A Large-Scale Ku-Band Backscatter Model of the East-Antarctic Megadune Fields

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***Abstract*— The megadune region of East-Antarctica has a unique topology consisting of microrelief features, sastrugi and long, coherent snow dunes. The azimuth modulation signature in this region is characterized by higher backscatter, less modulation, and more local maxima than in a nearby non-dune region. We develop a fourth-order best-fit model to describe the azimuth modulation and apply it independently to two disjoint portions of the megadune region.**

I. Introduction

In this study we consider the ku-band backscatter signature of the East Antarctic megadune fields observed with QuickSCAT. Backscatter signature has been used to investigate many geophysical phenomena and to gain insight into the underlying mechanisms that produce it. The megadune region's unique combination of topography and extreme southern position lends itself to a study of this kind. We first present background information about the structure of the megadune fields from geophysical studies and traverses. We then present an azimuth analysis of backscatter data from the megadune region.

II. Geophysical Background

Megadunes are periodic snow-pack surface ripples that occupy more than 500,000 km^2 in East-Antarctica. The dominant features of the megadune region are the dunes themselves, with 2-4 m amplitude, 3-5 km period, and up to hundreds of kms in extension, and sastrugi, wind-formed erosional features of meter scale, nestled in the troughs of the dunes. The dunes extend transversely to the katabatic wind direction, while the sastrugi extend along the katabatic wind direction. Further features of the megadune region include large-grained, glazed firn on the leeward faces of the dunes, and what is termed "severe sastrugi" at the base of the windward faces of the dunes [1]. This superposition of large-scale continental slope, meso-scale dunes and sastrugi, and small-scale surface features makes this region an interesting subject of study.

For this study we consider two separate fields in the megadune region. These regions are superimposed upon the megadune field as described by Fahnestock et al. [2] in Figure 1. The study region near the top of the figure is referred to as the "west" dune field, and the other, which is nearer the bottom of the figure, is referred to as the "east" dune field. For simplicity we bound each field with a four sided polygon. The locations of the vertices of these boundaries are listed in table I. The regions are not continued farther south because visual images show that the dunes there are less coherent. The areas of the study regions are 27,200 km^2 in the west field and 77,700 km^2 in the east field. We also define a "non-dune field" outside the megadune region. which is shown in black in Figure 1.

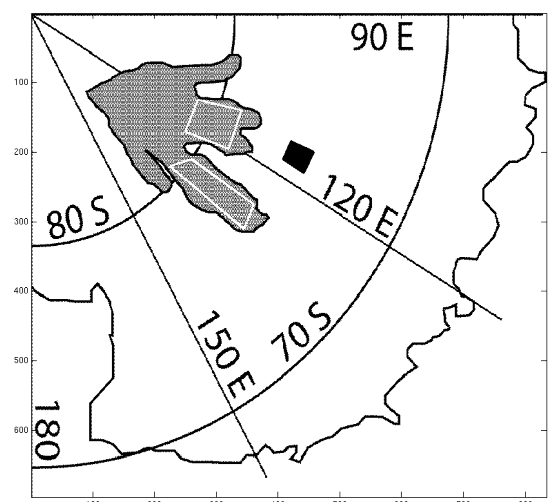

Fig. 1. East and West Dune Fields Defined. The Megadune region as identified by Fahnstock et al. [2] is shaded. The two study regions are outlined in white, the non-dune field is shown in black.

TABLE I
The vertices of the three regions. Latitude is measured in degrees south, longitude in degrees east.

West Dune Field		East Dune Field		Non-Dune Field	
lat:	lon:	lat:	lon:	lat:	lon:
81	122	79.8	126.4	75	113
78.5	118.3	76.3	127.2	73	113
78.7	112.8	76.2	130.8	73	116
80.7	113.8	80.7	132.4	75	116

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III. Raw Data

Although scatterometers are designed to indirectly measure surface wind vectors over the ocean, due to orbit geometry that results in frequent polar passes they are also well suited to studies of the cryosphere [3]. Quickscat is a scanning pencil beam scatterometer that provides H-pol data at 46.4° incidence angle and V-pol data at 54.1° incidence angle over a 25 km by 30 km footprint. QuickSCAT's scanning geometry provides a very wide range of azimuth observations, which we exploit to study the azimuth dependence in the study regions. The following azimuth model development and analysis use QuickSCAT data from the 2005 austral winter (Julian Days 180-220).

We are able to combine 40 days of data into a consistent data set because the study regions are temporally stable. Figure 2 shows average backscatter as a function of day during the 2005 austral winter at azimuth angles $100° < \phi < 108°$ in the non-dune region. In this azimuth range backscatter shows relatively little response to changes in azimuth angle. For the ranges of days and azimuth angles considered, the mean backscatter is -9.76 dB, with a variance of 0.004 dB.

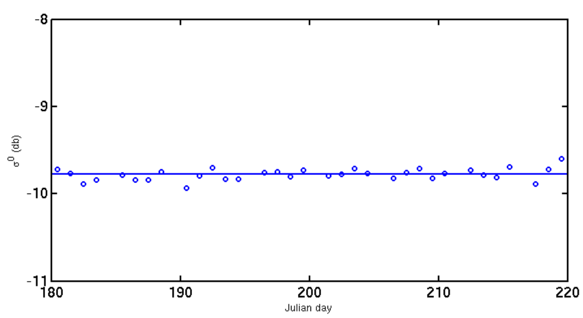

Fig. 2. Mean backscatter as a function of day during the 2005 austral winter over the non-dune region for $100° < \phi < 108°$. A vertical line is shown at the mean value, σ^0 = -9.76.

IV. Azimuth Modulation Model

Backscatter signature is defined as the manner in which backscatter changes with observation geometry (incidence and azimuth angles). In general, the normalized radar backscatter σ^0 is a function of (among other things) local incidence angle, which on a tilted surface depends on nominal azimuth angle.

Previous studies (for example, [3]) use a Fourier Series model,

$$\sigma^0(\phi) = a_0 + \sum_{k=1}^{N} a_k \cos(k\phi) + b_k \sin(k\phi), \qquad (1)$$

to approximate $\sigma^0(\phi)$ over snow. Figure 3 displays the results of applying this model to the two study regions and the non-dune region. Unfortunately, in the study regions QuickSCAT provides measurements for only (approximately) $30° < \phi < 330°$. A wider range of azimuth angles is observed in the more northern non-dune field. Superimposed on the data is a least-squares model fit for $N = 4$, the magnitudes, $M_k = \sqrt{a_k^2 + b_k^2}$, and phases, $\chi_k = \frac{b_k}{a_k}$, of which are shown in Table II. Table III shows the peak-to-trough modulation amplitude for each data set.

TABLE II

Values of magnitude and phase of equation 1 (for $N = 4$) over each region. M is in dB, χ in degrees.

		West Dune Field		East Dune Field		Non-Dune Field	
	k	M_k	χ_k	M_k	χ_k	M_k	χ_k
H-pol	0 (a_0)	-3.44	-	-2.64	-	-8.66	-
	1	0.51	1.91	0.24	1.02	0.27	-29
	2	0.48	17.11	0.32	52.18	0.84	52.8
	3	0.23	16	0.16	20.9	0.07	-1.82
	4	0.23	-22.07	0.18	16.1	0.28	-67.5
V-pol	0 (a_0)	-4.1167	-	-3.66	-	-9.89	-
	1	0.48	2.37	0.44	2.35	0.15	-64.47
	2	0.437	16.42	0.40	20.36	0.39	69.13
	3	0.24	12	0.26	7.24	0.07	-1.08
	4	0.135	-11.33	0.17	9.54	0.28	-42.68

TABLE III

Peak-to-trough modulation amplitudes for each data set, measured in dB.

	West Dune Field	East Dune Field	Non-Dune Field
H-pol	0.071	1.02	2.19
V-pol	0.77	1.02	1.51

V. Analysis

In Figure 3 one immediately notices the different azimuth modulation pattern in the non-dune region compared to the two dune fields. The dune fields are characterized by a fourth order pattern of higher backscatter and less modulation than the non-dune fields. It is well established that backscatter σ^0 in Antarctica is largely due to volume scattering effects. The higher backscatter in the dune fields is attributed to highly recrystallized firn and large grain sizes [2].

Previous studies [3, 4] have shown the azimuth modulation pattern over much of Antarctica is primarily second order. This second order pattern has been attributed to the ubiquitous presence of wind-formed sastrugi. In most cases stronger backscatter is observed from the cross-sastrugi directions, weaker backscatter from the up/down sastrugi directions. The H-pol non-dune field azimuth pattern shown in Figure 3 is a typical second order pattern of the kind reported by [3] for many spatially disparate locations in Antarctica. The non-dune field azimuth pattern for V-pol data, however, better fits to a fourth order model. More research is necessary to determine if this is typical of the continent as a whole, or isolated to the region we happen to be observing.

The azimuth modulation pattern in the dune fields is also primarily fourth order. Figure 4 displays squared fit error versus N for all six data sets. As N approaches four, the improvement in fit is substantial. Above $N = 4$, increasing N does little to improve the squared error of the approximation. An exception is the non-dune field H-pol case which shows little improvement above $N = 2$. The squared fit error is

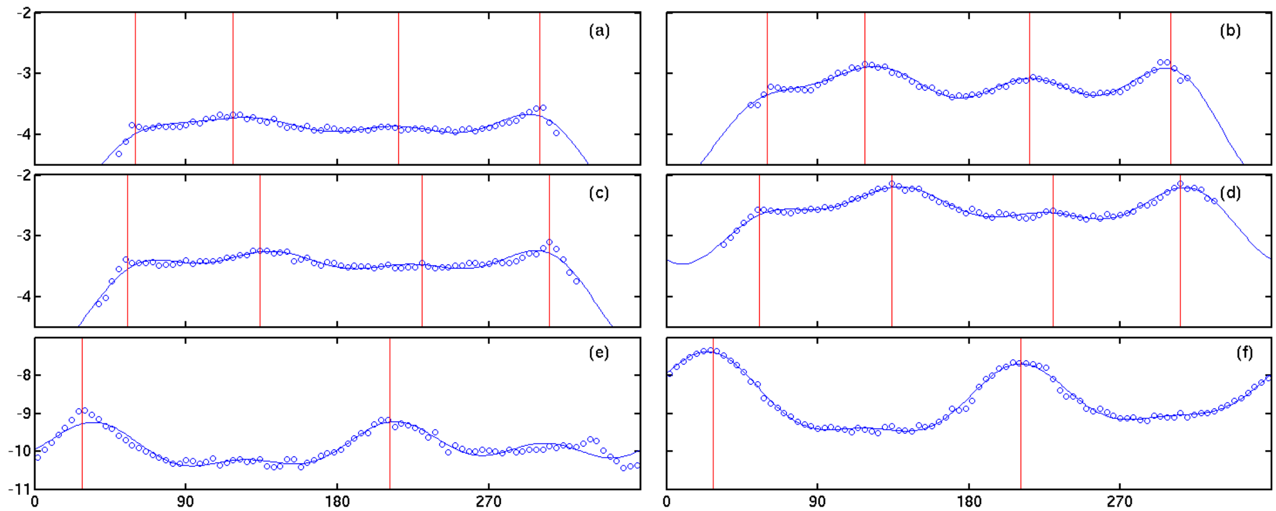

Fig. 3. Azimuth modulation over the east, west and non-dune fields. Backscatter σ^0 values are averaged over 4° wide azimuth bins. The variance of each bin is on the order of 0.5 dB. Lines are best fit curves of equation 1 for and $N = 4$. Vertical lines indicate local maxima. (a) west dune field, V-pol, (b) west dune field, H-pol, (c) east dune field, V-pol, (d) east dune field, H-pol, (e) non-dun field, V-pol, (f) non-dune field, H-pol.

larger in the non-dune regions due to larger peak-to-trough modulation amplitude, as shown in table III. The smaller modulation amplitude in the dune fields is perhaps due to reduced sastrugi coverage.

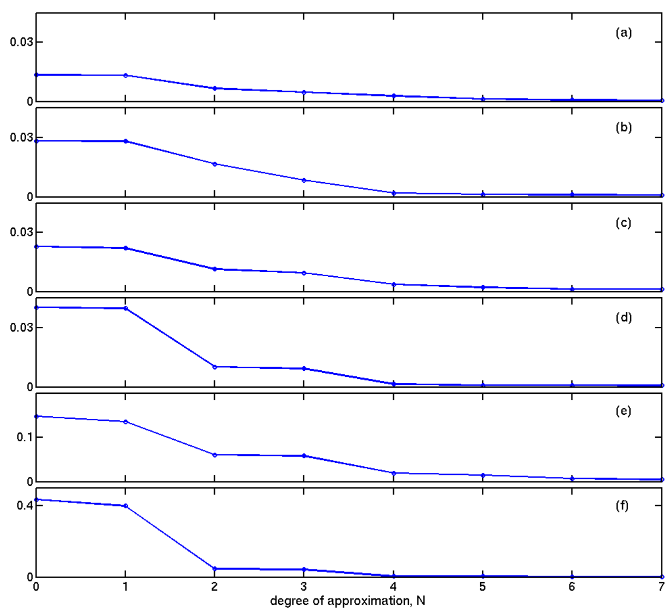

Fig. 4. Mean squared error as a function of degree of approximation for the west, east, and non-dune fields. (a) west dune field, V-pol, (b) west dune field, H-pol, (c) east dune field, V-pol, (d) east dune field, H-pol, (e) non-dun field, V-pol, (f) non-dune field, H-pol.

The locations of the local maxima and minima in the dune fields are telling. Visual images [2] show that the dunes in both study regions, but most particularly those in the east dune field, extend in the north/south direction, transverse to the katabatic wind flow. Both dune fields show local minima at $\phi \approx 180°$ (south) and a trend towards a minima near $\phi \approx 0°$(north). Just as less backscatter is observed in the up/down sastrugi direction, the same appears to be true in the up/down dune direction. More research is needed to establish the dune's precise contribution to the backscatter signature.

VI. Summary

Using QuickSCAT data from the 2005 austral winter we develop a least-squares best-fit azimuth modulation model for two disjoint portions of the megadune field and one non-dune region. While much of Antarctica exhibits a predominately second order azimuth modulation pattern, the megadune region exhibits a predominately fourth order pattern with higher backscatter, and less modulation.

References

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