SPATIAL AND TEMPORAL CHARACTERIZATION OF AGRICULTURAL CROP VOLUMES BY MEANS OF POLARIMETRIC SAR TOMOGRAPHY AT C-BAND

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ABSTRACT

In this paper, agricultural crop volumes are analysed using (polarimetric) tomographic SAR methodologies. A procedure for the separation of the ground and volume multibaseline coherences is proposed. This separation is used in particular to investigate the polarization dependency of the vegetation vertical structure in order to get first insights about orientation effects. This analysis has been carried out for different crops and on different development stages. The presented results have been obtained by processing a multibaseline fully polarimetric data set purposely acquired at C-band by the DLR's airborne sensor F-SAR in 2014.

***Index Terms*—** Synthetic aperture radar, tomography, polarimetry, agricultural crops.

1. INTRODUCTION

Synthetic aperture radar (SAR) data interpretation and modelling of agricultural vegetation is challenging since it depends on both the crop species and its development stage within the phenological cycle. In addition, possible frequency-dependent orientation effects in the vegetation volume lead to an increased scattering complexity, e.g. compared to forests [1, 2]. Such effects are difficult to be characterized since they depend on the species under study and but the development stage. For instance, it could be possible that the vegetation volume of a certain species behaves like an oriented volume in an early development stage and changes its structural behaviour to a random volume in a later phenological stage.

The application of (polarimetric) tomographic SAR techniques to multipolarimetric-multibaseline (MPMB) data sets enables the analysis of the profile of the backscattered power along height and hence the 3-D characterization of the scattering mechanisms occurring in vegetated fields. One important issue is the separation of the ground and volume scattering contributions by estimating their multibaseline coherences in each polarization channel. Once the volume coherences are obtained, the variation of the related vertical power profile across the polarization channels allows to get insights on orientation effects.This knowledge is important for instance to assess the validity of coherent scattering models used to interpret and to invert polarimetric interferometric SAR data for retrieving physical variables, such as vegetation height and soil moisture.

In this work, a simple methodology based on the algorithm presented in [3] is proposed and used to separate ground and volume coherences independently of the orientation degree. Afterwards, the obtained oriented volume (OV) solution is compared to the random volume (RV) solution, which can be achieved by exploiting an algebraic procedure [4]. Finally, this comparison has also been carried out by considering only the vegetation scattering center heights. Indeed, center heights can be estimated with higher accuracy and less complexity compared to a full polarimetric interferometric characterization, at the cost of a non-negligible reduction of the available structure information. Experimental results have been obtained by processing a data set at C-band acquired by the DLR's airborne sensor F-SAR for different dates in the phenological cycle.

2. VOLUME STRUCTURE CHARACTERIZATION

For distributed scatterers like volumes, the MPMB complex data vectors $\{\mathbf{y}(n)\}_{n=1}^{N}$ in a N-dimensional multilook cell can be assumed to be represented by a multidimensional, complex-valued, zero-mean Gaussian process. As a consequence, they can be fully described by the $(3K \times 3K)$-dimensional MPMB covariance matrix $\mathbf{R}$, being K the number of flight tracks. $\mathbf{R}$, in turn, can be expressed as the sum of the ground and volume MPMB covariance matrices $\mathbf{R}_G$ and $\mathbf{R}_V$ respectively.

In order to estimate $\mathbf{R}_V$, a parametric model for the vertical power distribution needs to be assumed, as non-parametric methods suffer from resolution problems especially in low vegetation like crops. However, a detailed model would require an inversion in a highly dimensional space. To counteract this issue, here we employ a sub-optimal, yet effective procedure. The ground is assumed to be shaped as a Dirac-δ. Therefore, its MPMB backscattering signal can be reconstructed after its height and complex reflectivities are estimated for each pixel in the multilook cell. In a second step, the ground signal can be subtracted from $\{\mathbf{y}(n)\}_{n=1}^{N}$ in order obtain the volume-only MPMB vectors $\{\mathbf{y}_V(n)\}_{n=1}^N$. The estimation of ground height and complex reflectivities is carried out by applying the methodology described in [3] to each polarization. In addition, this algorithm yields the scattering center height of the volume. In the OV case one volume center height for each polarization is retrieved. The algorithm has also been extended to the RV case, in which only one volume center height is estimated.

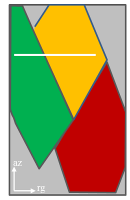
The availability of $\{\mathbf{y}_V(n)\}_{n=1}^N$ allows to estimate $\mathbf{R}_V$. Again, in the OV case, $\mathbf{R}_V^{(OV)}$ is just the sample covariance matrix estimate. Conversely, in the RV case, $\mathbf{R}_V^{(RV)}$ is obtained by applying the Kronecker product model fitting in [4] limited to one scattering mechanism.

3. EXPERIMENTAL RESULTS

The experimental dataset was acquired by the DLR airborne sensor F-SAR in 2014 over an agricultural area near Wallerfing (South Germany) at different dates in the phenological cycle. The baselines were planned to be big enough to ensure the high vertical resolution required to image low vegetation heights and in a sufficient number to allow accurate inversion.

Ground measurements of soil parameters, vegetation height and vegetation water content (VWC) are available for the acquisition dates. This study focuses on a small patch (200 m in range, 300 m in azimuth) of the SAR scene including three different species, i.e. wheat, corn and barley, as schematically shown in Fig. 1(a). Four acquistion dates have been chosen for investigation, i.e. June 12, June 18, July 3, July 24, corresponding to different development stages. In Fig. 1(b) the vegetation heights for the individual dates are shown. The heights of wheat and barley are similar in all the dates, but barley is more developed than wheat and already harvested on the last date. Due to the ripening process, the VWC in the wheat decreases from 70% to 30%, and the height reduces slightly from the first to the last date. The barley shows a similar behaviour with a decrease of VWC from 65% to 40% between the first and the third date. In contrast, the corn plants grow from 0.7 m to full height (3 m) during the study period. The VWC stays on a high level of 90% to 95% throughout the dates and the final development stage is not reached by the last analysed date. However, the morphology of the corn plants changes completely during the time period under study.

In the following, results for the MPMB SAR acquisitions at C-band for the four dates introduced above are presented. The MPMB data consists of 9 parallel tracks per acquisition date with exception of June 18, where only 8 tracks have been acquired. The Rayleigh resolution in correspondence of the position of the patch in the scene is approximately 0.8 m. The separation procedure described in section 2 is demonstrated for the first and the last date for one range line in Section 3.1. Then, the two characterizations for the volume coherences are compared with respect to the different species and acquisition dates in Section 3.2.



(a) Patch.

	corn	wheat	barley
June 12	70 cm	95 cm	85 cm
June 18	90 cm	90 cm	80 cm
July 3	150 cm	90 cm	80 cm
July 24	300 cm	80 cm	----

(b) Vegetation heights.

Fig. 1: Patch under study. The white line indicates position of the range slice used for visualisation.

3.1. Retrieval of volume contribution

Fig. 2 shows the reflectivity profiles in the range-height plane for the azimuth line shown in Fig. 1 obtained with the Fourier beamformer (hence without any model assumption) in VV polarization for June 12 and July 24. The powers are normalized to the peak and obtained using a multi-look cell of 3.5×3.5 m, corresponding to approximately 50 independent looks. The superimposed white line is the Lidar ground DTM. Wheat and corn can be distinguished and the extension of the vertical profile in height matches the heights measured on ground on the dates of acquisition. For both species, the vertical profiles change dramatically from one date to the other. Regarding wheat, on June 12 the most powerful contribution is located mainly close to the vegetation top and it moves to the ground in correspondence to the tractor tracks. On July 24, instead, the profiles look more extended in height and the strongest peaks are close to the ground. This sudden change between the two dates might be due to the loss in vegetation water content leading to an electromagnetically more transparent vegetation volume. Concerning the corn field, the very low vegetation is difficult to be identified from the Fourier profiles on June 12. In comparison, the height increase by more than 2 m in July 24 is apparent from the reflectivity profiles. Given the same height Rayleigh resolution this increase of height allows also to distinguish the changing plant morphologies at different range coordinates, in contrast to the more homogeneous scattering of wheat.

The retrieved results for the volume contribution after the removal of the ground backscattering in the OV case are shown in Fig. 3. For the sake of simplicity, here only the tomographic slices in VV are plotted. For both species, the isolated volume power distributions follow the variation already observed in the original reflectivity profiles of Fig. 2; distinguishable features inside the volume are preserved. It is worth commenting that, in general, for lower plant heights (i.e. with heights below or in the order of the Rayleigh resolution) very small variations can be observed between the shapes of the volumes of different species. This may suggest

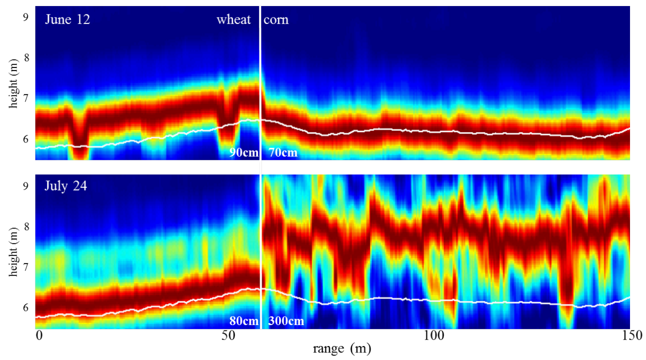


Fig. 2: Fourier slices for the two dates in VV-polarization normalized to the peak. White line: Lidar DTM.

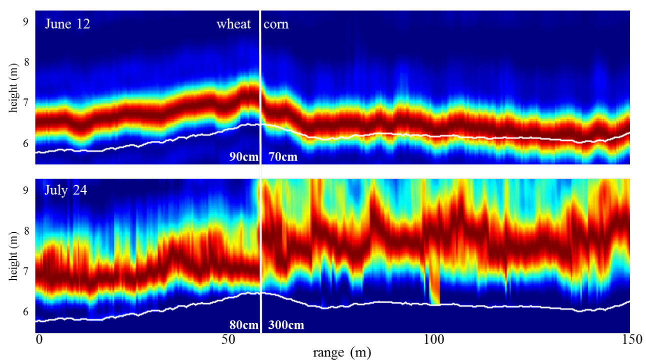


Fig. 3: Fourier volume slices for the two dates in VV-polarization normalized to the peak. White line: Lidar DTM.

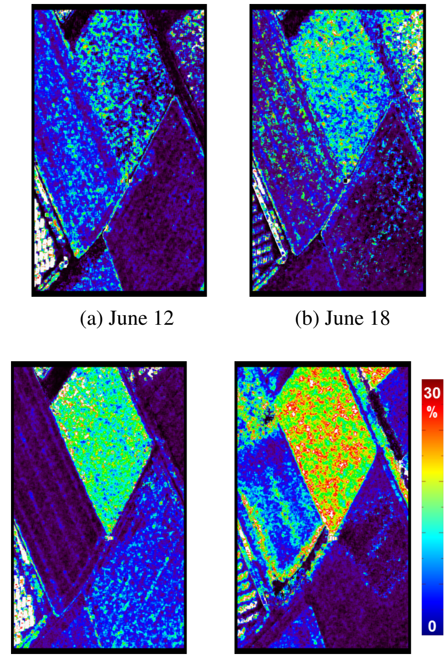
that those volumes could be well represented by their scattering center height. In contrast, taller plants (e.g., the corn on the last date) shows a more dynamic volume contribution representing the structural variation. In this case, a single scattering center may not be sufficient to approximate the volume structure.

3.2. Volume characterization

The characterization of the vegetation volume regarding orientation effects is assessed by means of two measures. Specifically, the deviation from an oriented volume to a random volume model is quantified in terms of the normalized distance χ_{mod}:

$$\chi_{mod} = \frac{\|\mathbf{R}_V^{(RV)} - \mathbf{R}_V^{(OV)}\|_F}{\|\mathbf{R}_V^{(RV)}\|_F}, \quad (1)$$

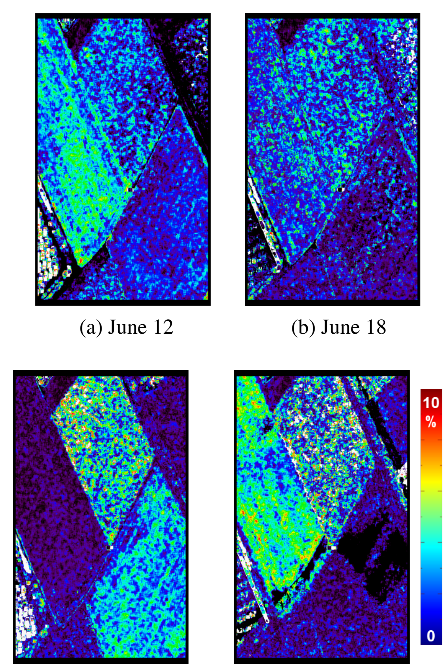
where $\| \, . \, \|_F$ indicates the Frobenius norm. In order to understand which degree of complexity is necessary to retrieve information about orientation effects, a second measure χ_{pc}



(a) June 12 (b) June 18

(c) July 3 (d) July 24

Fig. 4: Maps of χ_{mod} (relative deviation of an OV assumption from the RV model calculated with the Frobenius norm) for the different acquisitions.



(a) June 12 (b) June 18

(c) July 3 (d) July 24

Fig. 5: Maps of χ_{pc} (relative deviation of the polarimetric phase centers with respect to the volume phase center assuming a RV).

based on the estimated phase centers is introduced. χ_{pc} has been calculated as the maximum difference between the volume scattering center heights in the different polarization channels normalised by the common height provided by a random volume assumption. The results for χ_{mod} and χ_{pc} are reported in percentage for the dates under analysis in Fig. 4 and Fig. 5, respectively. It is possible to observe that:

- For the wheat, the average χ_{mod} is low on June 12 (around 5%) and progressively decreases until July 3. On July 24, χ_{mod} increases to 10%. This behaviour may suggest that a higher degree of orientation is exhibited just before harvesting, however the difference to a random volume could still be neglected. A very similar trend is shown by χ_{pc}. As already commented in Section 3.1), this correspondence might be an effect of the low vegetation height compared to the tomographic resolution.

- For the barley, χ_{mod} is very similar for the first two dates and slightly increases on July 3. On July 24, the vegetation is already harvested. Like wheat, the temporal variations of χ_{pc} are consistent with the ones of χ_{mod}, maybe again due to the low height resolution.

- For the corn, substantial differences between χ_{mod} and χ_{pc} can be observed. While χ_{pc} shows limited changes, χ_{mod} is able to describe the increase of the deviation from a RV model towards an OV with the plant development. χ_{mod} reaches the 25% on July 24, starting from the 10% on June 12, denoting structural changes at a larger extent. Surely, this fact is positively influenced by the larger plant heights compared to the other species.

As a final comment, it is worth pointing out that the increase in orientation for barley and wheat before harvesting is in correspondence to the biggest losses of VWC (see comments at the beginning of Section 3). Notwithstanding the mentioned limitations in the tomographic resolution, this trend might be explained remembering that lower VWC means higher penetration, therefore sensitivity to a larger amount of vegetation components, as shown in Fig. 3.

4. CONCLUSIONS

In this work a simple procedure to separate ground and volume scattering has been proposed and tested with C-band data. The proposed algorithm only needs the knowledge of the ground height. If not available a priori, it can reliably be estimated from the data. An analysis of the retrieved volume-only reflectivity profiles suggested that the knowledge of the volume scattering center height can be enough to characterize the vegetation vertical structure in the case in which the vegetation height is comparable to the tomographic resolution.

It has also been shown that the availability of the volume only coherences can be used to evaluate the significance of orientation effects. First results allow to conclude that changes in the orientation characteristics are present, but small for low vegetation heights. Larger changes have been observed in correspondence of lower VWC, that might be explained with a higher penetration. An orientation descriptor for the variation of the scattering center heights leads to similar conclusions. For higher vegetation, the differences of the volume descriptions provided much more information, and they increase with plant development. However, the same changes are mapped at a much lower extent by the scattering center heights. In the future, beyond carrying out a more detailed analysis of the results, more dates will be evaluated in order to map a complete phenological cycle for each species. In addition, the influence of frequency (L- and X-band) and of the spatial scale (i.e. multilook) on the volume characterization will be investigated.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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