FOREST STRUCTURE FROM LONGER WAVELENGTH SARS

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1. INTRODUCTION

Synthetic Aperture Radar (SAR) Tomography (T-SAR) is a major tool for the analysis of scenarios characterized by a complex vertical structure, such as forested areas, by virtue of its capability to resolve multiple targets basing on multi-baseline observations [1]. The idea behind the concept of T-SAR is rather simple: the availability of multiple baselines offers the possibility to gather the backscattered echoes not only along the azimuth direction, but also along the cross-range direction, defined by the axis orthogonal to the Line Of Sight (LOS) and to the orbital track. Accordingly, the backscattered echoes can be focused not only in the slant range, azimuth plane, but in the whole 3D space. Unfortunately, many factors exist that hinder the straightforward application of this simple approach for the investigation of forested areas. In first place, the feasibility of tomographic analyses is mainly determined by temporal decorrelation and wave penetration. Temporal decorrelation represents a structural constraint of the acquisition system, for which the only countermeasure is to keep the repeat pass time as short as possible. Accordingly, stable structures such as trunks and branches offer more reliable information if the acquisitions are gathered at different times. Longer wavelength microwaves (P and L-Band) are able to penetrate the vegetation layer down to the ground, even in case of a dense forest . X-Band microwaves are reported to be able to penetrate into the vegetation layer as well, even though ground scattering is expected not to contribute to the received signal, unless in case of very sparse forests [2]. Both these factors suggest the use of longer wavelengths in the framework of a repeat pass spaceborne mission. Even at longer wavelengths, however, there are factors to be taken into account prior to performing Tomographic analyses: i) as the separation between the ground and the canopy is subject to the condition that either the ground or the canopy are present in the 3D resolution cell, it follows that the capability of T-SAR to separate the ground and the canopy depends not only on baseline aperture, but also on system bandwidth; ii) correct focusing is subject to the condition that phase contributions due to propagation disturbances, such as those induced by platform motion or atmospheric propagation, are properly compensated for [3], implying the need for a phase calibration step; iii) in presence of specular reflections Tomographic techniques do not suffice for the aim of discriminating ground and volume scattering [4].

This paper is intended to briefly discuss the three points above in light of the results recently achieved in the framework of the ESA campaign BioSAR 2008[1], basing on multi-baseline and multi-polarimetric SAR surveys at P-Band and L-Band acquired by DLR's airborne system E-SAR over the forested areas within the Krycklan catchment, Norther Sweden. The spaceborne case is also considered, basing on simulated BIOMASS data [5].

1.1. On the role of pulse bandwidth

It is a well known results in the framework of SAR Tomography that the vertical distribution of the backscattered power is obtained as the Fourier Transform of the interferometric coherences, under the assumption of data stationarity [6]. Considering only spatial decorrelation, the interferometric coherence can be decomposed in the product of two terms, one associated with volumetric decorrelation and the other with flat terrain decorrelation, [7]. The Fourier transform of the latter terms represents

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the tomographic point spread function arising from pulse bandwidth. In the case of the candidate Earth Explorer core mission BIOMASS, for instance, the resolution limit arising from pulse bandwidth may be assessed in about 20 m, due to the allowed pulse bandwidth of 6 MHz.

In single-baseline applications the interferometric coherence is often evaluated after Common Band Filtering (CBF). This operation compensates for flat terrain decorrelation, and thus appears as an attractive tool to enhance the vertical resolution. In the framework of multi-baseline T-SAR, CBF can be accounted for by replacing the sample estimate of the data covariance matrix with the matrix of the coherences of each common band filtered interferometric pair. It may be shown that this operation results in a resolution enhancement by a factor 2 [8]. Though, positive definitiveness of the interferogram matrix is not granted, resulting in potential algorithm instability or non-physical results. This phenomenon can be at least partly recovered by imposing positive definitiveness, for example through diagonal loading or water filling techniques [9].

1.2. Algebraic Synthesis

The Algebraic Synthesis (AS) technique has been proposed in [4] as a tool for decomposing ground and volume contributions basing on multi-baseline and multi-polarimetric SAR data. The core of the technique is the Sum of Kronecker Product Decomposition, which allows to find the best least square approximation of the data covariance matrix given the hypothesis of two Scattering Mechanisms. Then, the element of the decomposition are linearly combined in order to retrieve the interferometric coherences and polarimetric signatures associated with ground-only and volume-only contributions, under a constraint of physical validity. Such a procedure has been shown to be consistent with PolInSAR in the single-baseline case, whereas the availability of multiple baselines results in further rejection of non valid solutions [4].

1.3. Retrieval of the ground phases

The solution for ground scattering is retrieved by maximizing the corresponding coherence amplitudes in all interferograms under the constraint of physical validity [3], implying that ground contributions are the most stable within the data. Afterwards, ground phases are obtained through the Phase Linking algorithm [10]. Phase Calibration is then performed by compensating the data for the estimated ground phases.

2. RESULTS FROM BIOSAR 2008

Experimental results are here shown basing on the data-sets from the ESA campaign BioSAR 2008. Four data-sets have been collected by illuminating the forested areas in the Krycklan catchment, Northern Sweden, at P-Band and L-Band, with look directions South West (SW) and North East (NE). Data have been acquired by DLR's airborne system E-SAR. Each data-set is constituted of 6 fully polarimetric SLC images, with a nominal pulse bandwidth of 100 MHz. An additional data-set has been produced by DLR in order to simulate BioMass acquisitions [5]. It is here worth recalling the huge resolution loss with respect to the E-SAR system, due to the 6 MHz pulse bandwidth and the azimuth antenna length in the order of 20 m. Fourier vertical resolution varies from near to far range between 20 m and 80 m at P-Band, as a result of the large normal baseline variation along the imaged swath. It is worth noting that the choice of the baselines for this experiment has been conditioned by the necessity of simulating the BIOMASS system, and thus to use a much reduced bandwidth. Finally, LIDAR measurements have been made available by FOI.

Results are here discussed basing on the retrieved backscattered power distributions for a single azimuth cut, see figure (1). Due to the coarse Fourier vertical resolution, each of the panels to follow has been obtained through the Capon Spectral Estimator. The data covariance matrix has been evaluated by exploiting an averaging window as large as 60×60 m (ground range, azimuth), corresponding to about 500 independent looks in the 100 MHz case and 5 independent looks in the BIOMASS case. Each panel is presented in ground geometry. A further re-sampling operation has then been performed in order to flatten the topography, in such a way as to directly relate the vertical coordinate to the elevation of the targets above the ground. Each of the results has been obtained after compensating the data for the retrieved ground phases. Such operation has allowed the removal of residual phase contributions due to platform motion. Although resulting in a phase accuracy within $5° - 10°$, such contributions have been observed to result in focusing degradation, therefore witnessing the strict requirements of Tomographic applications [3].

Results relative to the 100 MHz case are shown in figure (1), left column. At P-Band, relevant contributions from the ground level below the forest are found in HV, resulting in the phase center to be almost ground-locked, suggesting specular volume reflections. In order to retrieve a suitable solution for describing the structure of volume contributions above the ground it has been decided to associate volume scattering with the largest scattering mechanism along the vertical direction. This solution will be hereinafter referred to as Largest Volume Solution (LVS)[2]. An important improvement is visible at P-Band, resulting in a better match with LIDAR.

The BIOMASS (6 MHz) case has been tackled by assuming the CBF-based approach depicted above. Results are shown in (1), right column. Despite the huge resolution unbalance, it may be appreciated that BIOMASS results are consistent with the full bandwidth case, thus demonstrating the possibility to infer structural information from low resolution data.

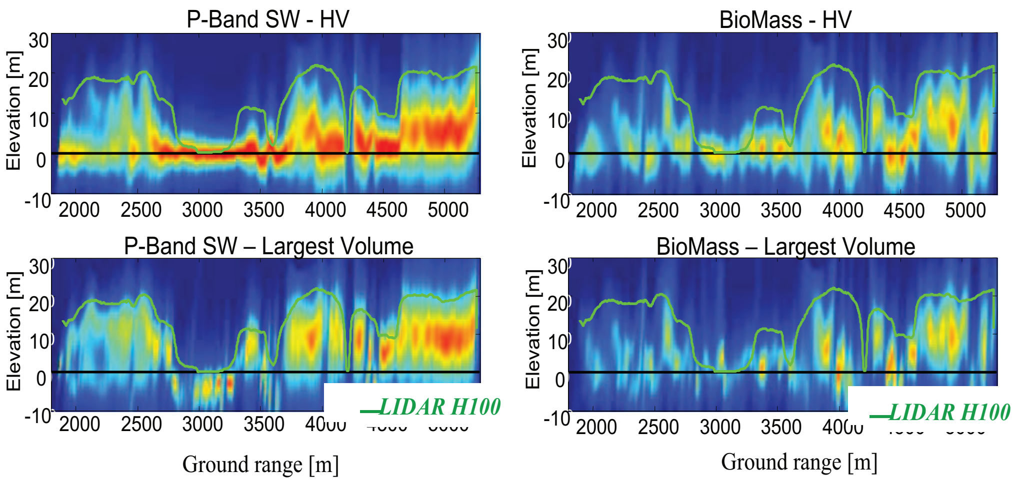

Fig. 1. Top left: Tomographic profiles for the HV channel; 100 MHz pulse bandwidth. Top right: Tomographic profiles for the HV channel; 6 MHz pulse bandwidth. Bottom left: Tomographic profiles for the LVS; 100 MHz pulse bandwidth. Bottom right: Tomographic profiles for the LVS; 6 MHz pulse bandwidth.

Forest height has been assessed through a direct investigation of the shape of the tomographic profiles. Despite its simplicity, this approach as resulted in quite a satisfactory agreement with LIDAR measurements, see Figure 2. In both the full bandwidth and the BIOMASS cases no significant bias is observed for forests higher than 10 m. Standard deviation has been assessed in about 3 m in the airborne case and 4 m in the BioMass case[3]. A large bias is present for forests below 10 m in the BIOMASS case, consistently with the theoretical limit.

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[2]See [11] for a discussion about the physical meaning of other solutions.

[3]Note that BIOMASS estimates have been smoothed by using a median filter as large as 1 hectare.

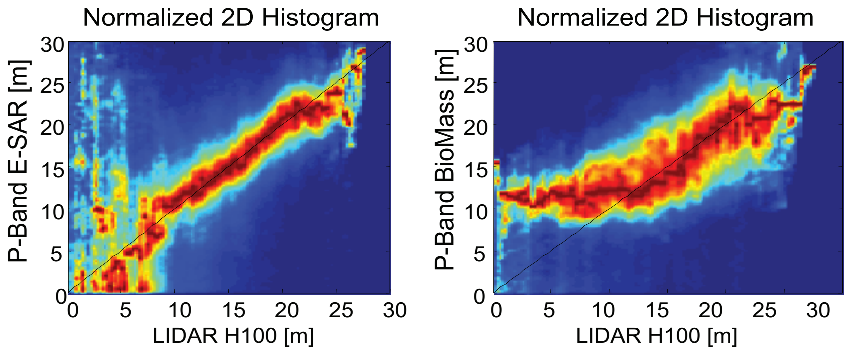

Fig. 2. Joint distribution of forest heights estimated by SAR and LIDAR. Left Panel: E-SAR. Right Panel: BioMass. Both panels have been normalized such that the maximum is unitary along each column.

4. REFERENCES

[1] A. Reigber and A. Moreira. First demonstration of airborne sar tomography using multibaseline l-band data. *IEEE Trans. on Geoscience and Remote Sensing*, pages 2142–2152, September 2000.

[2] I. Hajnsek, F. Kugler, Seung-Kuk Lee, and K.P. Papathanassiou. Tropical-forest-parameter estimation by means of polinsar: The indrex-ii campaign. *Geoscience and Remote Sensing, IEEE Transactions on*, 47(2):481–493, Feb. 2009.

[3] S. Tebaldini and F.Rocca. On the impact of propagation disturbances on sar tomography: Analysis and compensation. In *Radar Conference (RadarCon'09)*, Pasadena, US, 2009.

[4] S. Tebaldini. Algebraic synthesis of forest scenarios from multibaseline polinsar data. *Geoscience and Remote Sensing, IEEE Transactions on*, 47(12):4132–4142, Dec. 2009.

[5] F. Heliere, C.C. Lin, F. Fois, M. Davidson, A. Thompson, and P. Bensi. Biomass: A p-band sar earth explorer core mission candidate. In *Radar Conference, 2009 IEEE*, pages 1–6, May 2009.

[6] F. Gini, F. Lombardini, and M. Montanari. Layover solution in multibaseline sar interferometry. *Aerospace and Electronic Systems, IEEE Transactions on*, 38(4):1344–1356, Oct 2002.

[7] Howard A Zebker and John Villasenor. Decorrelation in interferometric radar echoes. *IEEE Transactions on Geoscience and Remote Sensing*, 30(5):950–959, sept 1992.

[8] S. Tebaldini. Multi-baseline sar imaging: Models and algorithms. Ph.d. thesis, Politecnico di Milano, Milan, Italy, 2009.

[9] Petre Stoica and Randolph L. Moses. *Introduction to Spectral Analysis*. Prentice-Hall, New Jersey, 1997.

[10] A. M. Guarnieri and S. Tebaldini. On the exploitation of target statistics for sar interferometry applications. *Geoscience and Remote Sensing, IEEE Transactions on*, 46(11):3436–3443, Nov. 2008.

[11] Stefano Tebaldini, Mauro Mariotti d'Alessandro, Andrea Monti Guarnieri, and Fabio Rocca. Polarimetric and structural properties of forest scenarios as imaged by longer wavelength sars. In *IGARSS 2010, submitted*, Honolulu, US, 2010.