POTENTIAL & CHALLENGES OF POLARIMETRIC SAR INTERFEROMETRY TECHNIQUES FOR FOREST PARAMETER ESTIMATION IN THE CONTEXT OF THE BIOMASS MISSION

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ABSTRACT

World forests contain a significant amount of carbon that is, in consequence of natural and human induced deforestation and regrowth processes, affected by rapid changes and therefore difficult to quantify in terms of biomass/carbon storage. This uncertainty remains because of the lack of reliable and frequent information of biomass levels on a global scale. Spaceborne Synthetic Aperture Radar (SAR) could provide the required global and temporal coverage of the world's forested areas. Innovative new inversion approaches allow today accurate meassurement of vegetation structure parameters such as forest height and biomass [1][2][3]. The coherent combination of polarimetric and interferometric SAR at lower frequencies by means of Pol-InSAR is sensitive to the vertical distribution of scattering processes within a resolution cell and can be used for model-based inversion of forest height and structural parameters.

The estimation of forest height (and its close relation to forest biomass) becomes important in the frame of BIOMASS mission, a P-band SAR mission currently under review as a candidate mission in the ESA Earth Explorer Opportunity Programme series. The main objective of the BIOMASS mission is to provide consistent global estimates of forest biomass, forest disturbance and re-growth.

The ITU allocation that limits dramatically the system bandwidth at P-band to only 6MHz at 432-438MHz combined with the technological challenges following the realization of a P-band spaceborne mission and the imposed constrains makes Pol-InSAR inversion not trivial and requires an optimized Pol-InSAR inversion schema. In this paper we discuss Pol-InSAR inversion in the context of the BIOMASS mission scenario and analyze the possible performance and the associated system requirements for forest parameter estimation techniques in the frame of the BIOMASS system and mission operation scenario. The performance analysis is supported and validated by airborne Pol-InSAR experimental ands simulated data.

In this study, we assess the impact of sensor related parameters (bandwidth, NESZ, and range/azimuth ambiguities) on Pol-InSAR inversion performance and evaluated the expected performance. We analyse the potential performance and the associated system requirements for forest parameter estima-tion adapted to the specification of the BIOMASS mission.

Pol-InSAR inversion: Single baseline inversion

In the Quad-pol single baseline case the inversion problem is balanced with six unknowns $(h_v, \sigma, m_{1-3}, \varphi_0)$ and three measured complex coherences $[\tilde{\gamma}(\vec{w}_1) \quad \tilde{\gamma}(\vec{w}_2) \quad \tilde{\gamma}(\vec{w}_3)]$ each for any independent polarization channels.

$$\min_{h_v,\delta,m_i,\phi_0} \left\| \begin{bmatrix} \tilde{\gamma}(\vec{w}_1) \\ \tilde{\gamma}(\vec{w}_2) \\ \tilde{\gamma}(\vec{w}_3) \end{bmatrix} - \begin{bmatrix} \tilde{\gamma}_V(h_v,\delta,m_1) \\ \tilde{\gamma}_V(h_v,\delta,m_2) \\ \tilde{\gamma}_V(h_v,\delta,m_3) \end{bmatrix} \right\| \tag{1}$$

With respect with the general scattering scenario, with moderated extinction and relative small m values the approximation that the smallest m_3 equals zero has been proved to be efficient **Error! Reference source not found.**.

Pol-InSAR inversion: Coherent multi baseline inversion

Each of the available spatial baselines with corresponding vertical wave numbers κ_{zi} where $i \in \{1,2\}$ provides a set of three different complex coherences $[\tilde{\gamma}(\vec{w}_1) \;\; \tilde{\gamma}(\vec{w}_2) \;\; \tilde{\gamma}(\vec{w}_3)]_i$. A direct combination requires relative and absolute baseline to baseline phase calibration. An alternative way that relaxes the phase calibration requirements is to estimate first for each single baseline the complex coherence $\tilde{\gamma}(\vec{w}_3 \mid \kappa_{zi})$ without ground component $m_3 = 0$, then for this constellation all possible h_V, σ and γ_{deco} are collected, i.e. the one associated with $\tilde{\gamma}_V(\{h_V, \sigma, m_3 = 0, \gamma_{Deco}\} \mid \kappa_{zi})$. Then in a second step, h_V, σ and γ_{deco} (that are baseline invariant) are estimated according to

$$\min_{h_V, \sigma, \gamma_{deco_i}, \phi_0} \left\| \begin{bmatrix} \tilde{\gamma}(\vec{w}_3 \mid \kappa_{z1}) \\ \tilde{\gamma}(\vec{w}_3 \mid \kappa_{z2}) \end{bmatrix} - \begin{bmatrix} \tilde{\gamma}_V(\kappa_{z1}, \{h_V, \sigma, \gamma_{deco}\}\ ) \\ \tilde{\gamma}_V(\kappa_{z2}, \{h_V, \sigma, \gamma_{deco}\}\ ) \end{bmatrix} \right\| \tag{2}$$

This approach assumes that γ_{deco} is independent of baseline as it is in case of system or noise decorrelation. Of course the inversion can be extended from a dual to a multi-baseline problem:

$$\min_{h_V, \sigma, \gamma_{deco_i}, \phi_0} \left\| \begin{bmatrix} \tilde{\gamma}(\vec{w}_3 \mid \kappa_{z1}) \\ \tilde{\gamma}(\vec{w}_3 \mid \kappa_{z2}) \\ \vdots \\ \tilde{\gamma}(\vec{w}_3 \mid \kappa_{zN}) \end{bmatrix} - \begin{bmatrix} \tilde{\gamma}_V(\kappa_{z1}, \{h_V, \sigma, \gamma_{deco}\}\ ) \\ \tilde{\gamma}_V(\kappa_{z2}, \{h_V, \sigma, \gamma_{deco}\}\ ) \\ \vdots \\ \tilde{\gamma}_V(\kappa_{zN}, \{h_V, \sigma, \gamma_{deco}\}\ ) \end{bmatrix} \right\| \tag{3}$$

Simulated Data

Simulation parameters were chosen according to the potential future spaceborne BIOMASS mission (P-band). A number of different parameters must be considered for extrapolating of spaceborne data from airborne data. These are not only system (sensor) related parameters, but also those related to the propagation path (ionosphere) and the temporal baseline amongst two acquisitions (temporal decorrelation).

The steps for the generation of the simulated data can be summarized as follows: Step 1: Reduction of spatial resolution; Step 2: Increase of Noise Equivalent Sigma Zero; Step 3: Adding of azimuth ambiguities and Step 4: Adding of range ambiguities.

Forest heights are estimated by means of Equation (1) and shown in Figure 1. Left image shows Pol-InSAR inversion results from P-band airborne SAR data and the right image of Figure 1 shows height results based on simulation data (spaceborne case) over the Remningstorp test site in Sweden **Error! Reference source not found.Error! Reference source not found.**. Simulation results are higher than the forest height map derived from airborne SAR data. Nevertheless simulation results are still sensitive to forest structure in spite of lower resolution and higher noise level.

Figure 2 left shows the comparison between airborne SAR data height and simulation results. There is a tendency that the inverted forest height from simulation data is higher than from the airborne data result. After normalizing by total number of samples for a given airborne inverted height (see Figure 2 right), we can see that low forests are more affected by constraints imposed by mission design than high forests.

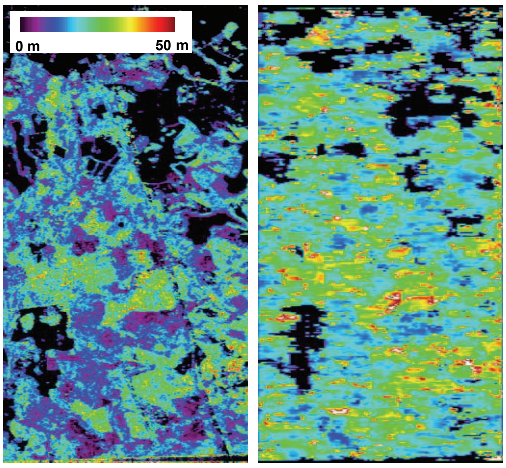

Figure 1. Forest height invsersions, scaled 0 to 50m. (Left) airborne SAR data, (Right) simulation data.

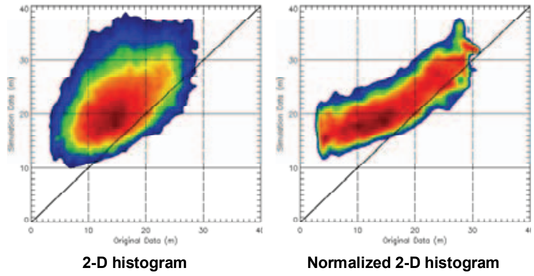

Figure 2. P-band Pol-InSAR inversion height comparison between airborne SAR data and simulation data. (Left) 2-dimensional histogram, (Right) 2-dimensional histogram normalized along column line.

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