Radar Backscatter Measurements From RADARSAT SAR Imagery of South Pole Station, Antarctica

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ABSTRACT

Ice Sheet backscatter around South Pole Station was measured from several different azimuthal angles using RADARSAT-1 SAR data. We observed strong azimuthal anisotropy (3-4 dB) between radar look directions across and along the prevailing wind direction. We speculate that the azimuthal variation of backscatter around the South Pole area may be largely attributed to systematically oriented sastrugi and buried sastrugi. Radar backscatter is well correlated with surface topography over a spatial wavelength band of 15 to 20 km. We propose that grain size variations control backscatter patterns associated with undulating surface topography.

INTRODUCTION

Radarsat-1 acquisitions in support of the 1997 Radarsat Antarctic Mapping Project (RAMP) included repeated observation of South Pole Station [1]. Observations occurred throughout the 35 day mission and occurred along many different orbits. Consequently ice sheet backscatter around South Pole was measured with several different azimuthal angles and for incidence angles ranging from 54° to 57°.

In this paper we investigated the azimuthal variation of radar backscatter which is a phenomenon described by other investigators for different sensors of Antarctica. Based on the analysis of 50 km resolution ERS-1 scatterometer data Rott and Rack [2] reported that azimuthal anisotropy is pronounced in strong katabatic wind zone. Noltimier and Jezek [3] also observed azimuthal anisotropy from overlapping ascending and descending ERS-1 SAR images on a pixel by pixel basis. Here we rely on the high resolution of Radarsat data and the unique imaging geometry at South Pole to more completely characterize the azimuthal response. We also examine local variations in radar backscatter σ^0 superimposed on the azimuthal signal. We show these are related to surface topography.

RADARSAT BACKSCATTER MEASUREMENTS

Azimuthal Anisotropy

The region surrounding South Pole Station is characterized by undulating surface topography that has 15 to 20 km wavelengths with about 8 m amplitude. The mean annual temperature is about −50° C with a mean surface elevation of 2800 m above mean sea level. Annual water equivalent precipitation at South Pole Station is low, ranging from 6 to 10 cm/year.

Figure 1 represents one of the geocoded Radarsat SAR images draped over the digital elevation model (DEM, Mosley-Thompson, personal communication). A 70 times vertical exaggeration is applied to the DEM. The radar look direction of this image is orthogonal to the prevailing wind direction. We observe several km-scale patterns in σ^0 across the scene. These patterns seem to be correlated with 20 km wavelength surface topography.

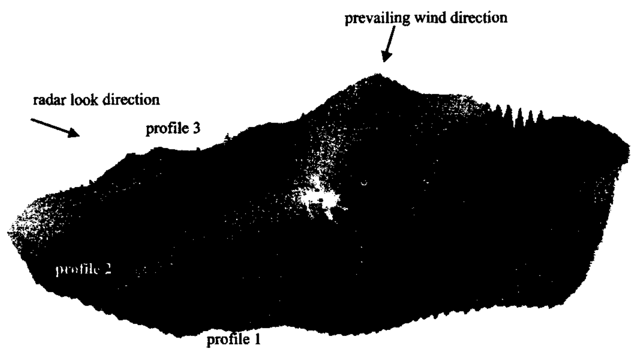

Figure 1. RADARSAT SAR draped over DEM. The bright, central area is South Pole Station.

We selected 19 Radarsat images of the South Pole area with azimuth direction spaced approximately at 20 degree increments. The azimuth direction is defined as the angle measured clockwise from the Greenwich Meridian. We used terrain corrected and geocoded 25 m resolution SAR imagery.

Figure 2 shows how scene-averaged σ^0 varies with azimuth. We observed 3-4 dB azimuthal anisotropy in scene averaged σ^0. The average σ^0 is brightest for look directions orthogonal to the prevailing wind direction which is about 35 degrees. This average σ^0 drops for other angles and seems to be independent of azimuth direction for a ±60° range of azimuth angles centered about the prevailing wind direction.

Following the conclusion of Rott and Rack [2], we speculate the azimuthal variation of backscatter around the South Pole area is largely attributed to systematically oriented sastrugi and buried sastrugi. The ensemble of buried sastrugi contributes enough scattered energy to result in strong backscatter for directions orthogonal to the wind direction.

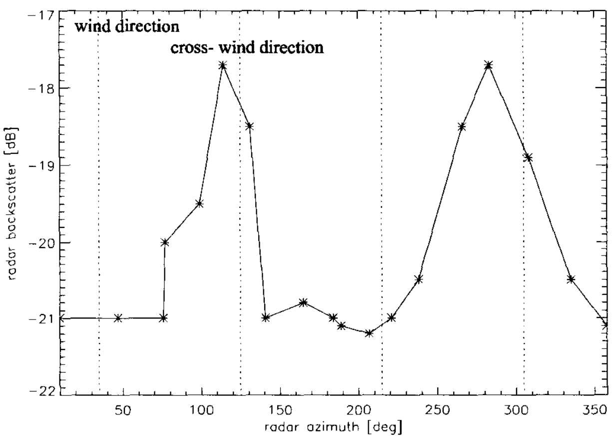

Figure 2. Radar azimuth direction versus scene averaged radar backsctter. The dotted lines represent azimuths along and across the prevailing wind direction.

Backscatter Variation

We studied the relationship between elevation and backscatter, by selecting two representative image frames, whose azimuth directions are 283° (orbit: 9870) and 47° (orbit: 9908), respectively. The 283° azimuth direction is orthogonal to the prevailing wind. The 47° azimuth direction is nearly along the prevailing wind direction. Transects of σ^0 across the frames (mapped in Figure 1) are shown in Figure 3. Other frames whose look directions are orthogonal to or along the prevailing wind direction show similar patterns as shown in Figure 3.

Again we observe that the average σ^0 varies about 3-4 dB depending on the radar azimuth direction. Radar backscatter profiles are also well correlated with elevation profiles for spatial wavelengths of about 15-20 km. σ^0 varies at most by about 4 dB across ridges and troughs in surface topography when azimuth direction is orthogonal to the wind direction. Both the mean signal level and the signal variation associated with surface topography (about 1dB) are smallest for look directions aligned with the prevailing wind direction.

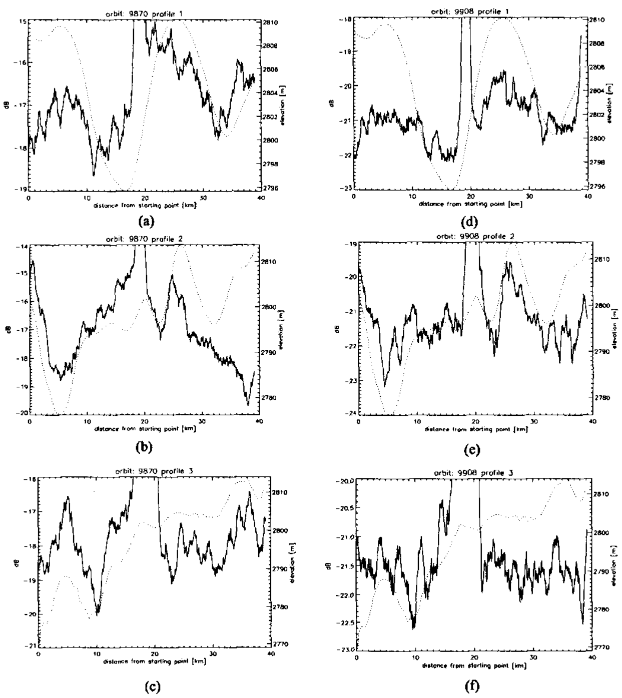

Figure 3. Elevation profile versus radar backscatter. Distance is given with respect to the profile starting point, indicated by the profile label. The dotted line represents elevation profile and the solid line represents the radar backscatter profile. (a) to (c) show profiles for the frame orthogonal to the prevailing wind direction and (d) to (f) show the profile for the frame along the prevailing wind direction.

We propose that grain size variations control backscatter patterns associated with surface topography. This is based on the hypothesis that topography controls local variations in accumulation rate. In turn accumulation rate modulates grain size.

To test our hypothesis we adapted a backscatter model for dry snow zones developed by Forster et al. [4]. Figure 4 shows the backscattering coefficient versus the accumulation rate at –50 °C. We estimate the imaginary part of permittivity for snow at -50 °C using Tiuri's model [5]. Forster's model overestimates the backscatter coefficient at this temperature, but the slope of backscatter change with accumulation remains almost same for other values of permittivity. Average accumulation rate at South Pole is about 8.5 cm/year [6]. Data from Mark [7] show that accumulation rate varies by 1.6 cm/year and is inversely correlated with topography. Figure 4 shows that a 1.6 cm/year variation about the mean leads to about a 1.5 dB variation in σ^0. That value is similar to what we observe.

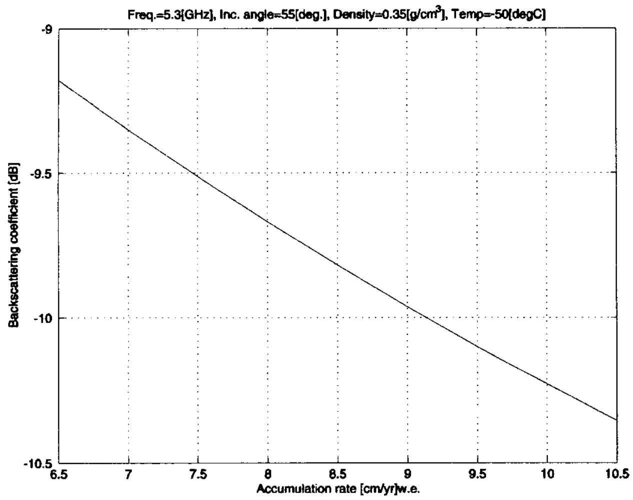

Figure 4. Accumulation versus backscatter obtained from the model by Forster et al. [4].

CONCLUSIONS

We showed that the radar backscatter is well correlated with surface elevation for spatial wavelengths of about 15-20 km. This pattern seems related to accumulation variations caused by the surface undulations. We also observed strong azimuthal anisotropy that seems to be related with systematically oriented sastrugi along the prevailing wind direction.

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