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FITTING A THREE-COMPONENT SCATTERING MODEL TO POLARIMETRIC SAR DATA

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1.0 INTRODUCTION

A major problem in analyzing polarimetric SAR data such as that produced by the NASA/JPL AIRSAR is in understanding the scattering mechanisms which give rise to features in the different polarization parameters. Researchers, on examining some polarimetric SAR data from their scene of interest for the first time, often notice unusual bright or dark features when displaying one of the many possible polarization representations of the data (e.g. total power, HH, VV or HV cross-section, HH-VV phase difference, HH-VV correlation coeffficient, etc.) It is usually pertinent to ask what scattering mechanisms give rise to the unusual features?

Much excellent work has recently been done on modelling polarimetric radar backscatter for both naturally occurring terrain and man-made objects. These models are usually complex, and require a large number of input parameters to successfully predict the observed backscatter. For example, in modelling the backscatter return from a forest, measurements of tree heights and diameters, tree density, leaf size and angular distribution, branch size and angular distribution, trunk dielectric constants, ground roughness and dielectric constant are commonly required as inputs. All these models solve the 'forward problem', in predicting backscatter from a number of ground-based measurements of the imaged objects. It is difficult, if not impossible, to invert these models to provide a unique solution, simply because the number of input parameters (the 'ground truth') is often much larger than the number of output parameters (the radar measurements) in the forward problem.

In this paper, a new technique for fitting a three-component scattering mechanism model to the polarimetric SAR data itself, without utilising any ground truth measurements, is presented. The three scattering mechanism components included in the model are volume scatter from randomly oriented dipoles, first-order Bragg surface scatter and a dihedral scattering mechanism for two surfaces with different dielectric constants. The model fit yields an estimate of the contribution to the total backscatter of each of the three components. The backscatter contributions can also be compared to give the relative percentage weight of each. The model fit has an equal number of input parameters (the polarimetric radar backscatter measurements) and output parameters (the backscatter contributions from each of the three components and two parameters describing them). The model can be applied to entire images or to small areas within an image to give a first-order estimate of the relevant scattering mechanisms. The model has been applied to many C-, L- and P-band AIRSAR images of different types of terrain. Results will be presented at the workshop.

2. THE MODEL

The model fit includes three very simple scattering mechanisms. First, for volume scattering, it is assumed that the radar return is from randomly oriented, very thin cylinder-like scatterers. By making several simplifying assumptions the second-order statistics of the resulting scattering matrix can be derived. After normalizing with respect to the VV cross section, these are:

$$\langle |S_{HH}|^2 \rangle = \langle |S_{VV}|^2 \rangle = 1, \ \langle S_{HH} S_{VV}^* \rangle = \langle |S_{HV}|^2 \rangle = 1/3 \tag{1}$$

The double-bounce scattering component is modelled by scattering from a dihedral corner reflector, where the reflector surfaces can be made of different dielectric materials, corresponding to a ground-trunk interaction for forests, for example. The vertical surface (e.g. the trunk) has Fresnel reflection coefficients R_{th} and R_{tv} for horizontal and vertical polarizations, respectively. The horizontal surface (the ground) has Fresnel reflection coefficients R_{gh} and R_{gv} . The scattering matrix for double-bounce scattering is then:

$$S = \begin{bmatrix} -R_{gv} R_{tv} & 0 \\ 0 & R_{gh} R_{th} \end{bmatrix} \tag{2}$$

The second-order statistics for double-bounce scattering, after normalization with respect to the VV term, are:

$$\langle |S_{HH}|^2 \rangle = |\alpha|^2 , \ \langle |S_{VV}|^2 \rangle = 1, \ \langle S_{HH} S_{VV}^* \rangle = -\alpha , \ \langle |S_{HV}|^2 \rangle = 0$$

$$\text{where } \alpha = R_{gh} R_{th} / R_{gv} R_{tv} \tag{3}$$

For the surface scatter, a first-order Bragg model is used, with second order statistics (after normalization):

$$\langle |S_{HH}|^2 \rangle = |\beta|^2 , \ \langle |S_{VV}|^2 \rangle = 1, \ \langle S_{HH} S_{VV}^* \rangle = \beta , \ \langle |S_{HV}|^2 \rangle = 0 \tag{4}$$

where β is real. For all of these backscatter components, it is assumed that the like- and cross-polarized returns are uncorrelated, and that the backscatter is reciprocal. Further, assuming that the volume, double-bounce and surface scatter components are uncorrelated, the total second order statistics are the sum of the above statistics for the individual mechanisms. Thus the model for the total backscatter is:

$$\langle |S_{HH}|^2 \rangle = f_s|\beta|^2 + f_d|\beta|^2 + f_v$$

$$\langle |S_{VV}|^2 \rangle = f_s + f_d + f_v$$

$$\langle S_{HH}S_{VV}^* \rangle = f_s\,\beta - f_d\,\alpha + f_v/3$$

$$\langle |S_{HV}|^2 \rangle = f_v/3 \qquad (5)$$

where f_S, f_d and f_V are the surface, double-bounce and volume scatter contributions to the VV cross section.

The above model gives four equations in five unknowns. A solution can only be found if one of the unknowns is fixed. Since neither the surface nor the double-bounce mechanism contribute to the HV term, this can be used to estimate the volume scatter contribution directly. This can then be subtracted off the three remaining terms, leaving three equations in four unknowns. The sign of the real part of the residual $S_{HH}S_{VV}^*$ term can then be used to decide whether double-bounce or surface scatter is dominant. If $Re\left(S_{HH}S_{VV}^*\right)$ is positive, then surface scatter is determined to be dominant, and α is set to 1. If $Re\left(S_{HH}S_{VV}^*\right)$ is negative, then double-bounce scatter is determined to be dominant, and β is set to 1. Then f_S, f_d, f_V and β or α can be estimated from the residual radar measurements.

3. SUMMARY

A new technique for fitting simple backscatter mechanisms to polarimetric SAR data has been presented. The model can be used to determine to first order what the dominant scattering mechanisms are which give rise to observed backscatter in polarimetric SAR data. Results of application of the model to AIRSAR images of different types of terrain will be presented at the workshop.

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