# 3D FOREST STRUCTURE DERIVED FROM POLARIMETRIC MULTIBASELINE INSAR DATA AND ITS RELATION TO BIOMASS

*Stefan Sauer, Florian Kugler, Seung-Kuk Lee, Kostas Papathanassiou*

German Aerospace Center (DLR), Microwaves and Radar Institute (HR), Germany

## 1. ABSTRACT

In this paper, recently conceived polarimetric array signal processing techniques are applied for producing 3D images over forested scenes from multibaseline POL-InSAR observations. Subsequently, the optimal scattering mechanisms are investigated using polarimetric decomposition algorithms. The derived structural forest parameters serve as a basis for determining the biomass. This three-dimensional analysis is compared with the results achieved on the POLSAR images and validated by employing ground-truth measurements. The multibaseline Pol-InSAR datasets over tropical (INDREX-II), boreal (BIOSAR I and II), and temperate (TempoSAR) forests were acquired by the E-SAR system of DLR.

## 2. INTRODUCTION

While SAR polarimetry (POLSAR) permits the identification of elementary scattering processes inside the resolution cell, SAR interferometry (InSAR) determines the height of scatterers. Polarimetric SAR interferometry allows the estimation of the vertical location of scattering mechanisms [1]. To extract physical parameters from single-baseline POL-InSAR observations different coherent models describing the reflection processes have been proposed [2]. Schemes to inverse the electromagnetic models for retrieving forest parameters such as tree height and underlying ground topography have been introduced [2, 3]. A three-dimensional model-based radar imaging technique of vegetation using single- and dual-baseline polarimetric interferometric SAR observations called Polarization Coherence Tomography has been developed lately [4].

An extension of conventional two-dimensional SAR imaging is SAR Tomography that permits the reconstruction of the three-dimensional scatterer distribution [5]. The tomographic SAR imaging approach has been applied to forested areas where both the ground level and the tree canopy have been distinguished resulting in an estimation of tree height and ground topography.

Recently, a new way of analyzing polarimetric multibaseline (MB) InSAR data has been conceived by adapting array signal processing algorithms to this configuration [6, 7]. These polarimetric methods permit the estimation of the reflector height, the scattering mechanism, and the polarimetric reflectivity. In this paper, they are applied for generating three-dimensional images of forested scenes from polarimetric multibaseline InSAR data. Subsequently, the optimal scattering vectors are examined by polarimetric decomposition approaches [8, 9]. Furthermore, it is investigated how to combine on a model-based level the individual techniques and in which way the observation space can be optimally exploited in the context of a spaceborne implementation with a reduced number of acquisitions. Additionally, the correlation between biomass and forest morphology information deduced from SAR measurements is explored. The results are validated using ground-truth data [12, 13].

After introducing the polarimetric array signal processing algorithms in section 3 and the polarimetric decomposition techniques in section 4, the experimental results are presented in section 5. Polarimetric multibaseline InSAR datasets acquired by the E-SAR system of DLR during the INDREX-II, BIOSAR I and II, and TempoSAR campaigns are used.

## 3. POLARIMETRIC MB INSAR ARRAY SIGNAL PROCESSING TECHNIQUES

In this section, spectral analysis techniques are extended to the fully polarimetric MB InSAR configuration. In this situation, the antennas not only receive the signals in diverse polarizations [14, 15], but emit the electromagnetic waves and receive the echoes in polarimetric mode. The following adaptation to the fully polarimetric case not merely increases the number of observables, but especially finds the optimal polarization combination for height estimation. Furthermore, these algorithms allow examining the scatterer physical properties by analysis of their polarimetric behavior.

The detailed description follows in the final paper.

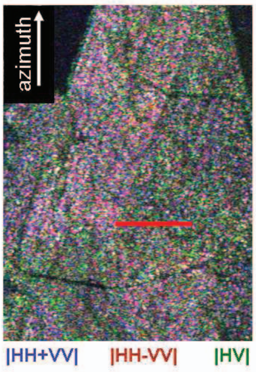

**Fig. 1**. POLSAR image (part of Remningstorp testsite).

## 4. POLARIMETRIC DECOMPOSITION

The polarimetric decomposition is based on the model introduced in [8] that includes three scattering mechanisms, namely canopy (or volume), double-bounce, and surface scattering. The model for the total backscatter is given by [8]

$$\begin{aligned}
\langle S_{hh}S_{hh}^*\rangle &= f_s|\beta|^2 + f_d|\alpha|^2 + f_v \\
\langle S_{hv}S_{hv}^*\rangle &= f_v/3 \\
\langle S_{vv}S_{vv}^*\rangle &= f_s + f_d + f_v \\
\langle S_{hh}S_{vv}^*\rangle &= f_s\beta + f_d\alpha + f_v/3 \\
\langle S_{hh}S_{hv}^*\rangle &= \langle S_{vv}S_{hv}^*\rangle = 0 \qquad (1)
\end{aligned}$$

where $f_s, f_d$, and $f_v$ are the surface, double-bounce, and volume scatter contributions, and $\alpha$ and $\beta$ correspond to the co-polarized correlations of double-bounce and surface scattering, respectively. The contribution of each reflection mechanism to the span $P$ is obtained as [8]

$$P = P_s + P_d + P_v \equiv \left(|S_{hh}|^2 + 2|S_{hv}|^2 + |S_{vv}|^2\right) \qquad (2)$$

with

$$\begin{aligned}
P_s &= f_s\left(1 + |\beta|^2\right) \\
P_d &= f_d\left(1 + |\alpha|^2\right) \\
P_v &= 8f_v/3. \qquad (3)
\end{aligned}$$

Moreover, other polarimetric decompositions including a shape factor [9] and an orientation coefficient [10, 11] will be investigated.

## 5. EXPERIMENTAL RESULTS

The performance of the introduced algorithms is validated using fully polarimetric multibaseline interferometric datasets over tropical (INDREX-II campaign [12]), boreal (BIOSAR I and II [13]), and temperate (TempoSAR) forests. The measurements were acquired by the E-SAR system of DLR and consist of three or more baselines in repeat-pass mode. Furthermore, ground truth data are available allowing to model vertical forest structure for validation.

Three-dimensional (pseudo-)tomographic slices have been computed for the sample line depicted in the POLSAR image (Remningstorp testsite) in figure 1. The 3D images are calculated in a height range of -10 m to 70 m by means of polarimetric beamforming, Capon, and MUSIC using dual-baseline POL-InSAR observations. figure 2 shows the optimal scattering vectors in the Pauli polarization basis: Whereas beamforming produces spectra having broad peaks and high sidelobes, the resolution is considerably refined by the polarimetric Capon and MUSIC algorithms. The forest ground can be clearly identified at around 0 m, and canopy structure above ground is visible.

The 3D images will be used to perform polarimetric decompositions. This polarimetric structural analysis will be compared with results that can be achieved by carrying out polarimetric decompositions on a single POLSAR image and with ground-truth measurements.

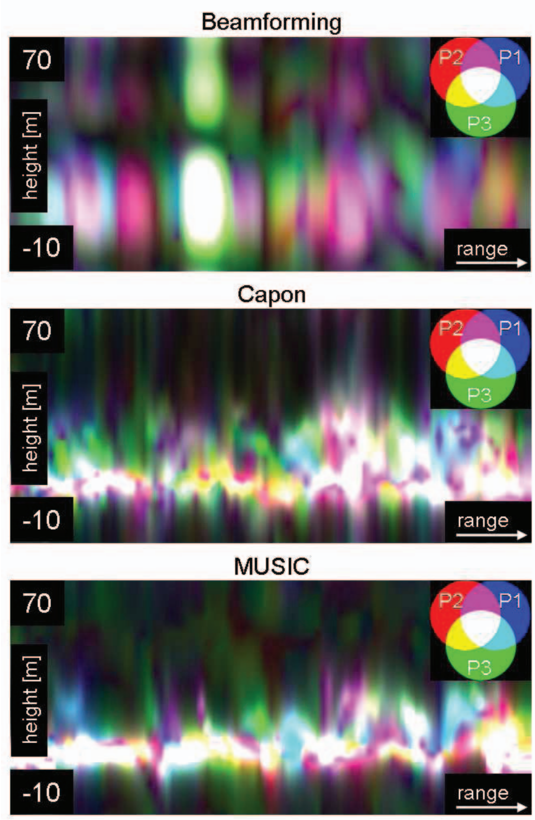

**Fig. 2**. 3D images obtained by polarimetric (top) beamforming, (middle) Capon, and (bottom) MUSIC.

## 6. OUTLOOK

In this paper, recently conceived polarimetric array signal processing techniques have been applied for generating 3D images over forested scenes from multibaseline POL-InSAR observations. Currently, the optimal scattering mechanisms are investigated using polarimetric decomposition algorithms.

At the conference, we will present how to exploit in an optimum way the polarimetric multibaseline InSAR observation space that is restricted in the framework of spaceborne missions. Finally, first results concerning the retrieval of biomass by means of forest morphologic insights obtained from SAR measurements will be shown.

## 7. REFERENCES

[1] S. R. Cloude, K. P. Papathanassiou: *Polarimetric SAR interferometry*, IEEE Trans. Geoscience Remote Sensing, vol. 36, pp. 1551-1565, Sept. 1998.

[2] K. P. Papathanassiou, S. R. Cloude: *Single-Baseline Polarimetric SAR Interferometry*, IEEE Trans. Geoscience Remote Sensing, vol. 39, pp. 2352-2363, Nov. 2001.

[3] S. R. Cloude, K. P. Papathanassiou: *Three stage inversion process for polarimetric SAR interferometry*, IEEE Proc.-Radar Sonar Navig., vol. 150, pp. 125-134, June 2003.

[4] S. R. Cloude: *Dual-baseline coherence tomography*, IEEE Geoscience and Remote Sensing Letters, vol. 4, no. 1, pp. 127-131, Jan. 2007.

[5] A. Reigber, A. Moreira: *First Demonstration of Airborne SAR Tomography Using Multibaseline L-Band Data*, IEEE Trans. Geoscience Remote Sensing, vol. 38, no. 5, pp. 2142-2152, Sept. 2000.

[6] S. Sauer: *Interferometric SAR Remote Sensing of Urban Areas at L-Band using Multibaseline and Polarimetric Spectral Analysis Techniques*, Ph.D. thesis, University of Rennes 1, Rennes, France, March 2008.

[7] S. Sauer, L. Ferro-Famil, A. Reigber, and E. Pottier: "Polarimetric Dual-baseline InSAR Building Height Estimation at L-Band," *IEEE Geoscience and Remote Sensing Letters*, vol. 6, no. 3, pp. 408-412, July 2009.

[8] A. Freeman and S. L. Durden: *A Three-Component Scattering Model for Polarimetric SAR Data*, IEEE Trans. Geoscience and Remote Sensing, vol. 36, no. 3, pp. 963-973, May 1998.

[9] A. Freeman: *Fitting a Two-Component Scattering Model to Polarimetric SAR Data From Forests*, IEEE Trans. Geoscience and Remote Sensing, vol. 45, no. 8, pp. 2583-2592, Aug. 2007.

[10] M. Neumann: *Remote sensing of vegetation using multi-baseline polarimetric SAR interferometry: theoretical modeling and physical parameter retrieval*, Ph.D. thesis, University of Rennes 1, Rennes, France, Jan. 2009.

[11] M. Neumann, L. Ferro-Famil, A. Reigber: *Estimation of forest structure, ground, and canopy layer characteristics from multibaseline polarimetric interferometric SAR data*, IEEE Trans. Geoscience and Remote Sensing, forthcoming issue.

[12] I. Hajnsek, F. Kugler, S.-K. Lee, and K. P. Papathanassiou: *Tropical-Forest-Parameter Estimation by Means of Pol-InSAR: The INDREX-II Campaign*, IEEE Trans. Geoscience and Remote Sensing, vol. 47, no. 2, pp. 481-493, Feb. 2009.

[13] S.-K. Lee, F. Kugler, K. Papathanassiou, I. Hajnsek: *The Impact of Temporal Decorrelation Over Forest Terrain in Polarimetric SAR Interferometry*, Proc. of POLinSAR 2009, Jan. 2009.

[14] R. O. Schmidt: *Multiple Emitter Location and Signal Parameter Estimation*, Proc. RADC Estimation Workshop, Rome Air Development Center, N.Y., Oct. 1979.

[15] E. R. Ferrara, T. M. Parks: *Direction Finding with an Array of Antennas Having Diverse Polarizations*, IEEE Trans. on Antennas and Propagation, vol. 31, pp. 231-236, March 1983.

[16] F. Lombardini, M. Montanari, F. Gini: *Reflectivity Estimation for Multibaseline Interferometric Radar Imaging of Layover Extended Sources*, IEEE Trans. on Signal Processing, vol. 51, pp. 1508-1519, June 2003.