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) are presented in this paper. The study area is located in Norway, 66° N, 14° E. Fully polarimetric C- and L-band SAR data from EMISAR, an airborne instrument operated by the Danish Centre for Remote Sensing (DCR), 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 by 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 L- and C-band polarization responses derived from an wet snowcover correspond to surface scattering with a diffuse scattering component. The extent of the wet snowcover observed by ERS SAR corresponds to EMISAR observation.

KEY WORDS: SAR, Snow, ERS

1.0 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. [1], [2]). 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 [3]. 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).

2.0 THEORY

2.1 Polarimetric SAR measurements and features

The objective of a radar polarimeter is to measure the scattering matrix from an area of the earth's surface. The 2x2 dimensional complex scattering matrix **S** relates the incident electric field E_i to the scattered field Es by [4]:

$$\begin{bmatrix} E_{Sh} \\ E_{Sv} \end{bmatrix} = \frac{e^{jkr}}{r} S \begin{bmatrix} E_{i1} \\ E_{i2} \end{bmatrix} = \frac{e^{jkr}}{r} \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix} \begin{bmatrix} E_{i1} \\ E_{i2} \end{bmatrix}$$

where the subscripts v and h refer to horizontal and vertical polarization, k is the wavenumber and r is the range, i.e. the distance between the radar antenna and the surface scattering area. For a reciprocaly scattering medium $S_{hv} = S_{vh}$. To measure Svv, a horizontally polarized wave is transmitted, and both the amplitude and the phase of the electric field of the horizontally and vertically polarized part of the scattered wave are measured simultaneously. The other two elements are obtained in a similar fashion by transmitting a vertically polarized wave. Once the complete scattering matrix is measured, the output for any desired combination of transmit and receive polarization can be synthesized. The syntesized backscattering coefficient is given as:

$$\sigma_0(\psi_r, \chi_r, \psi_t, \chi_r) = \frac{4\pi}{A} \left\langle \left| \frac{E^r}{|E^r|} \cdot S \frac{E^t}{|E^t|} \right|^2 \right\rangle$$

Where (ψ_r, χ_r) and (ψ_t, χ_t) are the orientation and ellipticity angles of the receiving and transmitting antenna polarization ellipses, respectively, A is the illuminated area, the symbol <> denotes ensemble averaging, S is the scattering matrix and Et and Er are the transmitted and received electric field, respectively. The polarization response, previously called polarization signature, is used to represent the variation of scattering cross section as function of polarization.

2.2 Scattering models and properties

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 [3]. The dielectric loss within the wet snow volume is high and the scattering contribution from the snow- ground interface may be neglected. For dry snow at high incidence angle the backscattering coefficient at vv is higher than at vv [5], except for very thick snow layers, because higher transmission of vv through the air-snow interface and higher reflectivity of vv at the snow-soil interface. For increasing snow depth the effect of reflection at the bottom becomes smaller, causing a smaller difference between vv and vv. For a very thick snow cover the backscattering at vv polarization is grater than that of vv polarization, because more is transmitted into the snow pack. This difference depends on the angle of incidence, snow grain size and the reflectivity of the snow-soil interface.

3.0 The EMAC-95 EXPERIMENT

The Norwegian part of the EMAC Snow and Ice experiment [7] test area is located at Kongsfjellet and at the Okstindan glacier, Norway, 66° N, 14° 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 where fully polarimetric C- and L-band EMISAR data were acquired. A DEM with 5m x 5m resolution in Universal Transversal Mercator (UTM) zone 33 coordinate system, with datum WGS84 has been used for geocoding of the ERS data.

Table 1: Data from EMAC'95, Kongsfjellet, Norway

			ERS	Field data	Air-photo
Date	Time (UTC)	Band			
22 March	14.21	L		xxx	
23 March	15.31	C		xxx	
29 March			D		
1 May	15:38	L		xxx	
3 May	12:45	C		xxx	
7 June			D		
5 July	12.12	L		xxx	
6 July	08.40	C		xxx	
11 July			A		
12 July			D		
14 July					xxx

The ground measurements include measurements of snow density, snow grain size, snow liquid water content and surface roughness. The measurements were taken along two transects or profiles: West profile and East profile. 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 were georeferenced using GPS.

The area was completely covered with snow in March. At 400 meter elevation the snow was wet while at 1000 meter the snow was nearly dry. The depth of the snow range from 1 meter up to more than 4 meters. In July the area was partly covered with wet snow. Figure 1 presents the air temperature and precipitation measured at Susendalen met station, located 60 Km south of the study area.

The ERS-1 SAR data have been terrain corrected using a Digital Elevation Model (DEM) data with a 5m pixel spacing, absolute radiometric calibrated and converted to backscattering coefficient images by correcting for the antenna pattern, range loss and variation in resolution area. The available dataset are listed in Table 1.

Fig. 2 shows the EMISAR C-vv backscattering coefficient image from and one airphoto from July 14. We clearly observe the extent of the wet snow cover in the EMISAR data white (low backscatter). The airphoto from Kongsfjell is from 14 July 1995 and the mean altitude above ground is 700 m, using a Kodak Aerochrome Infrared Film Type 2443 in 23 cm x 23 cm format. The wavelength-interval is 525-900 nm and the film has three emulation layers with maximum response in green, red and near infrared (550, 650 and 750 nm).

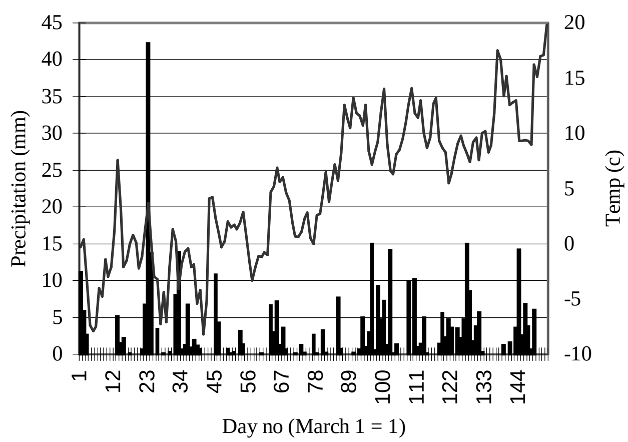
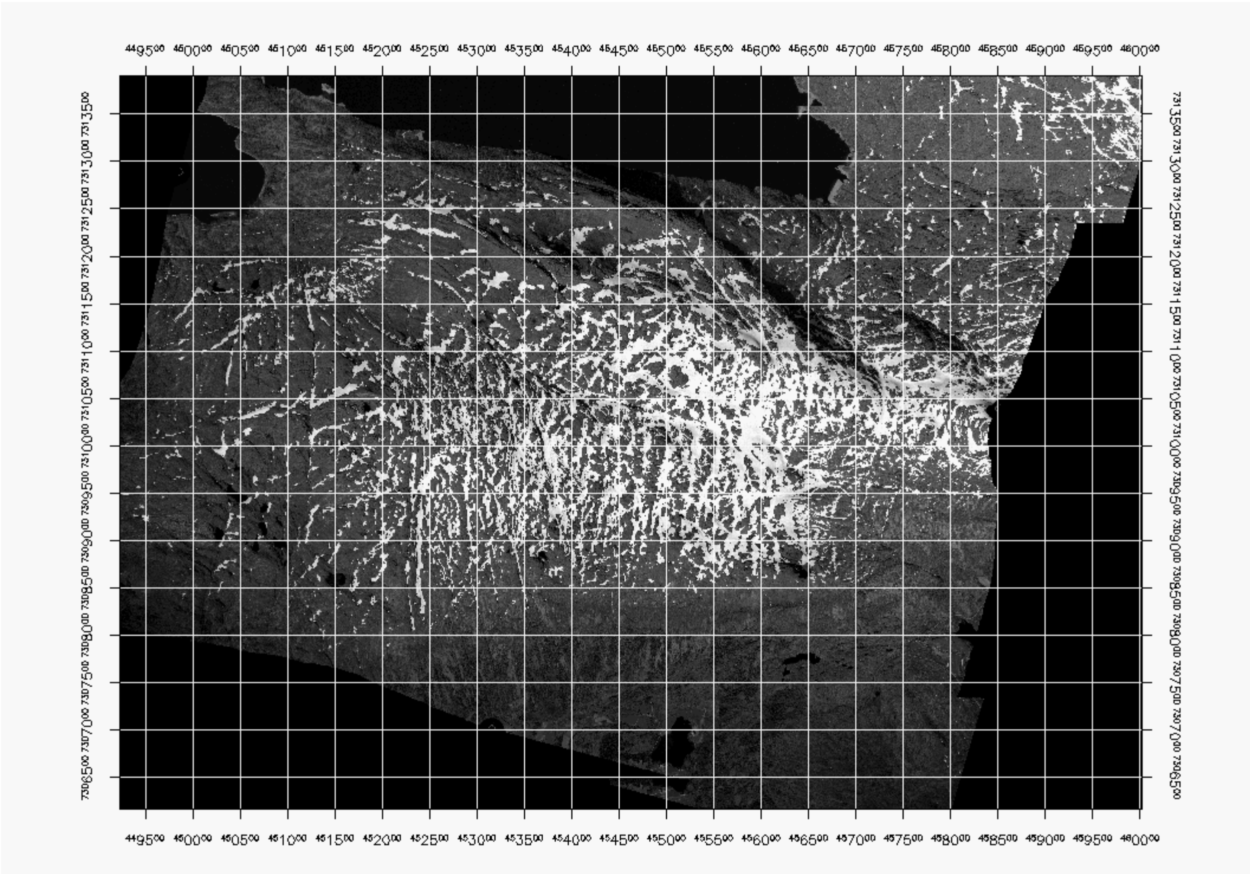


Figure 1. Air temperature and precipitation at Susendalen met station.



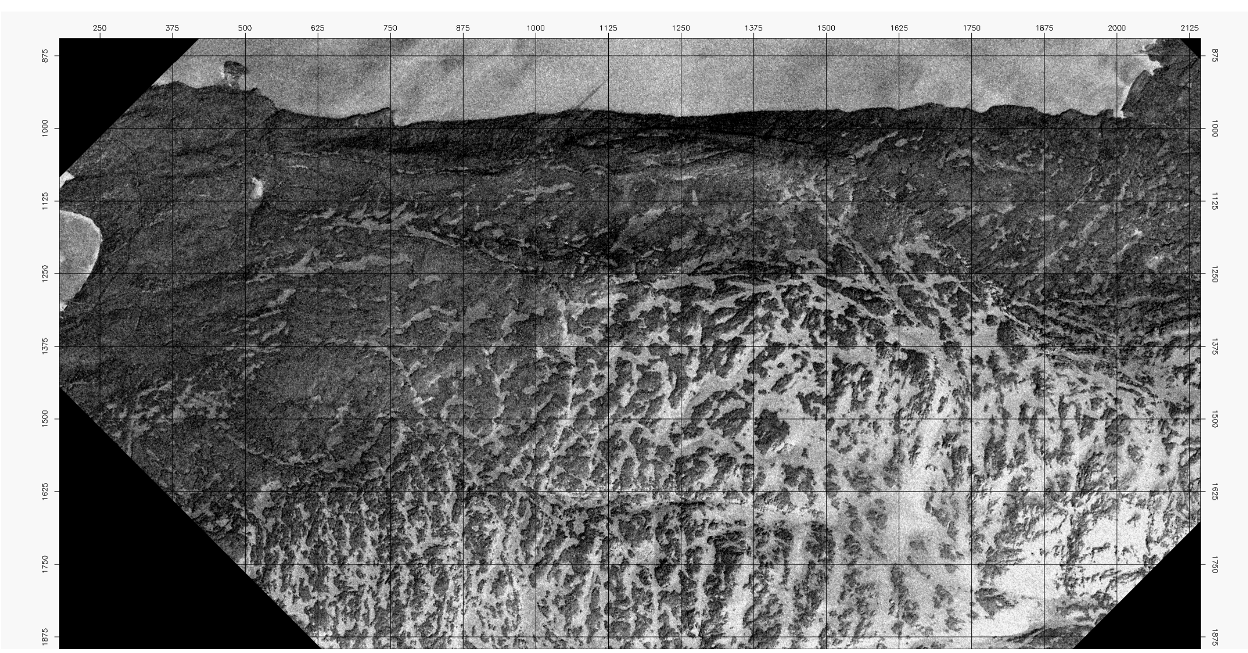


Figure 2. Top) Airphoto from Kongsfjellet 14 July, bottom) EMISAR C-vv backscattering coefficient image from Kongsfjellet July 6 1995.

3.1 EMISAR

The EMISAR polarimeter measures the four elements (vv, 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 [6]. The incidence angle varies from 35^o to 60^o at the near and far range respectively. The complex imagery includes four files (vv, hv,vh and vv) of one look, slant range scattering matrix data. The radar brightness, βo, of an homogenous area is obtained as 4 π multiplied by the spatial average pixel intensity (I^2 + Q^2), and the back-scattering coefficient σ_o is given by:

$$\sigma_0 = \beta_0 \sin(\theta) = 4\pi \sin(\theta) < I^2 + Q^2 >$$

The radar cross section of an point target is 4 π times the total energy of the target as found with the integral method. Table 2 presents the radar cross section derived from the C vv 6 July data over the corner reflectors using the integrated approach [8] with 21 x 21 pixels area

Table 2. Radar cross section for trihedral corner reflectors in, C-vv July 6

Corner Name	Position	Elevation (m)	Reflector Type	Theoretic RCS [dBm$^{2]}$	Measured RCS [dBm^2]
RE-2	3456,692	400	Sq-0.7	31.1	30.76
RE-4	4278,395	700	C-0.7	25.08	23.6
RW-3	1814.,3052	570	C-0.7	25.08	23
RW-5	2335,3107	800	C-0.7	25.08	22.85
RW-6	2966,2510	950	C-0.7	25.08	21.7 (17x17)
RW-7	3263,2246	1000	C-0.7	25.08/	21.1
Rw-8	3855,2319		Sq-07	31.1	29.91

We observe a deviation from the theoretical values for RW-6 and RW-7 reflectors. The EMISAR data is processed using a mean height above flat earth of 1100 meter. Since the elevation within the area varies from 400 to 1100 meters some errors in the calibration is expected. However this does not explain the big deviation for RW-6 and RW-7, which may be caused by misalignment of the corners. Figure 3 shows the C-band co-polarization responses for the trihedral corner reflectors. Orientation angle 0 and 90 correspond to vv and vv polarization, respectively. We observe that the measured polarization response differs slightly from the theoretical. EMISAR data are normally not cross talk calibrated since the cross talk ratio is better than -25dB [6]. This and/or channel imbalance may cause the observed deviation.

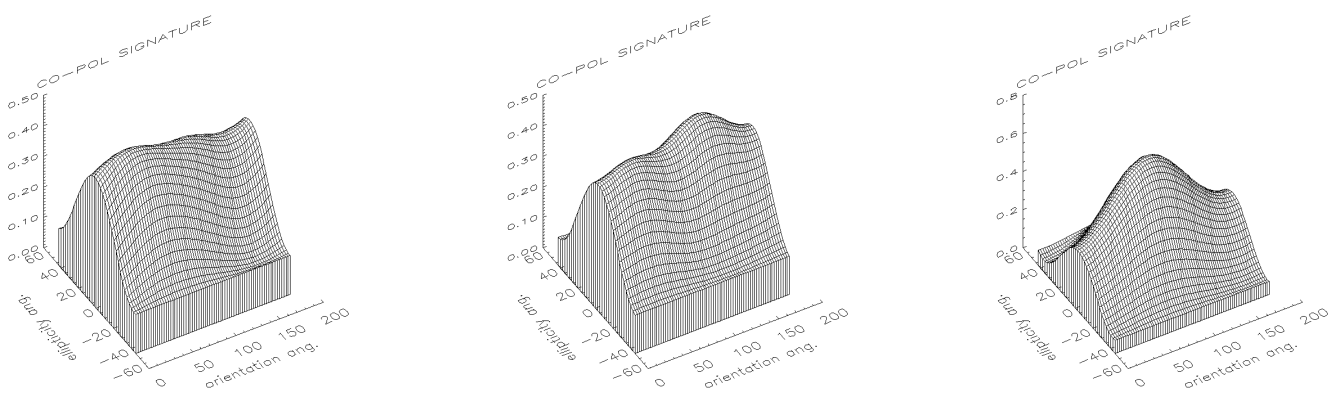


Figure 3. C-band co-polarization response from 6 July derived from an 21 x 21 pixels area around thrihedral corner reflectors RW3, RW7 and RW8, respectively.

3.2 EMISAR Polarization response from snow covered terrain

Fig. 4 shows the C- and L-band co-polarization responses derived from the March and July EMISAR data close to RW7. In March the snow cover was dry (W < 1%). The C-band polarization response correspond to rough surface response with a high degree of diffuse scattering represented by the high pedestal. At L-band the polarization response correspond to smooth surface scattering with a high diffuse scattering component. We observe that the diffuse scattering component is higher at C-band than at L- band. In the case of a dry snowcover the absorption loss within the snow is low and the snow-ground interface is the major scattering source. The volume scattering within the snow may be modeled as Rayleigh scattering. Thus the volume scattering component is higher at C-band than at L-band. From the difference in C- and L-band co-polarization response we may assume that the snow-ground interface is rough at C-band and smooth at L-band.

In July the C- and L-band polarization responses correspond to rough surface scattering with a diffuse scattering component. However, we observe that the diffuse scattering component at L-band is lower than at C-band. Insitu measurements show that the snow cover is wet resulting in high absorption loss. At L-band the signal will penetrate deeper into the snow than at C-band giving rise to a higher volume scattering component. The observation contradicts this assumption.

C-band **L-band**

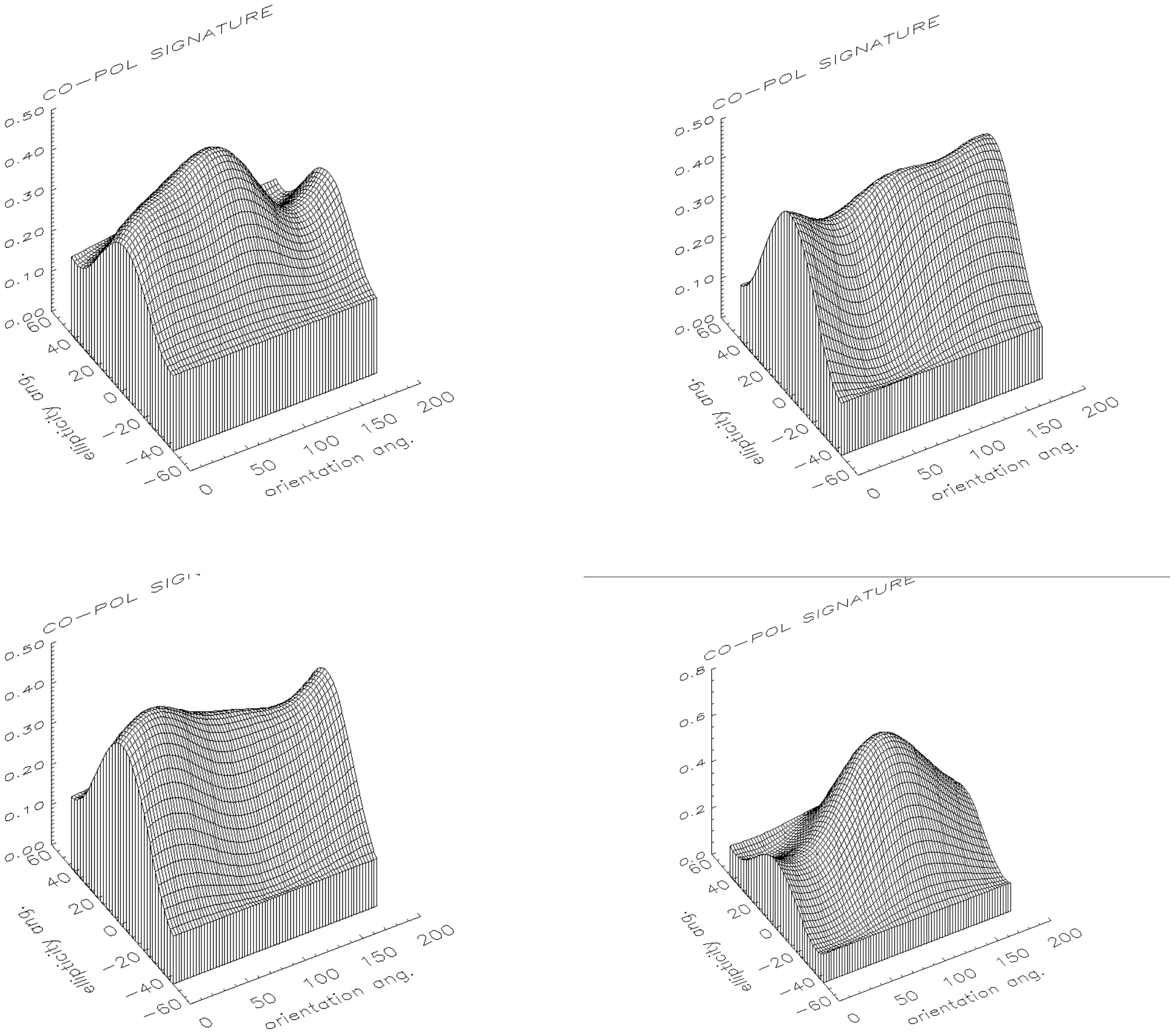


Figure 4. Snow co-polarization responses derived form an area close to W7 for C- and L-band. (March upper; July lower).

4.0 CLASSIFICATION EXPERIMENT

One experiment using the 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* and *Area 2*, and one smaller region located within Area 2 for classification, *Area 3*, see Figure 1. 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.

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.

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 [10] was applied. Data from the entire West Profile, including Area 1 and 2, were speckle filtered by a 3×3 mean filter and applied for the clustering. 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%.

Table 3: Backscatter statistics for Area 1 and 2. The values are given in dB.

Class	Area 1 Mean	Area 1 St. dev.	Area 2 Mean	Area 2 St. dev.
Snow vv	-15.8	2.8	-20.1	3.1
Bare gr.vv	-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

Table 4: Classification results for discrimination between snow and bare ground for Area 3 given by overall error rates (%). “Sum” is the sum of all polarizations and “Multi” is a multi-variate combination of the four polarizations.

Type	K-means
vv	10.2
vv	7.2
HV	12.2
VH	12.2
Sum	8.6
Multi	9.0

5.0 ERS DATA

ERS-1 SAR PRI dataset 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 x5 m) DEM data and geocoding software [4]. The DEM is derived from the stereo airphoto. A 3x3 Lee filter was applied to the data before conversion to dB. In Fig. 5 the mean ERS-1 SAR backscattering coefficient for from, 29 March, 6 June, 11 July and 12 July, respectively, are shown for two areas corresponding to Area1 and Area2. 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. On 29 March the area was covered with dry snow while in June the area was 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. In the geocoding process the change of area due to variation in local incidence angle has been corrected for. The observed difference is caused by the targest specific local incidence angle dependencies.

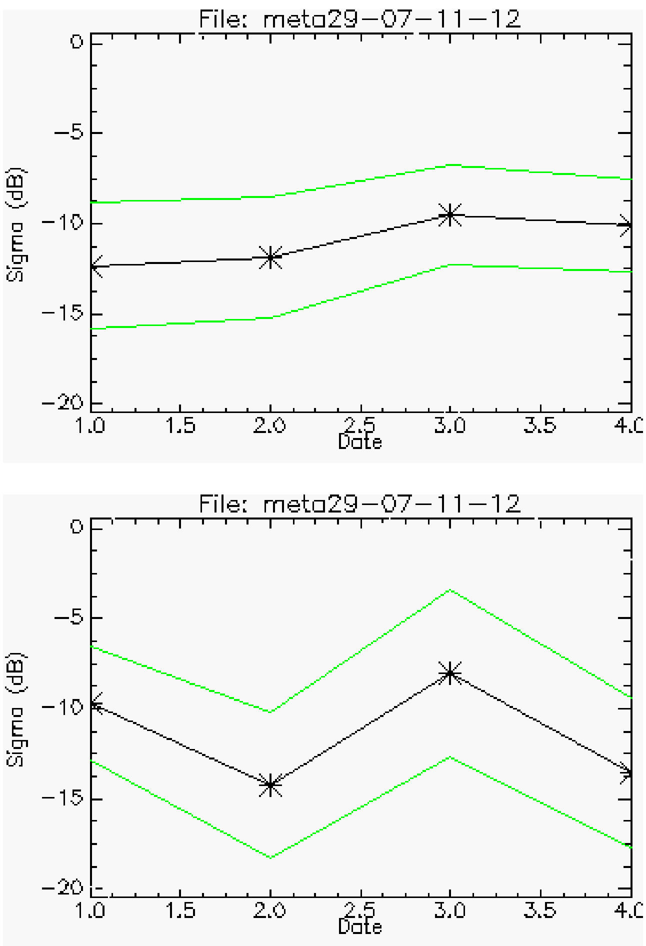


Figure 5. ERS mean backscattering coefficient from Area 1 top) and Area 2 bottom) for March 29, June 6, July 11 and July 12, respectively. The standard deviation is also shown.

6.0 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 at 50^{o} local incidence angle correspond to theoretical responses from rough surfaces. The polarization response at L-band show a lower degree of diffuse scattering than at C-band. The extent of an wet snowcover observed with ERS-1 SAR correspons to the airphoto and EMISAR C-vv data. A 4 dB decrease in the mean bacscattering from an area was observe between the 29 March data and the 12 July data.

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ACKNOWLEDGMENT

Parts of this work were carried out within SNOW-TOOLS, an Environment and Climate project funded by Commission of the European Community Contract no ENV4-CT96-0304. Many thanks to all members of the field team.