UTILIZATION OF COHERENT FOREST SCATTERING MODEL IN POLARIMETRIC SAR MEASUREMENT INTERPRETATION

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ABSTRACT

In this study we investigate pine forest backscattering in L-band by using a coherent field scattering model. We generate multilook data by a novel method for a realistic Scots Pine cylinder model and take a closer look at the probability density functions of the scattering. Multilook data are generated by rotating the tree model randomly around its vertical axis. We show that coherent field scattering model generates speckle and a realistic data distribution similar to real SAR measurement. The PDF is very close to multidimensional Gaussian distribution and, therefore, single averaged covariance matrix of the multilook data describes well the whole ensemble. We propose averaged covariance matrix formalism to be used for study also model output. Usage of covariance matrix formalism allows us to use descriptors like target entropy and alpha, which are commonly used to analyse SAR images, this helps also comparison between the model output and SAR image. We show that entropy and alpha values generated by our method for Scots Pine forest agree well with values measured for real forest with similar age and size.

1. INTRODUCTION

Demand for coherent scattering models has grown with the wider use of fully polarimetric and interferometric measurements. SAR based forest remote sensing needs models which can handle phase information precisely in order to response to wider use of polarimetric and interferometric data. Several models have recently been developed to simulate microwave backscattering from forest canopy. In [1] Saatchi and McDonald discussed coherent effects in microwave backscattering models for forest canopies. Lin and Sarabandi have presented a coherent backscattering model for forest [2] and used it to investigate polarimetric and interferometric responses [3]. Thirion et al. [4] applied a coherent scattering model to simulate backscattering from a mangrove forest. In [5] Papathanassiou and Cloude show the possibilities of interferometric polarimetry where the fully coherent signal plays the key role.

Theoretically, a fully coherent scattering model can describe the electromagenetic wave interaction with an object in a physically exact way. However, for complex targets, the coherent model generates also speckle. When modeling the scattering from a tree for L- or C-band with a fully coherent model, the reflections from the complex structure sum up coherently with virtually random phase, enhancing or canceling the resulting wave amplitude. This means that the model output depends drastically on target orientation, shape and incident and scattering direction. In such a case, a single backscattering value in a certain direction is not very informative in order to describe the target under the observation. Generally, when dealing with variables of random nature, we should investigate the probability density function of the variable. Here we propose a method to generate and investigate a probability density function of simulated scattering for a tree. We propose that by rotating the tree model around the vertical axis, we can generate a represenative collection of virtual looks for a given tree type and incident and scattering angle. We also show by an example that the generated probability density function is similar to SAR single look data. Its statistical characteristics are similar to real results from measurements. By using this method one can generate stable and noise free estimates for backscattering for homogeneous forest areas.

2. MODELING THE SCATTERING FROM A TREE

In this section we describe the scattering model and the cylinder model for the tree. The scattering model we use is a straightforward field computational model, making use of the truncated infinite cylinder approximation [6]. The model is based mostly on published material. The applicable frequency domain is restricted mainly by the infinite cylinder approximation. Several novel calculation techniques make the model very fast. The model takes into account direct reflections from cylinders to observation direction and also reflections from the ground. The scatterer is modeled as a collection of dielectrically homogeneous cylinders over dielectric half space. The object is illuminated with a plane wave and coherent sum of direct and ground reflection components is calculated in the far field zone for the chosen observation direction. The model is fully coherent, fully polarimetric and bistatic, allowing to choose illumination and scattering direction freely. The model gives good results for objects where higher order scattering has a small contribution.

As a scatterer, we use a cylinder model for 45 year old Scots Pine (Pinus Sylvestris). The model tree is generated by the LIGNUM tree growth model [8]. The LIGNUM model is based on extensive studies of tree growth in Finland and it is able to generate very detailed tree models. In order to lower the computational load, we have simplified the tree model by leaving out the needles. We believe that we can do that for L-band without seriously affecting the results we present. Ground is modeled as a layered half-space instead of using a more realistic random surface model like in [7]. By feeding the coordinates of the cylinders, their dimensions and dielectric properties into the scattering model and choosing the direction of incident plane wave and observing direction, our model produces scattering matrices in a chosen direction for direct scattering and ground reflections. The model runs are made for L- band. As complex relative permittivities for the cylinders and the soil we used $\epsilon_{\mathrm{tree}} = 15 + 5\mathbf{i}$ and $\epsilon_{\mathrm{soil}} = 7 + 1\mathbf{i}$, respectively, which should describe snow covered ground in winter conditions according to [9] and [10]. Values were chosen for comparison with existing EMISAR data.

3. GENERATING THE MULTILOOK DATA

Before we set up the backscattering simulation, let's take a closer look at how the incident wave scatters from the tree to different directions according to our model. Let's fix the incident wave direction and calculate the response in all scattering directions in the $\mathbf{XZ}$ plane. The scattering amplitude of this simulation is presented in Figure **??**. We can notice a very sharp scattering peak in the exact backscattering direction. This is caused by the fact that the ground is modeled as a smooth surface exactly perpendicular to the tree trunk. In reality, due to ground and tree trunk roughness, the backscattering peak very seldom hits the receiver as strongly as in an idealized mathematical model. This peak disturbs seriously our backscattering simulation. To avoid this non-natural peak we set a 3^0 difference between the incident and scattered directions. This tilting affects the direct scattering contribution very little, but avoids the sharp specular reflection peak. We found that in the simulations this arrangement eliminates the non-realistic strong ground-tree (or tree-ground) backscattering peak. The following simulations we made using this semi-monostatic setup. In Fig. 2 the backscattering amplitude is presented as a function of the azimuth direction. As it is seen in figures, the simulated scattering matrix values are very sensitive to the orientation of the tree and the receiver. Let's review briefly the statistical theory behind the SAR measurements. The assumption of a great number of scatterers in a resolution cell causes a coherent scattering measurement to behave according to multidimensional zero mean complex Gaussian distribution [11]. In [12] it is found that the L-band polarimetric data for coniferous forest follows mostly the Gaussian distribution. However, for longer wavelengths, the presence of texture may give rise to effects, which can be modeled better with the multivariate *K* distribution [11], which includes the Gaussian distribution as a special case. Note that this should be true for both, monostatic and bistatic measurement. The multivariate Gaussian pdf is completely described by its covariance matrix. The *K* distribution needs additional parameters for texture. Consequently, a covariance matrix estimate is a good description of a distributed homogeneous scatterer and it is widely used in radar polarimetry.The averaged covariance matrix preserves information on average power and average phase differences between scattering matrix elements but ignores the absolute phase information.

To inspect the PDF of the scattering in our modeling setup, we should generate a sufficient amount of independent samples from the same measurement setup. We propose that the samples should be collected by rotating the tree model around the vertical axis randomly. In this case all the imaging parameters remain constant. By assuming that interactive reflections

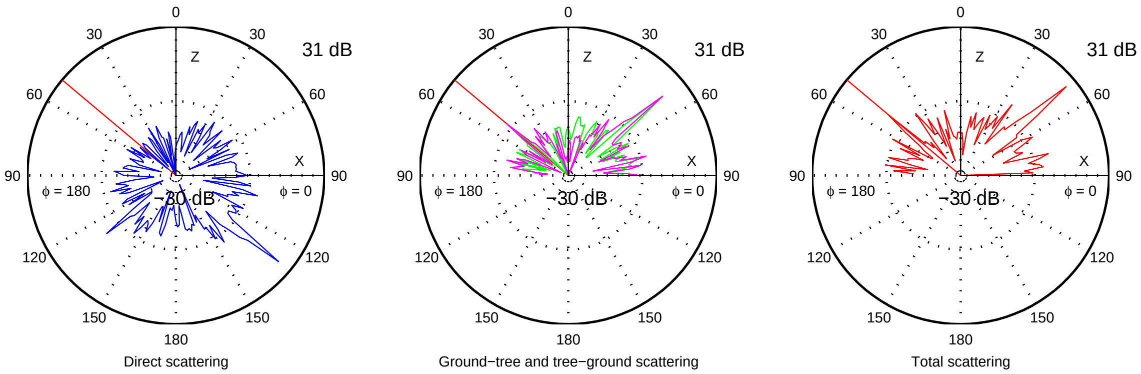

Figure 1: Bistatic scattering from the tree as a function of the polar angle at L-band, HH polarization. The incident direction, marked by the red line, is fixed to have polar a angle $\boldsymbol{\theta} = 50^0$ and azimuth angle $\boldsymbol{\varphi} = 180^0$ pointing to the origin. The left side panel shows direct scattering, the middle panel ground bounce contributions (green for ground-tree and magenta for tree-ground reflection), and the right side panel the total scattering. The ground bounce terms and total scattering are presented only for directions above the ground. The most prominent features in the direct scattering diagram are the forward scattering peak and the trunk reflection peak. The reflections of the same peaks can be identified in the other two diagrams.

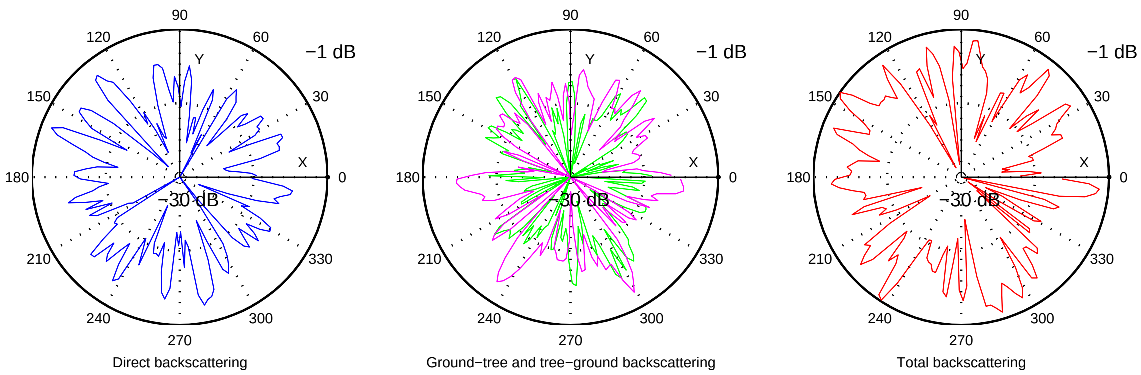

Figure 2: Monostatic backscattering from the tree as a function of the azimuth angle of the scattering direction at L-band, HH polarization. The difference in elevation between the virtual source and the receiver is 3^0. The polar angle is $\boldsymbol{\theta} = 50^0$. The left side panel shows direct backscattering, the middle panel ground bounce contributions (green for ground-tree and magneta for tree-ground reflection), and the right side panel the total backscattering.

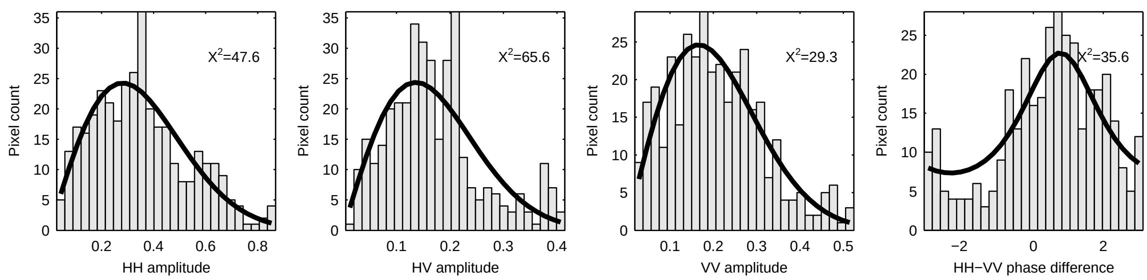

Figure 3: Histograms of the modeled scattering amplitude and the phase differences for different polarizations at L-band for or monostatic setup with 3^0 separated source and receiver. Histograms are generated by rotating the tree and calculating the scattering matrix in one degree steps. The solid lines represent the probability density functions that correspond to the distributed random scatterer assumption. Critical $\boldsymbol{\chi}^2$ value for 25 degrees of freedom and at 95% confidence level is 37.7.

between trees are very small, we can treat the covariance matrix averaged over the directions of a single tree also representative for a larger homogeneous forest area. The model forest of identical trees which are randomly rotated around z-axis gives the same averaged covariance matrix, because the covariance matrix does not take into account the absolute phase. In Fig. 3 we compare the total scattering amplitude histograms and the theoretical probability densities. The amplitude (absolute value) of a scattering should follow the Rayleigh distribution (marginal distribution of Gaussian distribution) and phase difference distribution can be found from [11]. As we can note, the histograms follow the theoretical lines rather well and we may conclude that the ensemble of scattering matrices obtained above is sufficiently well represented by the averaged covariance matrix $\mathbf{C}$. This averaged covariance matrix provides a simple way to compare simulation results with polarimetric SAR data.

4. RESULTS AND DISCUSSION

In order to compare our results with SAR measurements, we calculate polarimetric target entropy and alpha angle for simulated covariance matrix. Our results give $\mathbf{H} = 0.84$ and $\boldsymbol{\alpha} = 47^0$ for a 45-year old sparse Scots Pine stand; these are very realistic values despite the fact that our tree was modeled without needles and we had to use a slightly bistatic arrangement to avoid the problems caused by perfectly smooth ground in our model. However, we believe that the proposed method provides an interesting possibility to interpret the time domain field model calculations for trees and bring us closer to understanding of scattering inside a forest canopy.

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