

The Potential and Challenges of Polarimetric SAR Interferometry Techniques for Forest Parameter Estimation at P-band

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Abstract

In this paper we address the potential of Pol-InSAR forest parameter estimation projected onto the future P-band BIOMASS satellite system configuration and mission operation scenario. The impact of system parameters (bandwidth, NESZ and range/azimuth ambiguities) is evaluated and a performance analysis with respect to forest parameter estimation is performed and discussed. The performance analysis is supported and validated by using simulation data sets generated from E-SAR (Experimental Synthetic Aperture Radar) repeat-pass Pol-InSAR experimental data acquired in the frame of recent campaigns. Two campaign data sets (BioSAR 2007 / INDREX-II) have been selected and investigated.

1 Introduction

The world forests contain the largest part of carbon stored in living vegetation, but as consequence of deforestation, re-growth, forest fires, and so on, they are affected by permanent changes and therefore difficult to quantify in terms of biomass/carbon storage. This uncertainty remains because of a lack of reliable and timely regular information of biomass level and changes in biomass level across large areas.

Synthetic Aperture Radar (SAR) system could provide the required global and temporal coverage of the forest systems. Polarimetric SAR interferometry (Pol-InSAR) is new radar technology that especially allows us to investigate vegetation structure properties such as forest height and biomass [1][2][3]. The coherent combination of polarimetric and interferometric SAR 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. Indeed, model based (using Random Volume over Ground or RVoG model) forest height estimation has been successfully demonstrated using fully polarimetric and interferometric airborne repeat pass data at wide range of frequencies over different type of forests.

However, airborne SAR systems in general have better performance parameters in term of resolution, signal-to-noise ratio and range/azimuth ambiguities suppression than spaceborne configurations. In addition, airborne SAR systems can be flexibly deployed to avoid strong temporal decorrelation and ionospheric effects are not an issue. Due to these differences and to get an idea about inversion quality of spaceborne data, spaceborne acquisition conditions need to be simulated on basis of airborne data sets.

In the case of the planned BIOMASS spaceborne mission [8], sparse resolution is probably one of the most critical parameter as the International Telecommunication Union (ITU) allocation limits the system bandwidth at P-band dramatically to 6 MHz from 432 to 438 MHz. 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 estimation adapted to the specification of the BIOMASS mission.

Performance analysis is based on and validated with DLR's E-SAR airborne experimental data. The selected airborne SAR data sets are representative for the main global forest types (boreal, temperate, and tropical) and are modified to simulate acquisition conditions as given in the BIOMASS mission scenario [5].

2 Simulation 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).

Simulation steps for system parameters 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
Step 4: Adding of range ambiguities.

Table 1: Simulation parameter

Azimuth resolution (single look)	12.5 m
Range resolution (single look)	25.0 m
Peak to Sidelobe Ratio (PSLR)	20 dB
Distributed Target Amb. Ratio (DTAR)	20 dB
Noise Equivalent Sigma Zero (NESZ)	-28 dB

The used simulation approach is well described in [5].
The simulation parameters are shown in Table 1.

3 Pol-InSAR inversion methods

3.1 Single baseline inversion

In the Quad-pol single baseline case the inversion problem is balanced with six unknowns $(h_v, \sigma, m_{1-3}, \phi_0)$ and three measured complex coherences $[\tilde{\gamma}(\bar{w}_1) \tilde{\gamma}(\bar{w}_2) \tilde{\gamma}(\bar{w}_3)]$ each for any independent polarization channels.

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

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 [3].

3.2 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 $[\tilde{\gamma}(\bar{w}_1) \tilde{\gamma}(\bar{w}_2) \tilde{\gamma}(\bar{w}_3)]_i$. 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 $\tilde{\gamma}(\bar{w}_3 | \kappa_{zi})$ 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 $\tilde{\gamma}_V(\{h_v, \sigma, m_3 = 0, \gamma_{Deco}\} | \kappa_{zi})$. Then in a second step, h_v, σ and γ_{deco} (that are baseline invariant) are estimated according to

$$\min_{h_v, \sigma, \gamma_{deco}, \phi_0} \left\| \begin{bmatrix} \tilde{\gamma}(\bar{w}_3 | \kappa_{z1}) \\ \tilde{\gamma}(\bar{w}_3 | \kappa_{z2}) \end{bmatrix} - \begin{bmatrix} \tilde{\gamma}_V(\kappa_{z1}, \{h_v, \sigma, \gamma_{deco}\}) \\ \tilde{\gamma}_V(\kappa_{z2}, \{h_v, \sigma, \gamma_{deco}\}) \end{bmatrix} \right\| \quad (2)$$

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 multibaseline problem but then it becomes overdetermined:

$$\min_{h_v, \sigma, \gamma_{deco}, \phi_0} \left\| \begin{bmatrix} \tilde{\gamma}(\bar{w}_3 | \kappa_{z1}) \\ \tilde{\gamma}(\bar{w}_3 | \kappa_{z2}) \\ \vdots \\ \tilde{\gamma}(\bar{w}_3 | \kappa_{zN}) \end{bmatrix} - \begin{bmatrix} \tilde{\gamma}_V(\kappa_{z1}, \{h_v, \sigma, \gamma_{deco}\}) \\ \tilde{\gamma}_V(\kappa_{z2}, \{h_v, \sigma, \gamma_{deco}\}) \\ \vdots \\ \tilde{\gamma}_V(\kappa_{zN}, \{h_v, \sigma, \gamma_{deco}\}) \end{bmatrix} \right\| \quad (3)$$

4 Simulation results

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 [4][6]. 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.

5 Conclusions

The possibility of forest height estimates with simulation data according to the specification of BIOMASS mission was verified and demonstrated. However, P-band simulation data have a tendency to systematically overestimate forest height due to higher noise level and ambiguities. For the final paper, the coherent multi baseline inversion as described by Equation 3 will be conducted to reduce or mitigate these decorrelation effects.

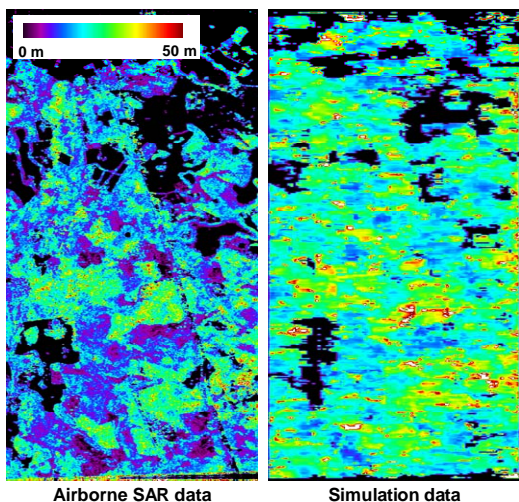


Figure 1. Forest height inversions, scaled 0 to 50m. (Left) airborne SAR data, (Right) simulation data.

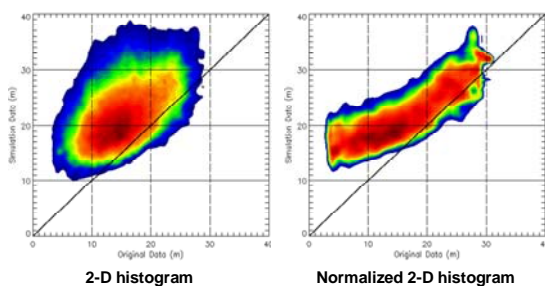


Figure 2. P-band Pol-InSAR inversion height comparison between airborne SAR data and simulation data. (Left) 2-dimensional histogram, (Right) 2-dimensional histogram normalized along column line.

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