Azimuth Modulation of Backscatter from SeaWinds and ERS Scatterometers over the Saharo-Arabian Deserts

Haroon Stephen and David G. Long
Brigham Young University Microwave Earth Remote Sensing Laboratory
459 Clyde Building, Provo, UT 84602
TEL: 801-378-4884, FAX: 801-378-6586
e-mail: stephenh@ee.byu.edu and long@ee.byu.edu

Abstract **– Saharo-Arabian deserts includes large expanses of sand dunes called ergs. These dunes are formed and constantly reshaped by prevailing winds. In this paper, we use backscatter (σ^o) measurements observed at various azimuth angles from SeaWinds scatterometer (QSCAT) and ERS scatterometer (ESCAT) to determine the σ^o azimuthal modulation over the sand dunes. A second order harmonic equation is used to model the σ^o measurements as a function of azimuth angle and provides similar results for both sensors. Images of the magnitudes of the model harmonics show many small scale linear features corresponding to the large dune fields in the ergs. The images of the phases of the two harmonics are coherent with the large scale topography of the area. Most ergs exhibit isophase related to the general orientation of large and small scale features of the sand surface.**

I. Introduction

The Saharo-Arabian desert is one of the most inhomogeneous region on the earth. It includes the Sahara desert in the North Africa and Arabian desert in the Arabian peninsula, each consisting of diverse terrains such as rocky mountains, small- and large-scale-gravel zones and vast sand-seas. The sand-seas exhibit very dynamic behavior attributed to the prevailing winds which continue to reshape the deserts by eroding and transporting the sand particles. These aeolian processes result in a terrain with a variety of sand features including many types of dunes and small scale ripples.

Satellite microwave earth remote sensing has proven to be very useful tool for studying various earth phenomena. Scatterometer backscatter (σ^o) measurements are sensitive to the geometrical and dielectric properties of the surface and over the desert terrain depend upon the underlying geometrical features such as sand dunes, mountains, flat plains, etc. and their soil moisture content.

SeaWinds scatterometer (QSCAT) and ERS scatterometer (ESCAT) provide Ku-band and C-band σ^o measurements of the Earth's surface, respectively. These σ^o measurements have been used operationally to measure near surface wind fields over the ocean. The QSCAT provides horizontal and vertical polarization σ^o data at surface incidence angles of 46° and 55°, respectively, which are densely sampled in azimuth angle. The ESCAT covers an incidence angle range of 18°-57° at vertical polarization. Combined ascending and descending pass data provide σ^o measurements at six different azimuth angles.

In this paper, the σ^o measurements from QSCAT and ESACT are investigated to evaluate azimuth angle dependence over the ergs of Sahara desert.

II. Azimuth Modulation Model

A previous study examined σ^o azimuthal modulation over Antarctic firn [1,2]. The azimuth angle modulation, caused primarily by sastrugi and snow dunes, was modeled as a simple second-order harmonic equation given by

$$\sigma^o(\phi) = A + M_1 cos(\phi - \phi_1) + M_2 cos(2\phi - \phi_2) \qquad (1)$$

where $\sigma^o(\phi) = \sigma^o$ at azimuth angles ϕ
$A =$ Mean σ^o (dB)
$M_i =$ magnitude of *ith* order harmonic
$\phi_i =$ phase angle of *ith* order harmonic.

Sand dunes could also exhibit an azimuthal dependence of σ^o data and we adapt this model to evaluate the azimuth angle modulation over the Saharo-Arabian desert region. Over the ocean surface, the σ^o azimuth angle modulation is the basis of wind field retrieval. The size and relative direction of the surface ripples in a measurement cell, a function of local wind speed and direction, determine the azimuth angle modulation. Over sand, σ^o involves both surface and volume scattering; however, its variability with ϕ depends primarily upon the geometric properties of the surface, the local slope and the small scale features such as surface waves, pebbles and rocks. This analysis assumes the sand surface to be stable over the time period of the study, late summer of the year 2000.

III. Azimuth Modulation

Figure 1 shows plots of σ^o and ϕ for QSCAT and ESCAT at 30.5°N and 1.68°E in Erg occidental, located in Algeria. Although QSCAT V- and H-pol σ^o is sampled at different incidence angles, they have almost identical σ^o azimuth angle modulation. The clusters of points corresponding to narrow azimuth angle windows exhibit a spread in the σ^o measurements which, in most cases, is of the order of 10 dB. Although the instrument noise is the primary source of this variability, the changes during the time period of the data and spatial variation may also contribute. The ESCAT azimuth angles are corrected to match the QSCAT azimuth angles. Since the ESCAT data is measured at a wide range of incidence angles, it is normalized to 40° using a linear model given by $\sigma^o(\theta) = \sigma^o(40^o) + B(\theta - 40^o)$, where B is the slope (dB/°).

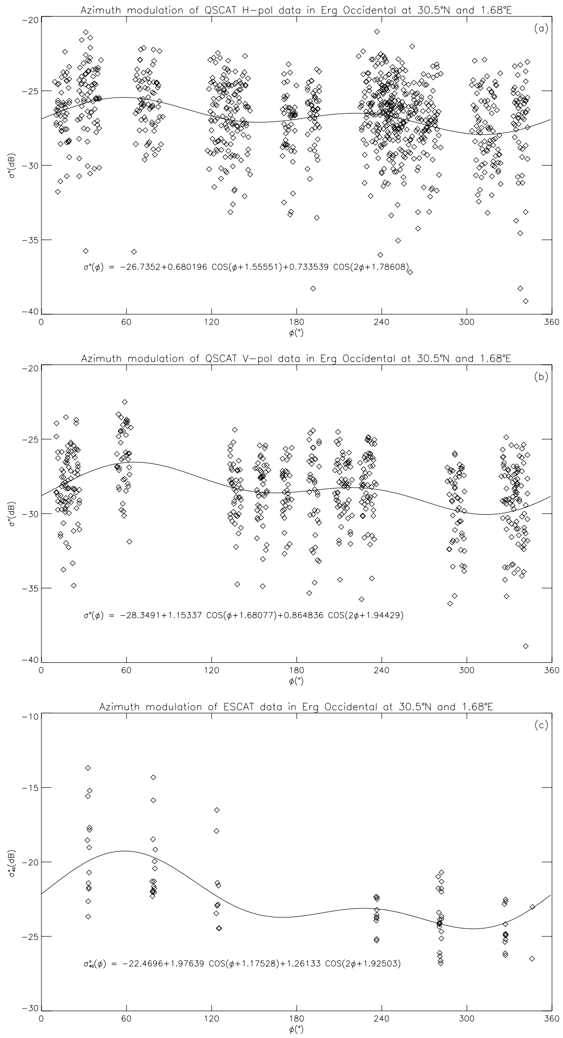

Fig. 1. Azimuth modulation of scatterometer data at 30.5°N and 1.68°E in the Erg Occidental during the late summer of 2000. The a) and b) figures are for the QSCAT H-pol and V-pol, respectively, during JD 182 through JD 212 and figure c) is for ESCAT data during JD 175 through JD 235 normalized to 40° incidence angle. (see text.)

The model in (1) is fit to the data using least squares and is represented by a solid line. The values of the model parameters are written in the form of an equation for each plot. At Ku-band, the H-pol A value is about 1.5 dB higher than V-pol while the magnitudes of the harmonics in H-pol are lower than those in V-pol. Although these differences could be a result of the different sensitivities of the two polarization, the lower incidence angle of the H-pol data is considered to be the primary reason. It is observed in the NASA scatterometer (NSCAT) data [not shown] that the Ku-band σ^o measurements at 40° incidence angle show V-pol values higher than H-pol over the Saharan Ergs. At lower incidence angles, the σ^o measurements over sand have higher contribution from the subsurface volume scattering. This lowers the energy of azimuth angle modulation which is mainly a surface phenomenon. The phases from both polarizations are within 0.2 radians of each other and together with the similarity in the shape of the two curves emphasize the presence of azimuth modulation.

The comparison of Ku- and C-band σ^o reveals consistency between ESCAT and QSCAT azimuth angle modulations. Despite poor ϕ sampling, the ESCAT data and fit have azimuth angle modulation similar to QSCAT as does NSCAT. The magnitudes of the harmonics have values higher than QSCAT whereas the second order phase is similar to that of the V-pol QSCAT data.

IV. Model Parameters

Figure 2 shows the results of model inversion of (1), combined with Scatterometer Reconstruction (SIR) Algorithm [3] over the whole study area. The A images, i.e. (a) and (d), have considerable spatial information coherent with the large scale topography. All the large ergs appear as dark regions with low A values whereas the mountains and the rocky terrains appear as bright areas with high A values. The C-band A values are generally lower than Ku-band with lower resolution (and lower noise) inherent from the coarser resolution of ESCAT sensor.

Images (b) and (c) represent the M_1 and M_2 parameter of the model for QSCAT data and comparison with A image reveals that almost all the ergs exhibit high magnitudes of the harmonics. The second order magnitude is noisier with diamond shape artifacts in the QSCAT map.

The areas with high M_1 and M_2 values correspond to the ergs in the region. This clearly indicates that the σ^o measurements over the ergs have higher azimuth angle modulation than the other terrain types in the Saharo-Arabian desert.

The (e) and (f) images represent the magnitudes of harmonics from ESCAT data. These images are less noisy and exhibit higher magnitudes over the ergs. The phase images [not shown] contain large isophase areas in the ergs.

The erg surface profile has two main spatial frequency components, corresponding to the two predominant land features. The low spatial frequency (wave number) component is the large scale dunes whereas the high wave number component corresponds to small ripples on the surface of the dunes. The first order harmonic is thought to be related to the lower wave number features which mainly contribute to the general surface slope in the foot print; whereas the second and high order harmonic could

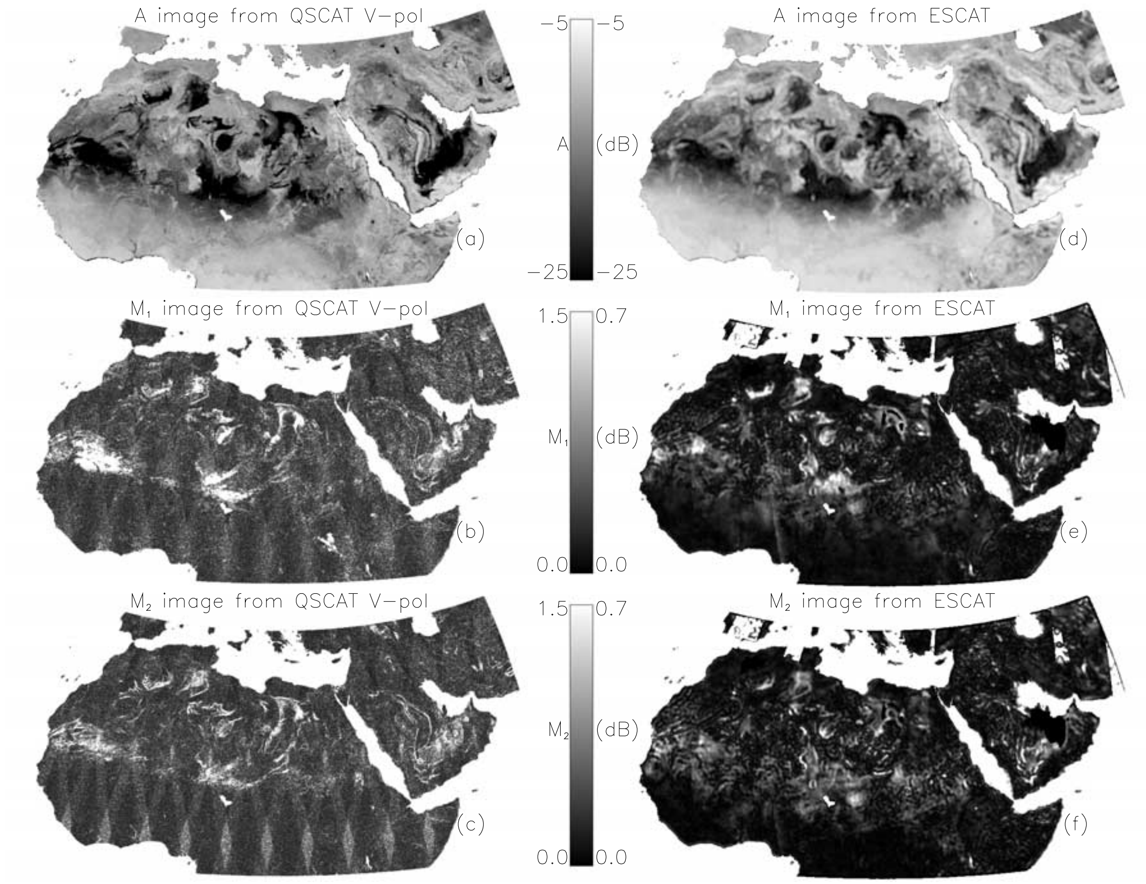

Fig. 2. SIR images of the model parameters from QSCAT and ESCAT data.

result from the higher wave number features i.e., the small scale surface ripples. Both the harmonics are generally stable over considerable durations of time but the second order parameters exhibit small seasonal variations, revealed in a time series [not shown]. Since the overall configuration of large dunes is usually stable, the small surface ripples must be the cause of second order seasonal variations. The surface ripples alter considerably in shape and orientation due to the changes in the prevailing wind patterns. These changes, augmented by the sediment transport over longer time periods, can result in the reshaping of large dune fields as well. The near surface wind fields and the topography have a complex interrelation. The wind patterns are governed by the topography whereas the topographic features are formed and shaped by the wind. The further emphasis of our research will be to relate the results from the model to the geophysical parameters such as reflection coefficient and surface correlation length.

V. Conclusions

A preliminary investigation has been conducted to study the azimuth modulation over the Saharo-Arabian desert using the QSCAT and ESCAT data. It is found that both Ku-band and C-band σ^o measurements are modulated in azimuth angle with high magnitudes apparent in the ergs. The two sensors are found to provide consistent results with some subtle differences attributable to unique characteristics of sensor design. The first order modulation is higher and less noisy than the second order modulation. The spatial phase distribution of both harmonics contain many isophase areas in the ergs.

References

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