purpose of classification, this indicates that local class statistics has to be applied. A classification test on a small area of K-means clustering showed that the best results was obtained for VV polarization with an error rate of 7.2%. All error rates were between 7.2 and 12.2%. The C-band polarization responses derived from the snowcover corresponds to smooth surface scattering.

The extent of the wet snowcover observed by ERS SAR correspond to EMISAR observation.

INTRODUCTION

The weather dependencies of the optical instruments, in particular the cloud cover, significantly reduce their applicability for operational monitoring of snow cover. Studies have demonstrated the capability of C-band SAR for detecting the extent of wet snow cover (e.g. [5], [3]). The scattering from a wet snow covered area is a combination of surface and volume scattering, and the relative strength between the two components depends on the snow properties- liquid water content, density ice particle size and shape and surface roughness [6]. The dielectric loss within the wet snow volume is high and the scattering contribution from the snow- ground interface may be neglected.

For a homogenous dry snow cover the absorption loss within the snow is low, and the snow cover is tranparent leaving the snow ground interface as the significant scattering source. In mountainous areas SAR data are radiometrically and geometrically distorted due to topography, and the data must be geometric corrected and calibrated using a Digital Elevation Model (DEM).

The EMAC-95 EXPERIMENT

The Norwegian test area is located at Kongsfjellet and at the Okstindan glacier, Norway, 66^o N, 14^o E. The snow test field cover elevations from about 400 m to 1100 m and contains different vegetation types varying from sparsely forested peatland to exposed rock. Three combined remote sensing and ground data acquisition campaigns were conducted at March 22- 23, May 1-3 and July 5-6. Fully polarimetric C- and L-band airborne SAR data were acquired using the EMISAR

The EMISAR polarimeter measures the four elements (hh, hv, vh and vv) of the scattering matrix from an area of the earth's surface. The EMISAR polarimeter data are one look slant range complex data focused to a resolution of 2 m x 2 m, motion compensated, imbalance compensated and absolute calibrated [1]. The incidence angle varies from 35^o to 60^o at the near and far range respectively. In Fig. 1 the EMISAR C-vv backscattering coefficient image from July 6 are shown. We clearly observe the the extent of the wet snow cover in white (low backscatter).

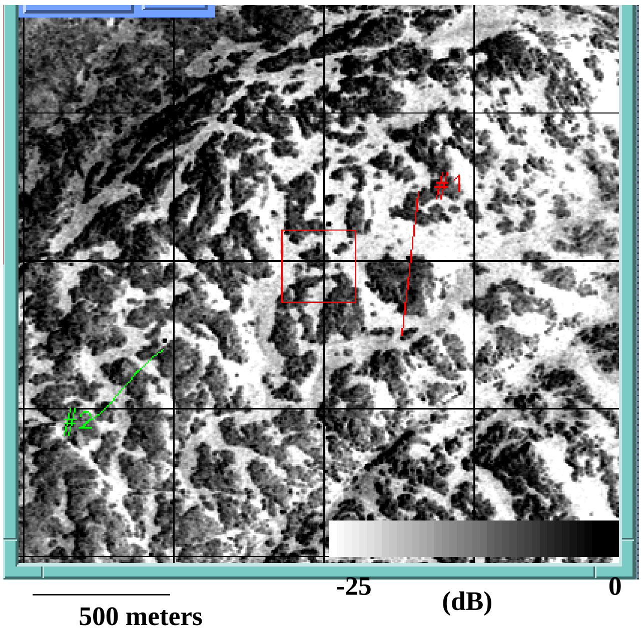

Figure 1. EMISAR C-vv backscattering coefficient image from Kongsfjellet July 6 1995.