A NEW APPROACH FOR POLINSAR FOREST PARAMETERS INVERSION: RESULTS USING THE ESA ALOS-PALSAR PROTOTYPE PROCESSOR

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ABSTRACT

In this contribution we show a preliminary inversion approach that uses the polarimetric and interferometric (PolInSAR) coherence phase to estimate the height of vegetated areas. The PolInSAR degree of coherence is first optimized to identify the ground and top-canopy height, and then corrected for the wave penetration and terrain slope. We use a coherent PolInSAR scattering model to estimated the correction parameters. ALOS-PALSAR data are used to illustrate the results.

1. INTRODUCTION

Polarimetric SAR interferometry [1] is the candidate for the estimation of the worldwide biomass. The key idea of PolInSAR technique is the discrimination between the canopy phase center and the ground phase center by using different polarizations, and the subsequent estimation of vegetation height by mean of the interferometric phase. The major contribution to this application has been the Random Volume over Ground (RVoG) model and its inversion procedure. Although some encouraging results have been presented, there is still a need of a deeper understanding of the dependence of the PolInSAR coherence on the vegetation parameters and, consequently, the need of improved inversion procedure. Our contribution provides an alternative procedure to the RVoG inversion using the coherent scattering model POLSARPROSIM distributed within the ESA Toolbox POLSARPRO [2]. Despite the procedure is at a preliminary stage, we outline the importance of the ground slope correction for the PolInSAR coherence and discuss the results using ALOS-PALSAR data.

2. FOREST PARAMETERS RETRIEVAL

The block diagram in Fig. 1 illustrates our procedure for the estimation of forest height using polarimetric and interferometric data. The left side of the diagram lists the processing steps of real data; the right side describes the PolInSAR chain of simulated data. Starting from the top of the diagram, we discuss the details of each step referring to ALOS-PALSAR polarimetric data. Polarimetric calibration of PALSAR product requires the knowledge of the receive and transmit distortion matrix, respectively R and T, and the one-way Faraday rotation angle to derive the scattering matrix \( S_i \), \( i = 1, 2 \),

\[
S_i = \begin{pmatrix}
S_{hh_i} & S_{hv_i} \\
S_{vh_i} & S_{vv_i}
\end{pmatrix} = F_i^{-1} T^{-1} M_i R_i^{-1} F_i^{-1}
\] (1)

where \( F_i \) is the Faraday rotation matrix, \( M_i \) the uncalibrated scattering matrix and \( S_{xy_i} \) the element of the scattering matrix \( S_i \), \( i = 1, 2 \), for receiving polarization \( x = h, v \) and transmitting polarization \( y = h, v \). After the polarimetric calibration, the coregistration of the two products is performed based on amplitude correlation and spectral shift and filtering. The next step removes the phase contribution \( \phi_{fe} \), due to the flat ellipsoid (WGS-84, 1984).
is assumed) calculated by a precise knowledge of the acquisition geometry. Interferometric processing at L-band potentially provides a better estimation of the ground topography than the available digital elevation models at C-band (e.g. SRTM) since low frequencies penetrate vegetated area. This implies that the flattening is performed using only the ellipsoid contribution without topographic information.

The main observable of POLInSAR algorithms is the complex interferometric degree of coherence $\gamma$ at different polarizations. It is useful to express the coherence in terms of the Pauli scattering vectors, $i = 1, 2$,

$$k_P = (S_{hv_i} + S_{vh_i}, S_{hv_i} - S_{vh_i}, 2S_{hv_i})^T \quad (2)$$

The interferometric scattering vector $k_P = [k_{P_1}, k_{P_2}]^T$ leads to represent the complete polarimetric and interferometric information by a $6 \times 6$ matrix:

$$T_6 = \langle k_P \cdot k_P^H \rangle = \begin{bmatrix} T_{11} & \Omega_{12} \\ \Omega_{12}^H & T_{22} \end{bmatrix} \quad (3)$$

where the superscript $H$ stands for transpose conjugate and the angular brackets for the spatial averaging. Matrices $T_{11}$ and $T_{22}$ are the conventional hermitian coherency matrices that describe the polarimetric properties for each image separately; $\Omega_{12}$ is the $3 \times 3$ cross-coherency matrix that combines the polarimetric interferometric information. The complex coherence can be expressed in terms of the elements of (3)

$$\gamma = \frac{w^n_{\Omega_{12}w}}{\sqrt{\left(w^n_{T_{11}w}\right)\left(w^n_{T_{22}w}\right)}} \quad (4)$$

where the vector $w$ expresses the selected polarization states or combination of polarization states at both ends of the baseline. The physical approach that identify the scattering phase center close to the ground and close to the top of the canopy iterates over the set of ellipticity and orientation angles of transmitting and receiving polarization. Hereafter is reported an iteration based on the numerical radius that leads to similar performance if matrix $T_6$ is properly estimated [3]:

1. Compute the matrices $T_{11}$, $T_{22}$ and $\Omega_{12}$.
2. Compute the matrix $\Pi = T_{11}^{-1/2}\Omega_{12}T_{22}^{-1/2}$.
3. Compute the numerical range of $\Pi$ over $N$ points (e.g. $N = 180$). Let $z$ the vector containing the values of coherence for the $N$ points. The $k$-th element of $z$, $1 \leq k \leq N$, has been obtained at the $k$-th step of the iteration.
4. Compute the matrix $\Theta = \arg \left\{ z \hat{\Omega} \right\}$, where $\arg()$ is applied to each element of the matrix $\hat{\Omega}$.
5. Find the maximum on $N(N - 1)/2$ elements: max{$|\theta_{ij}|:\theta_{ij} \in \Theta, 1 \leq i \leq N, i \leq j \leq N$}. Let $i^*$ and $j^*$ the row and column respectively at which the maximum occurs.
6. Calculate the two values of optimum coherence:

$$\gamma_{\text{opt}} = \zeta^{i^*}, \gamma_{\text{opt}} = \zeta^{j^*}.$$  

The lowest and highest phase center between $\gamma_{\text{opt}}$ and $\gamma_{\text{opt}}$, depends on the sign of $\theta_{ij}$.

Figure 2: From left to right, Pauli image of the PALSAR product ALPSRP0060247100, low phase center, high phase center. Color coding: blue$= -180^\circ$, red$= 180^\circ$.

The high phase $\phi_e$ and low phase $\phi_g$ of the optimum coherence corresponds physically to a phase center located close to the canopy and a phase center close to ground respectively. We assume that temporal decorrelation affects the accuracy of $\phi_e$ and $\phi_g$ and only slightly their mean value. It follows that the forest height retrieval can be based on the difference between $\phi_e$ and $\phi_g$ for moderate temporal decorrelation. Note that temporal artifacts change the coherence magnitude considerably and in unpredictable way, and this is a critical point in the RVoG inversion using PALSAR data. The phase difference mentioned above (scaled by the vertical wavenumber) does not correspond to the vegetation height because $\phi_e$ lifts off the ground and $\phi_g$ penetrates the canopy.

To compensate these effects we use a coherent POLInSAR simulator [2] from which we derive the exact position of the scattering phase centers. Many forest parameters impact on the phase center positions whilst varying the polarization. After an extensive model analysis [4], we identify that the trees height, the local range terrain slope and the forest density induce high variation in the coherence phase. For dense forest, we can correct the phase difference taking into account only the wave penetration and the local terrain slope, according to the following expression

$$h_v = \frac{(\phi_e - \phi_{\text{slope}} - \phi_{\text{penetr}}) - \phi_{\text{vel}}}{k_z} \quad (5)$$

where $h_v$ is the vegetation height, $\phi_{\text{slope}}$ compensates for the local terrain slope, $\phi_{\text{penetr}}$ and $\alpha$ for the wave penetration, and $k_z$ is the vertical wavenumber of the interferometric acquisition. The three parameters $\phi_{\text{slope}}$, $\phi_{\text{penetr}}$ and $\alpha$ are estimated from model simulations, similar to those of figg. 3 and 4.
3. RESULTS USING PALSAR DATA

The method described in the previous section has been applied to polarimetric and interferometric PALSAR data recently acquired over the Traunstein area (Germany). The spatial baseline of the acquisition is about 200 m. Fig. 2 shows the Pauli image of the acquisitions, and also the top and low phase center at the output of the optimum coherence algorithm (i.e. $\phi_v$ and $\phi_g$). The fringes visible in the upper part of the image reveal a residual topography in both coherence phase map. The topography is cancelled by the simple difference between the phase centers. The correction induced by the terrain slope is shown in fig. 5. The map has been obtained by projecting the appropriate portion of the SRTM DEM into the slant range geometry of the PALSAR acquisition. At each phase center has been associated also a terrain slope and the relative correction is derived by interpolating the curves of the optimum phase centers in the plot of fig. 3. From the correction map, it is visible that the topography introduces an important variation on the forest height estimation. The second correction is based on the plot of fig. 4. The phase difference versus forest height is given from model simulation using flat terrain; the parameters $\phi_{\text{penetr}}$ and $\alpha$ are then calculated by comparing the ideal case with the simulated case; finally, the forest height is corrected using (5). Fig. 6 shows the corrected phase center height which correspond closely to the vegetation height in the forested areas.

4. CONCLUSIONS

The forest height can be retrieved from polarimetric and interferometric SAR data using the phase separation of the POLINSAR coherence boundary in the complex plane. A scattering model is needed for the correction of the wave penetration and terrain slope distortion. The results using ALOS-PALSAR data are promising despite the well known limitations due to temporal decorrelation.

REFERENCES


