THE DEPENDENCE OF THE POLINSAR DEGREE OF COHERENCE ON FOREST PARAMETERS

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ABSTRACT

Understanding the dependence of observables on biophysical parameters is crucial for a correct exploitation of the information embedded in the SAR data. In this contribution we report on the sensitiveness that the polarimetric and interferometric phase presents versus forest parameters. Different characteristics of the acquisition sensor are also included in the analysis. We use a detailed coherence and discrete model enclosed in the ESA Toolbox PolSARPro.

1. INTRODUCTION

Modeling backscattering from natural targets is a challenging task in the simulation of Synthetic Aperture Radar (SAR) polarimetric and interferometric (POLInSAR) images. A promising application of POLInSAR technique is the estimate of tree height of forests. To this end, the availability of a reliable reference model for the POLInSAR observables is crucial: first, the model can be used to identify the biophysical parameters that have more impact on the observables; second, a parametric analysis helps to design an efficient inversion approach. The degree of interferometric coherence between a pair of polarimetric SAR images is an observable of major importance for forest parameters retrieval. The prediction of the POLInSAR coherence of forest stands has been addressed by two approaches. The first is the Random Volume over Ground (RVOG) model [1, 2] which combines incoherently the ground contribution with a random canopy contribution. The model is based on four input parameters: tree height, mean canopy extinction, ground-to-volume amplitude ratio and ground topography. The second approach simulates POLInSAR images by modeling the observed surface, including forest, bare soil and grass. The ESA toolbox POLSARPro [3] provides this simulator that coherently adds the direct contributions from vegetation and soil and the one from the ground-vegetation interaction, both for forest and grass. The input parameters are derived from the forest characteristics, the soil surface and the SAR parameters and acquisition geometry.

We have studied the dependence of the complex coherence versus these parameters, in particular trees height, terrain slope and forest density. Different bands (L-band and P-band) have been also considered in the analysis. The importance of this analysis is twofold: from one side it offers guidelines to improve the RVOG model or to design new forward coherence models; on the other side, it serves as basis for a new inversion procedure that will be illustrated as further step of our work [4].

2. POLSARPROSIM: A DETAILED POLINSAR SCATTERING MODEL

PolSARProSIM simulates the complex scattering matrix associated with airborne and space-borne SAR acquisition, assuming an ideal platform motion with straight and uniform trajectory. Hence, the model generates pairs of idealized polarimetric SAR images without residual motion, baseline or co-registration errors, or problems associated with temporal and SNR decorrelation sources [3, 5, 6, 7].

Following scene generation, the forward SAR simulation can be broken down in a number of stages. The scene is divided into a large number of small (compared with the SAR resolution) elements. For each scene element, the 3-dimensional realization of the element is used, along with the SAR parameters and appropriate scattering models, to determine its in-situ scattering amplitude. The spatial location of the scene element, and the SAR imaging geometry, are used to determine the phase centres both of the direct (first-order) backscatter, and of the indirect (second-order) ground-element backscatter. Account is taken of attenuation by tree-foliage and understorey vegetation in the calculations. The complex scattering amplitude is used to weight the focused contribution of the element to the SAR image, and the phase center is used to determine the location of the contribution in the image. Finally, polarimetric scattering contributions from all elements are summed coherently in the simulated SAR imagery.
The ground is described by a set of geometrical and biophysical parameters including surface roughness, correlation length, azimuth/range tilt of the mean terrain, moisture content and soil type [8]. The ground surface scattering calculation employs a two-scale model that superposes a small-scale [9] local roughness on a large-scale undulation [10]. In order to calculate the direct-ground backscattering coefficients, the large-scale surface is divided into small, triangular, flat and rough facets and each facet backscattering response is computed according to facet orientation, area and small-scale roughness. In general, each facet has a unique realization of surface roughness, leading to a speckle distribution over the ground surface. Soil moisture is used to calculate the soil permittivity that is incorporated into the backscattering coefficient calculation [8]. The facet centre position is used in conjunction with the SAR imaging geometry to determine the point of focus of the facet contribution to the SAR image, and, automatically, its contribution to the interferometric phase.

Trees and underlying short vegetation constitute the forest environment in the modelled scene. The main parameters that describe the forest are the mean tree height and the tree species, the area of the forest stand, the forest stand density in stems/ha and the height, density and composition of the short vegetation layer. Each tree in the forest stand is realized in detail and based on allometric equation parameters drawn from statistical distributions. The tree architectures have biophysical properties that correspond closely to those reported in the literature [10]. The branching structure is calculated to second order and includes: stems, primary branches originating in stems, and secondary branches originating in primary branches. The branching algorithm generates curved branches terminating on crown volume surfaces. Tertiary level elements such as twigs, leaves and needles, are simulated as a homogeneous cloud constrained within the tree crown. Both tree architecture and randomly generated tertiary element positions are preserved across the interferometric baseline to ensure proper coherence between imagery. Short vegetation on the ground is modeled as an homogeneous cloud of twigs and leaves, confined to a layer above the ground surface. The approaches employed to calculate both the short vegetation and forest tertiary element scattering contributions are similar.

The SAR image is treated as the coherent superposition of focused scattering events with associated scattering amplitudes. The coherent calculation proceeds according to scattering mechanism: direct-ground, direct-volume and ground-volume. The scattering amplitudes for each discrete scene element have associated effective scattering centres. Together with the SAR imaging geometry, these effective scattering centres determine the point of focus of backscatter in the two-dimensional SAR image plane. The simulated SAR (Fig. 1) images may be expressed succinctly using this discrete approximation model as

$$S_{pq}(x_0, r_0) = \sum_j F_{pqj} Q_{pqj}(x_0, r_0, s_j)$$

where $S_{pq}(x_0, r_0)$ is the resultant, complex pixel of the SAR image for receiving polarization $p$ and transmitting polarization $q$, at azimuth platform position $x_0$ and ground-range distance $r_0$. The scattering amplitudes $F_{pqj}$ result modulate the complex system point-spread-function $Q_{pqj}$, which depends upon azimuth and range, and the location of the effective scattering center $s_j$. The function $Q_{pqj}$ is calculated from the SAR viewing geometry, bandwidth and processing options. Image calculation proceeds by accumulating focused returns in the image until all discrete scene elements have been processed. The process is performed once for the first or master track at one end of the interferometric baseline, and then repeated for the second, or slave track, to form an interferometric pair of polarimetric images.

### 3. RESULTS

Fig. 2 shows the mean phase of the PolInSAR degree of coherence versus trees height (at L- and P-band), forest density, soil roughness and range terrain slope. The mean phase has been obtained by averaging the phase of the coherence over the vegetated area of the simulated images. The error bars of fig. 2 gives also the standard deviation. The reference scenario used in the simulations is detailed in tab. 1. As expected, the phase height increases whilst the trees height and forest density increase. The phase center height does not correspond to the ground surface or to the top of the canopy as consequence of the wave penetration in the canopy. At P-band, the EM energy penetrates more in the canopy and the coherence phase at HH polarization is close to the ground also for high trees height. All plots shows that the optimization procedure gives the best phase separation between ground and canopy return. The ground phase center is more affected by changing the soil properties, and the increasing value
Table 1: Reference values of parameters used for the simulation.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor altitude</td>
<td>3760 m</td>
</tr>
<tr>
<td>Baseline</td>
<td>10 m</td>
</tr>
<tr>
<td>Angle of incidence</td>
<td>50 deg</td>
</tr>
<tr>
<td>Area of the forest</td>
<td>110000 m²</td>
</tr>
<tr>
<td>Tree species</td>
<td>Pine</td>
</tr>
<tr>
<td>Forest Height</td>
<td>12 m</td>
</tr>
<tr>
<td>Density</td>
<td>300 stems/Ha</td>
</tr>
<tr>
<td>Large-scale roughness ($\sigma_r$)</td>
<td>5 cm</td>
</tr>
<tr>
<td>Terrain Slope</td>
<td>Flat terrain</td>
</tr>
</tbody>
</table>

Figure 2: Dependence of the mean phase of the PolInSAR coherence versus forest height (L- and P-band), forest density, soil roughness and range terrain slope. The dependence of the ground-to-volume ratio versus forest height is also shown. The simulations use the sensor characteristics of E-SAR sensor with 10 m horizontal baseline.

4. CONCLUSIONS

In this paper we have shown that the detailed PolInSAR scattering model embedded in the ESA Toolobox PolSARPro can be used for understanding the dependence of the interferometric coherence versus forest and scene characteristics. Apart forest parameters, such as trees height and forest density, we conclude that the terrain slope gives an important contribution to the PolInSAR coherence and hence must be considered for a correct inversion of forest parameters.

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REFERENCES


