Multipolarization signatures of snow compared to snowpack properties in Dronning Maud Land, Antarctica

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Introduction

The knowledge of snow pack properties and its temporal and spatial variability are of importance for the interpretation of backscattered signals in the microwave region. Spaceborne scatterometers provide valuable information on backscattering characteristics at low spatial but high temporal resolution. In addition, the surface is illuminated at different viewing angles during a single overflight.

This investigation focuses on the area of Dronning Maud Land, Antarctica. The backscattering properties from the two satellite borne scatterometers NSCAT (NASA) and Escat (ESA) as well as SAR (Synthetic Aperture Radar) images with high spatial resolution are compared to snow pack properties, in the first place accumulation rates derived by stake readings. This is done along a traverse route from the German Neumayer base (70°39'S, 08°15'W) at the ice shelf Ekströmisen to the German base camp Kottas (74°12'S, 9°44'W).

Differences in the backscattering signatures reflect the variable pattern in the snow morphology, although the relation is not straightforward. The signature study provides additional information for a better understanding of signals like radar altimeter and high resolution SAR.

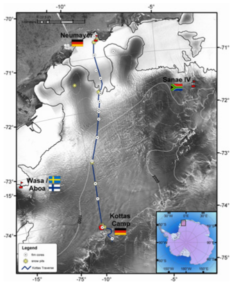

Figure1. Route of Kottas Traverse from the German Neumayer base (70°39'S, 08°15'W) at the ice shelf Ekströmisen to the German base camp Kottas (74°12'S, 9°44'W).

Snow accumulation

Accumulation data was gathered by repeated stake readings along Kottas Traverse in the years 1997 till 2001. The measured snow fall in meters was transformed into accumulation rates (kg m^{-2} a^{-1}) by using density profiles of the snow pack's upper 2 m. They were derived by snow pits studies, done at several points along the way. The single profiles reveal a high variability in accumulation in time and space.

Note: Mean accumulation values for a time period of 5 years had to be calculated from an increasing number of measurements along the profile (see Fig.2).

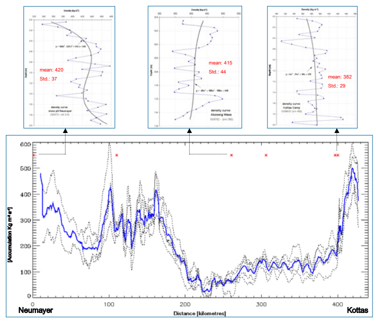

Figure 2. Snow accumulation along the Kottas Traverse in the years 1997-2001. The blue line represents a mean value for this time period. Red asterisks mark the location of snow pits, providing density profiles. Examples are shown above.

Scatterometer data

Radar scatterometers are active microwave instruments which provide information about surface backscatter properties, expressed by the normalized radar cross section σ^0. The windscatterometer onboard the European Remote Sensing Satellite (ERS-2) operates with 3 VV polarized antennas, using a frequency of 5.3 GHz (C-band). The NASA Scatterometer (NSCAT), carried by the Japanese Advanced Earth Observation Satellite (ADEOS-1) was working with 6 antennas in Ku band at 14.3 GHz (VV & HH Pol.).

Differences in σ^0 of the Antarctic ice sheet express a variing surface roughness as well as changing snow pack properties, like wetness, density, temperature or grain size.

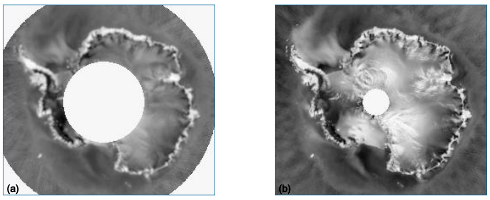

Figure 3. VV polarized Escat (a) and NSCAT (b) data as mean of all σ^0 measurements between incidence angles of 30-40°, taken from the middle of May till the end of June 1997, thus covering the satellites full repeat cycles of 35 (ERS) and 41 (ADEOS) days. The spatial resolution is 50x50 km² for Escat and 25x25 km² for NSCAT.

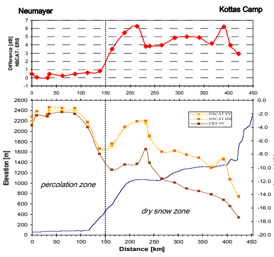

Figure 4. Scatterometer data from Fig. 3 along Kottas Traverse vs. elevation (blue line). The red line on top shows the difference of the VV polarized NSCAT and Escat σ^0 values.

Within the percolation zone near the coast no big differences in σ^0 can be observed between the two sensor types. Ice lences near the surface prevent from a deeper penetration of radar waves into the snow pack, regardless of the wave length. Here the antennas receive their backscattered energy mainly from near the surface. Though beginning at an elevation of about 500 m their profiles significantly separate. Around this height the dry snow is reached, where the longer ERS C-band microwaves can penetrate deeper into the snow, then the Ku-band NSCAT signals. Thus the absorbed part of energy increases stronger for ERS and less energy is backscattered towards the satellite sensor. The result corresponds with earlier findings (Drinkwater and others, 2001).

At 500 m a.s.l. the difference of σ^0 reaches about 2 dB. This value can serve as a threshold, to get a quick overview of Dronning Maud Land's percolation zone.

Accumulation - σ^0 cross correlation

By looking at Fig. 9 it seems obvious that the variations in the backscatter coefficients σ^0 of a snow surface are related to mass balance variations. Comparing both parameters along Kottas Traverse, an increase in snow accumulation goes together with an decrease of σ^0. For quantification of this phenomena, a scatterplot was done (Fig. 10) and a correlation factor estimated for each of the two traversed snow zones. They form distinct clusters, with σ^0 as well as the accumulation rate being on a higher level for the percolation zone, compared to the dry snow zone.

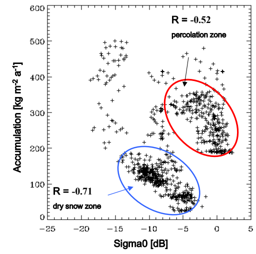

Figure 10. Envisat ASAR σ^0 plotted against the accumulation rate along Kottas traverse (see also Fig.9).

Incidence and azimuth angle dependence

Anisotropy

Previous studies demonstrated that anisotropies in the scatterometer signal are related to surface features like sastrugis. In order to estimate the significance of this issue, a factor of anisotropy (FA) was calculated, taking into account all of the σ^0 measurements within the incidence angle range of 30 – 40° (Fig. 6). Highest values are observed in East Antarctica's katabatic wind region.

$$FA = \frac{\sum_{j=1}^{18} \left|\overline{\sigma_j^0} - \overline{\sigma^0}\right|}{\overline{\sigma^0}}$$

j = 1,18 azimuth angle classes in 20° steps

$30° \le \theta \le 40°$

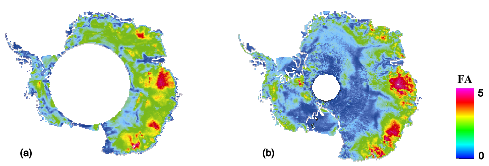

Figure 5. Factor of Anisotropy for Escat (a) and NSCAT (b) images

Ratio

The backscatter coefficient σ^0 is decreasing with increasing incidence angle not only due to energy loss with distance from the sub satellite track, but also influenced by the snow pack's backscattering properties. In order to characterize differences in the incidence angle dependence of σ^0 for the Antarctic snow cover the ratio (RA) was determined as:

$$RA = 10\left[\log\frac{\sigma^0_{\Delta\theta_1}}{\sigma^0_{\Delta\theta_2}}\right] = \sigma^0_{\Delta\theta_1}(dB) - \sigma^0_{\Delta\theta_2}(dB)$$

$25° \le \Delta\theta_1 \le 30°$

$40° \le \Delta\theta_2 \le 45°$

$0° \le \varphi \le 360°$

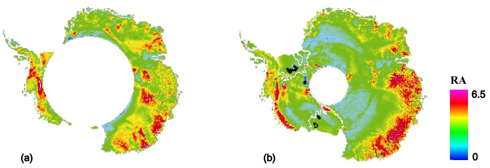

Figure 7. Ratio for Escat (a) and NSCAT (b) images

Applying the IDL programming tools POLY_FIT and LMFIT to our scatterometer data, its dependence on incidence and azimuth angle was described by mathematical terms. Within the range of 20 - 50 degrees σ^0 can be described as a linear function of the incidence angle. For the azimuthal modulation a cosinus funcion was used, to describe the expected two minima and maxima of the curve.

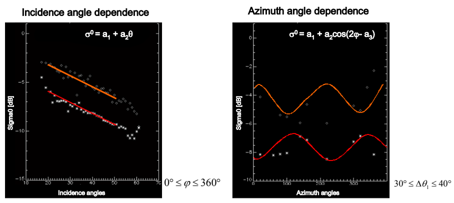

Figure 8. NSCAT data as mean of all σ^0 measurements, taken from the middle of May till the end of June 1997 for the area of the German station Kohnen (Asterisks) at 75°S, 0°E/W on the West Antarctic inland Plateau and the Indian station Maitri (Diamonds) at 71° S / 11.74° E near the coastline.

Envisat ASAR Backscatter coefficient σ^0 normalization

The decrease of σ^0 with incidence angle increase can be described as a linear function between angles of 20-50 degrees . This was used to normalize ENVISAT ASAR to an incidence angle of 35°. The diagram in Fig. 9 presents the results as profile line along Kottas Traverse vs. the mean accumulation 1997-2000 (see also Fig.2).

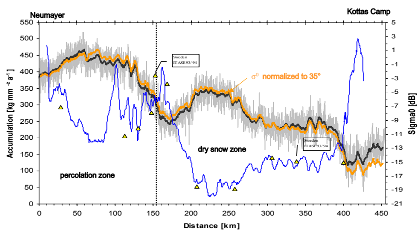

Figure 9. Envisat ASAR wide swath data from March 2004, plotted against accumulation rates along Kottas Traverse (see Fig. 2). Yellow Triangles present accumulation data, received by firn core analyses.

Conclusion

Scatterometer provide valuable information about incidence and azimuth angle dependence of the snow surfaces backscatter coefficient σ^0, which shows strong variations across the ice sheet of Antarctica. This can serve for normalization of high resolution Envisat ASAR data. SAR in turn can be used to study the relation between the snow's morphology and its backscattering properties in more detail. The backscatter coefficient σ^0 shows a clear negative correlation to insitu accumulation data. For a better understanding further studies are required, taking into account influences like the wind field, snow grain size or the temperature of the snow.

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