POLARIMETRIC AND STRUCTURAL PROPERTIES OF FOREST SCENARIOS AS IMAGED BY LONGER WAVELENGTH SARS

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1. INTRODUCTION

SAR data gathered from forested areas collect contributions coming from the vegetation layer, from the ground below and from other scattering mechanisms (SMs). Multi-baseline (MB) data allow a tomographic analysis thus retrieving information about the vertical structure of the target as shown in [1]. Multi-polarimetric (MP) acquisitions enrich the data. The joint exploitation of Multi-polarimetric Multi-baseline (MPMB) data suggests the possibility of linking the estimations of the vertical structure of different SMs with their polarimetric signature. A formal framework in which this task can be accomplished is provided by the Algebraic Synthesis (AS) technique, which is based on the assumption of the Sum of Kronecker Products (SKP) structure [2]. By assuming the presence of two SMs (for example ground and volume scattering), the SKP assumption leads to a cross dependence between polarimetric and structure covariance matrices, in that ground structure is shown to be related to volume polarimetry, and dually volume structure is shown to be related to ground polarimetry. The aim of this paper is to investigate the implications of this cross relation.

2. ALGEBRAIC SYNTHESIS

The AS technique proposed in [2], which the reader is referred to for proofs and discussions, relies on three general hypotheses: i) statistical uncorrelation of the different SMs, such as ground, volume, and ground–trunk scattering; ii) invariance of structural parameters (such as volume extinction and top height, for example) with respect to polarization; iii) data stationarity across different tracks, which may be expected to hold if events like fires, frosts, deforestation do not occur during the acquisition campaign. It follows after the three hypotheses above that the covariance matrix of the MPMB data is structured like a SKP:

$$\mathbf{W} = \sum_{k}^{K} \mathbf{C}_k \otimes \mathbf{R}_k \tag{1}$$

where: K is the total number of SMs that contribute to the SAR signal; $\mathbf{C}_k$ is the polarimetric covariance (among different polarizations) matrix associated with the $k-th$ SM $[3 \times 3]$; $\mathbf{R}_k$ is the interferometric covariance matrix (among different tracks) associated with the $k-th$ SM $[N \times N]$. Hereinafter $\mathbf{C}_k$ will be referred to as *polarimetric signatures*, whereas matrices $\mathbf{R}_k$ will be referred to as *structure matrices*, as they carry the information about the vertical structure of the targets. The key to the exploitation of the SKP structure is the result proven by Van Loan and Pitsianis [3], after which any matrix can be decomposed as:

$$\mathbf{W} = \sum_{k}^{K} \lambda_k \widetilde{\mathbf{C}}_k \otimes \widetilde{\mathbf{R}}_k \tag{2}$$

where $\widetilde{\mathbf{C}}_k$, $\widetilde{\mathbf{R}}_k$ are two sets of orthonormal matrices which are easily derived from $\mathbf{W}$ through an SVD-like analysis and λ_k is a set of weighting factors, conventionally sorted in descending order.

The expression shown by the equation (2) follows by constraining matrix orthogonality, so that it represents a mathematical decomposition rather than a physical one; because of this, the matrices $\widetilde{\mathbf{C}}_k$, $\widetilde{\mathbf{R}}_k$ cannot be associated directly with the SMs, but they rather identify the subspaces in which the covariance matrices associated with the different SMs lie. Still, subspace identification allows to establish a direct relationship between the covariance matrices associated with the SMs and the matrices which appear in equation (2). It is shown in [2] that this relationship is linear, invertible, and defined by exactly $K(K-1)$ real numbers. As discussed in [2], two main phase centers may be expected within the data. The first is ground locked and may be due to a direct Bragg surface backscatter or to a double bounce. The second is at canopy height and is due to the direct canopy layer backscatter. Basing on such assumptions only the first two terms of the summation (2) are kept, therefore resulting in two bi-dimensional signal subspaces, spanned by matrices $\widetilde{\mathbf{R}}_1, \widetilde{\mathbf{R}}_2$ and $\widetilde{\mathbf{C}}_1, \widetilde{\mathbf{C}}_2$, respectively. Such an operation leads to a great simplification of the problem of determining the matrices associated with the SMs, since the degrees of freedom are reduced to just two, meaning that all possible solutions may be represented by two parameters only [2]. Therefore, it is possible to algebraically synthesize ground and volume scattering by finding the correct value of such two parameters. Yet, it should be remarked that the choice of considering two SMs relies on the hypothesis that contributions from others SMs are negligible. Otherwise, the estimated structures and polarimetric matrices depend on a mixture of those mechanisms which are actually present. The parametrization for two SMs is expressed by:

$$\begin{aligned}
\mathbf{R}_g &= a\widetilde{\mathbf{R}}_1 + (1-a)\,\widetilde{\mathbf{R}}_2 \\
\mathbf{R}_v &= b\widetilde{\mathbf{R}}_1 + (1-b)\,\widetilde{\mathbf{R}}_2 \\
\mathbf{C}_g &= \frac{1}{a-b}\left((1-b)\,\widetilde{\mathbf{C}}_1 - b\widetilde{\mathbf{C}}_2\right) \\
\mathbf{C}_v &= \frac{1}{a-b}\left(-(1-a)\,\widetilde{\mathbf{C}}_1 + a\widetilde{\mathbf{C}}_2\right)
\end{aligned} \tag{3}$$

where the subscript g refers to ground scattering whereas the subscript v the volume scattering, and (a, b) are the (real valued) parameters needed to represent the solutions. Equations (3) shows that, apart from a scaling factor, $\mathbf{R}_g$ and $\mathbf{C}_v$ share the same dependence on the parameter a. Accordingly, constraining a particular polarimetry of the volume within the signal subspace corresponds to setting a certain structure of the ground, and vice-versa. Dually, the parameter b connects ground polarimetry with volume structure.

3. RESULTS FROM BIOSAR 2008

Experimental results are here reported basing on the P-Band data set collected in Krycklan (northern Sweden) in October 2008 during the ESA campaign BioSAR 2008. The data set is composed by 6 fully polarimetric acquisitions characterized by a maximum horizontal baseline of 40m. Fourier vertical resolution varies from near to far range between 20 m and 80 m, as a result of the large normal baseline variation along the imaged swath.

The analyses to follow are intended to show the variation of the polarimetric signatures and structure matrices with respect to parameters (a, b), according to equation (3). We remark that the choice of the parameters (a, b) does affect the resulting polarimetric signatures and structure matrices, but not the Sum of their Kronecker Products, so that every solution results in exactly the same data covariance matrix. Furthermore, only the values of (a, b) corresponding to positive definite polarimetric signatures and structure matrices have been considered, in such a way as to ensure the physical validity of the solution in any case [2].

The results to follow are referred to a single location in the near range area within the imaged scene, in such a way as to provide a straightforward interpretation by showing planar (rather than 3D) graphs. However, the following results can be largely generalized to vast part of the imaged scene. The data covariance matrix has been evaluated by exploiting about 500 independent looks, corresponding to an estimation window of about 60×60 m, in such a way as to minimize coherence bias and dispersion. Finally, the area under analysis is characterized by a vegetation as high as 15 m, according to LIDAR measurements. A first important result relative to the SKP Decomposition is that the approximation error committed by taking only two Kronecker products has turned out to be lower than 10%, after which it follows that the assumption of two SMs is well justified. Still, no information is provided about the physical interpretation of such two SMs, as the associated polarimetric signatures and structure matrices depend on the choice of the parameters (a, b). The analysis of the resulting polarimetric signatures is reported in figure (1). The left panel shows the variation of the polarimetric signatures in the alpha-entropy (α, H) plane, obtained by applying the Cloude-Pottier decomposition [4]. The right panel, instead, reports the variation of the co-polar coherence. The analysis of the resulting structure matrices is reported in figure (2). The structure matrices have been analyzed by evaluating the associated Tomographic profiles by applying the Capon spectral estimator [5]. Observing figure (2) it may

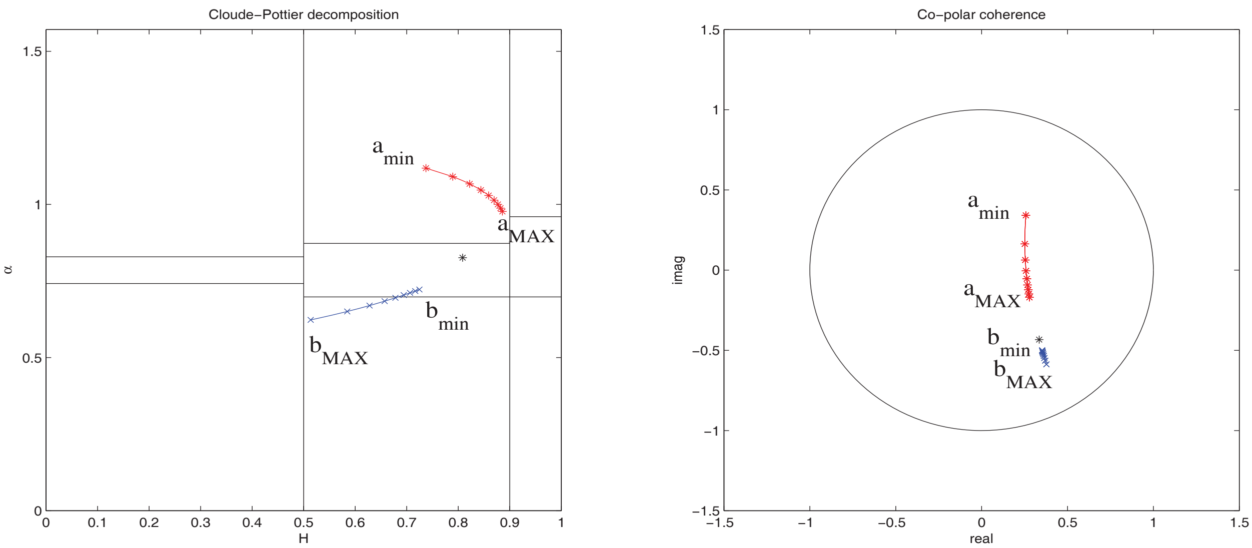

Fig. 1. Polarimetric analysis. Left panel: Cloude-Pottier decomposition of volume (red asterisks) and ground (blue asterisks) polarimetric signature corresponding to different values of the parameters a and b, respectively. The black asterisk is relative to the original (i.e. not decomposed) data. Right panel: co-polar coherence for volume (red asterisks) and ground (blue asterisks) polarimetric signature corresponding to different values of the parameters a and b, respectively. The black asterisk is relative to the original (i.e. not decomposed) data.

be appreciated that the ground structure (left panel) is well resolved, and gets sharper as the entropy of the volume polarimetry increases. Volume structure (right panel) undergoes a dramatic change by varying the parameter b: the backscattered power is densely concentrated about forest top height in correspondence with the highest entropy ground polarimetry, whereas it is more dispersed as the parameter b increases, and gathers ground locked contributions by forcing low entropy ground polarimetry (largest b). In other words, assuming low entropy ground contributions methodically results in presence of ground-locked volume contributions. Such a behavior indicates the presence of not negligible ground locked contributions characterized by a volume-like (i.e.: entropic) polarimetry, therefore suggesting the presence of specular contributions from ground-volume interactions. Finally, similar results have been obtained by processing L-band data from BioSAR 2008 and P-band data set collected in Remningstorp (Sweden) during the ESA campaign BioSAR 2007. Further results will be shown in the full paper.

4. ACKNOWLEDGMENT

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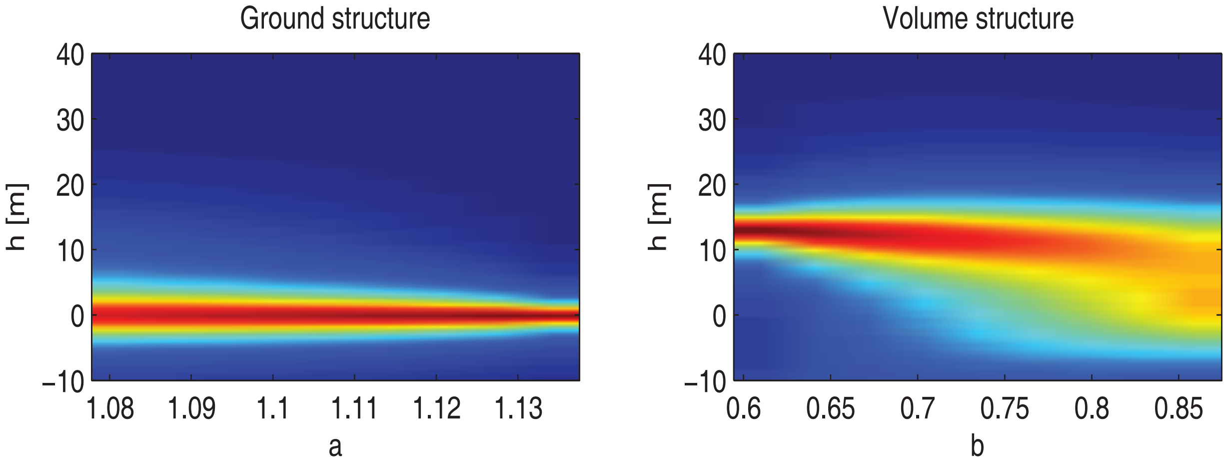

Fig. 2. Tomographic analysis. Left panel: Vertical structure associated with ground scattering for different values of the parameters a. Right panel: Vertical structure associated with volume scattering for different values of the parameters b.

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