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Forest parameter retrieval from P band data: Pol- and PolIn-SAR

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Abstract. A polarimetric and PolInSAR (Polarimetric Interferometric) analysis has been conducted on the Nezer forest (Southern France) at L and P band on high resolution SAR data acquired with the ONERA RAMSES system in January 2004.
The dataset was investigated for its potential for retrieval of forest parameters from SAR data using three different techniques:

- Radiometric inversion from the cross-polarized term,
- Polarimetric analysis based on the anisotropy parameter
- PolInSAR inversion based on the random-volume over ground model

This paper concentrates on polarimetric and PolInSAR inversion. The observed linear regression between anisotropy and vegetation height is inverted and provides a RMS error of the order of 2m. This technique displays no saturation at P band.
The PolInSAR data behaviour over the forest is consistent with the RVoG model. The standard inversion described in the literature is modified to account for the higher expected penetration at P band, by selecting a given extinction coefficient or a range of extinction coefficients. The inversion results are precise to within 1.2m. When the baseline is properly selected, the extinction coefficient is a weak parameter. Similar inversion results can be obtained by using only two polarimetric channels either (HH, VV) or (HH,HV) selected as they provide the largest variation in interferometric height.

Palavras-chave: remote sensing, forestry, low-frequency radar, biomass

1. Introduction

The Nezer forest is constituted by parcels of pine trees, which are characterised by different tree ages. It is an artificial forest managed by the French agronomic research center (INRA), providing an accurate and extensive ground truth.

In this paper, we present the data set, we then propose a polarimetric inversion technique based on the anisotropy parameter and finally the potential of PolInSAR data for vegetationcharacterisation is presented.

In an earlier paper [1], we have presented the calibration procedure and the radiometric analysis performed at L and P bands.

2. The dataset

This site is a well monitored forest with uniform rectangular plots of pine trees.[2]. A large variety of tree heights and age can be found. The forest is maintained and has little undergrowth. The topography is almost flat.

In **Figure 1**, the amplitude image and the interferometric complex coherence (argument and amplitude) for a P band couple are shown. In the phase image, the forest plots appear significantly higher than the bare surfaces.

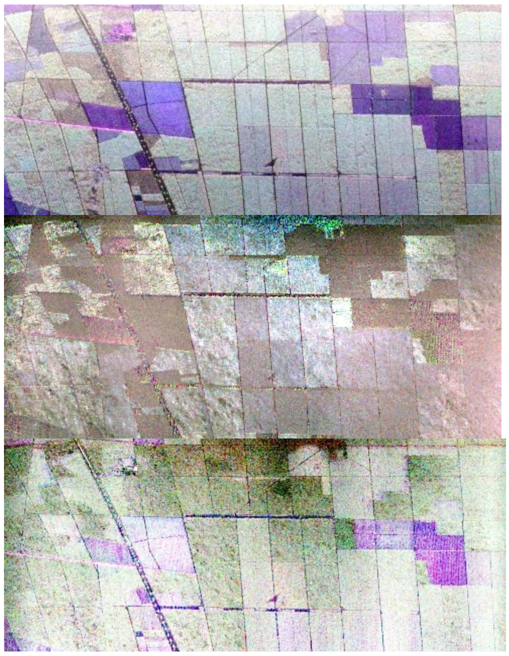

Figure 1: P-Band PolInSAR data set with the Sigma0 image (top), the interferometric phase (middle), the interferometric coherence (bottom) coded with HH in red, HV in green and VV in blue

3. Polarimetric inversion

The different polarimetric parameters as proposed by Cloude and Pottier [3] are analysed and their potential for biomass inversion is assessed. One particular parameter appeared extremely promising : the anisotropy.

Note that the L-band data presents a saturation level, whereas the P band analysis shows no such behaviour with a steady decrease in anisotropy as the age or height increases.

The full inversion was performed based on the relationship obtained by fitting a straight line through the points from **Figure 2** at P band [5]. The invesion results are presented in **Figure 3**, with a RMS error in height of the order of 2m.

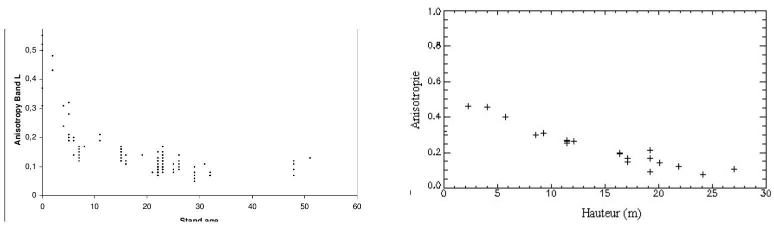

Figure 2 Anisotropy versus height at L band (top) and P band (bottom).

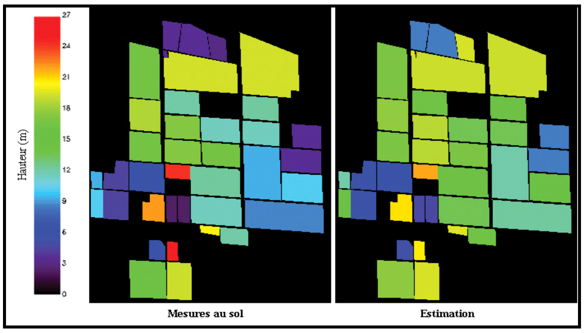

Figure 3: Ground measurements compared with inverted forest height map from the anisotropy relation at P band

The anisotropy parameter is an extremely interesting lead and needs to be fully evaluated on a large range of biome to access its true characterization potential. The studies to be conducted will have to explore the effect of slope, the effect of species and the behavior of such an indicator for denser forest. Furthermore, the anisotropy is a parameter which is extremely sensitive to thermal noise level as it is formed by using the second and the third eigenvalues obtained with the Cloude decomposition. The usual measure of SNR (signal to noise ratio) relies on the backscatter level in one channel. An analysis on the forest data indicates that the third eigenvalue is often as much as 8dB below the first one. In order to provide a meaningful measure of the anisotropy, i.e., of the third eigenvalue, we conclude that the $NE\sigma_0$ over the co-pol channel must be at least 3dB below the level of the third eigenvalue, implying a SNR of at least 12dB.

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4. PolInSAR dataset

Before any advanced analysis, it is essential to validate the PolInSAR calibration. This is done by analysing a bare surface.

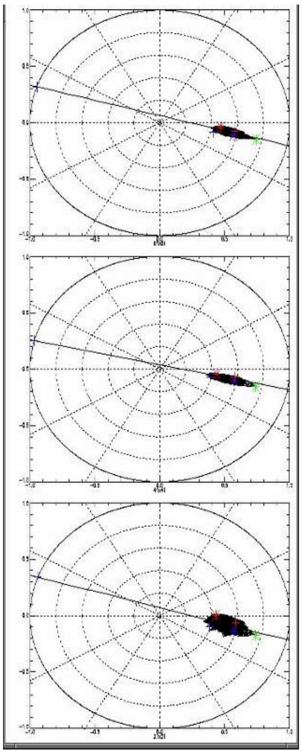

Figure 4: Coherency region corresponding to a bare surface for three window size 61x61; 41x41 and 21x21

As seen in **Figure 4**, the shape of the coherency regions are radial indicating a consistent height information between the different polarisations. As expected, the standard deviation of the phase varies with the coherence and the number of independent samples in the window following the formula:

$$\sigma_{\phi}^{2} = \frac{1}{2N} \frac{1-|\gamma|^{2}}{|\gamma|^{2}}$$

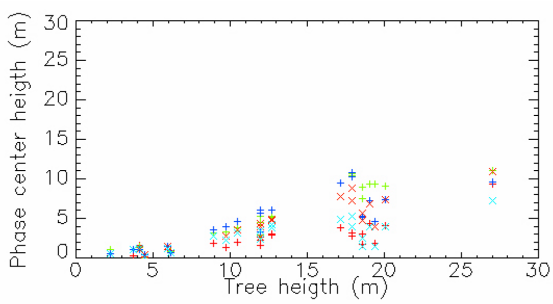

Figure 5: Polarimetric phase centers heights for different pine parcel heights. Color coding: HH, HV, VV HH+VV, HH-VV

Fig. 5. displays the different polarimetric phase center heights as a function of the forest height. The forest height is obtained from age with an allometric relation adapted to the Nezer

forest only [2]. We primarily observe that for forests higher than 6m, the polarimetric phase centers start to be widely dispersed.

Fig. 5. shows also that the relative positions of the polarimetric phase centers depend on the forest height and that the vertical position variations in function of the forest height appears to be continuous. This continuous vertical migration of the polarimetric phase centers during the forest growing has two origins. The first one is the height and size increase of the scattering objects (trunks, branches…) inducing a global elevation of the phase centres. This behaviour is observed for all the polarisation on Fig. 5. for the parcels lower than 15m. The second one is the creation or removal of coherent sources due to the size and geometry changes of these scattering objects. For example, it appears clearly on Fig. 5 that the double bounce phase centre (associated with HH-VV polarisation) becomes the lowest one for highest forests. Indeed, the DBH (diameter at breast height) increases when the forest becomes older. It induces an augmentation of the dihedral formed by the intersection of trunk and soil surface. Consequently, a double bounce scattering source appears at this level or becomes stronger, leading to a variation of the corresponding phase center height.

4. RvoG model and P band

In the Random Volume Over Ground model [4] the signal backscattered from the forest is modelled as the combination of a ground contribution and a volume only contribution. The ground contribution can be the surface scattering or double bounce effect linked to the tree trunks. The associated interferometric coherence is assumed to be one (no decorrelation). The interferometric coherence associated with the volume contribution is shown to be polarization independent (under the hypothesis that the attenuation is polarization independent) even though the corresponding backscattering depends on polarization. When both contributions are present (they are assumed independent), the corresponding interferometric coherence γ_T can be written as:

$$\gamma_T = f(\gamma_g, \gamma_v) = \frac{P_g}{P_g + P_v}\gamma_g + \frac{P_v}{P_g + P_v}\gamma_v$$

where γ_v is the volume only coherence and P_g, P_v are the power of the ground scattering (including the attenuation through the canopy) and the power return from the volume. The powers are depending on polarisation and the total coherence is simply the weighed average of the two coherences. The locus of the interferometric coherence when the polarisation varies, is close to a line segment (see **figure 6**) between the point B (ground) and A (volume only).

The inversion scheme as described by Cloude is as followed. (1) identify the line AB (2) Choose between the two intersection points the one associated with the ground $e^{i\varphi_0}$ (3) select the furthest point on the ellipse as $e^{i\varphi_0}\gamma_V$ (4) from γ_v, invert the vegetation height and attenuation.

$$\gamma_V = \frac{\int_{h_v}^{0} e^{uz}dz}{\int_{h_v}^{0} e^{vz}dz} = \frac{v}{u}\frac{\left[e^{uz}\right]_0^{h_v}}{\left[e^{vz}\right]_0^{h_v}} \text{ with } u = 2\frac{\sigma_x}{\cos\theta} + ik_z \text{ and } v = 2\frac{\sigma_x}{\cos\theta}$$

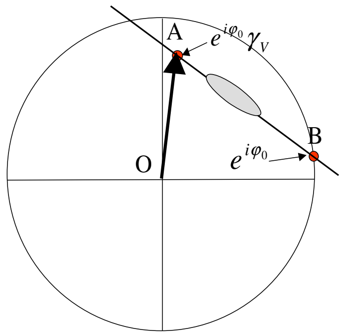

Figure 6: RvoG behavior. The grey ellipse is the one corresponding to the position of the interferometric coherence as the polarization varies

The parameter inversion is usually performed via a look-up table (LUT). In order for this scheme to be successful, one must be certain that **the volume only coherence** is observed for one polarisation. This can be true at X or C band but becomes more questionable as the frequency decreases. At P band, this is certainly rarely the case. On the complex unitary circle, the pseudo-ellipse will shift towards the ground point as penetration increases. **Figure 7** is an illustration of what can happen at P Band whenthe ellipse doesn't contain point A associated with the volume only contribution.

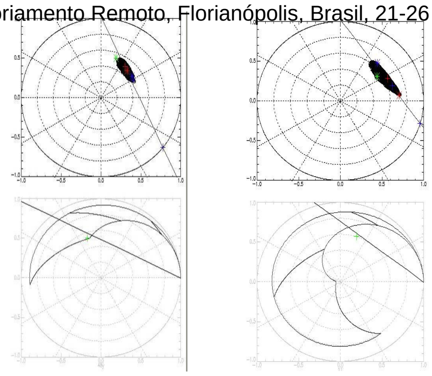

Figure 7: The complex unitary circle for two forest plots (age 48 on the left, age 11 on the right). The LUT is represented in the bottom figures and the green cross is the highest observed point.

For the young forest (right plots) and if we assume that the RvoG model is valid, we can conclude that the volume only contribution is not observed as the extreme (or highest) phase centre (green cross) in **Figure 7** is not inside the LUT (look-up table) area. In the following paragraphs, we describe how the initial procedure was modified for lower frequency acquisition.

4. Adapted inversion scheme

4.1 Straighforward approach

If the model is applicable, we know that the volume only coherence must lie on the fitted line between the last observed coherence and the circle. We then assume a given attenuation coefficient; for P band we chose 0.3dB/m from the analysis of a trihedral under canopy. The volume only contribution is determined as the intersection of the fitted line and the curve corresponding to the theoretical volume coherence associated with this attenuation coefficient. This position is then inverted for height.

In **Figure 8**, we present the corresponding inversion results. The lower vegetation are not inverted properly, certainly because little interaction occurs between the EM waves and the canopy at P band. The inverted height is extremely stable within a forest plot as can be seen in **Figure 9** with an observed variation of the order of 1m. The same approach was also followed for other attenuation coefficients ranging from 0.1 to 0.5 dB/m. The sensitivity of the inversion to the attenuation coefficient was found to be weak in our data set, certainly because for the studied baseline,.

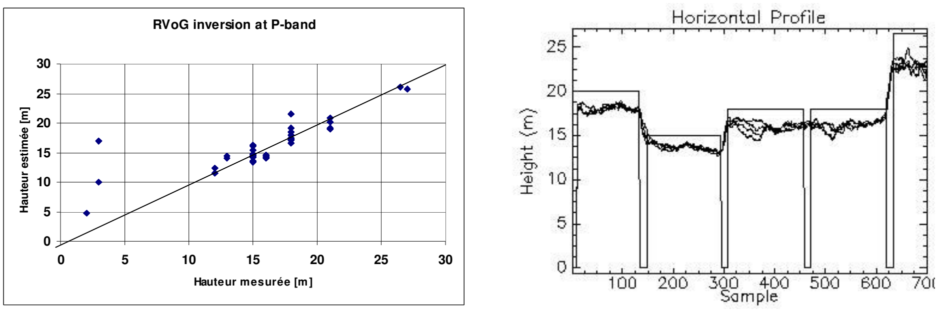

Figure 8: Inverted forest height versus ground measurements. RMS error of 1.2m (top figure), height profile (bottom figure)

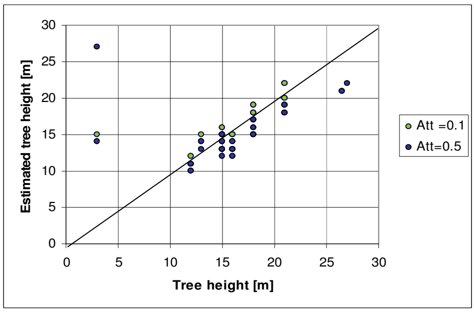

Figure 9: effect of the attenuation coefficient

In Figure 9, the inversion results for the two attenuation coefficients (0.1 and 0.5 dB/m) are provided.

Finally, we have investigated the effect of an inversion based on partial polarimetric information. A preliminary analysis of the data has shown that in the linear polarisation basis, HH and VV provided the largest phase center height variation, closely followed by HH, HV configuration. **Investigation of an inversion based only on two polarisation states showed no degradation in the results compared to the full polarimetric information when using either (HH,VV) or (HH, HV).** This is a important observation which need to be confirmed on other data set with different forest species and underlying relief.

3.2 Spectral approach

F Garestier [7-8] proposed a more advanced approach to the PolInSAR inversion at P band, relying on the time-frequency analysis of the data. The idea behind his algorithm is the variability of the observation geometry during a SAR acquisition. In order to reach the a given resolution δ_{az} , the range of azimut angle $\Delta\phi_{az}$ is known to be: $\Delta\phi_{az} = \lambda/2\delta_a$
By degrading the resolution on the RAMSES dataset, it is possible to vary this azimut angle and to observe a variation in the phase center height. He uses this analysis to maximise the "visible" part of the line, and is then able to invert height and attenuation.
Similar results are found with this technique without any a priori hypothesis on the attenuation factor.

4. Conclusion

We have presented a polarimetric inversion on P band data relying on the linear regression between the anisotropy parameter and the vegetation height.

We have found that Polinsar data can be successfully inverted using the Random Volume Over Ground (RvoG) model and an inversion procedure adapted to the P Band data, by assuming a known attenuation coefficient or a range of attenuation coefficients. The sensitivity to this parameter was observed to be weak given a proper baseline selection. The inversion proved to be performing very well at P band with a measured rms height error of 1.2m, therefore below the assumed ground measurement accuracy (Fig 8). The performance degrades significantly when the baseline is not adapted.
Furthermore, it was observed that similar inversion results can be obtained by performing PolInSAR inversion at P band based on the two co-polar terms, (HH, VV) or (HH,HV). This observation needs to be confirmed on other types of forest and in the case of a underlying topography. If this proved to be true for the majority of forest (including forest on sloping

terrain), it could have an important impact on the design of a space-borne mission as the signal to noise ratio in the co-polar channels is usually more favorable.

References

[1] Dubois-Fernandez P., F Garestier, I. Champion, X Dupuis, P Paillou, " Ramses P band and L band campaign over the Nezer forest: calibration and polarimetric analysis", EUSAR2006 symposium, Dresden, Germany, May 2006

[2] Champion, I., Loustau, D., Bert, D., Porté, A., Guédon, M., Jean-Courdier, F., Lagane, F., Lambrot, C., Lardit, A., Sartore, M., 2001, Tree architecture determination in remote sensing analytical models : The Bray experiment. Int. J. Remote Sensing, Vol. 22, N. 9, 1827-1843.

[3] P. Dubois-Fernandez, X. Dupuis, F. Garestier, "PolInSAR calibration of deramp-on-receive system: example with the RAMSES airborne system," Canadian Journal of Remote sensing., Volume 31 Number 1, February 2005. .

[4] S.R. Cloude, E. Pottier, " An Entropy Based Classification Scheme for Land Applications of Polarimetric SAR ", IEEE Transactions on Geoscience and Remote Sensing, Vol. 35, No. 1, pp 68-78 , January 1997

[5] F. Garestier, I. Champion, P. Dubois-Fernandez, P. Paillou and X. Dupuis " Polar and PolInSAR analysis of pine forest at L and P band on high resolution data"; IGARSS'05, Seoul, South Korea

[6] S.R. Cloude and K.P. Papathanassiou, "A three stage inversion process for polarimetric SAR interferometry", IEE proceedings, Radar, sonar and Navigation, Vol. 150, Issue 03, June 2003, pp 125-134

[7] F. Garestier, I. Champion, P. Dubois-Fernandez, P. Paillou and X. Dupuis " Polar and PolInSAR analysis of pine forest at L and P band on high resolution data"; IGARSS'05, Seoul, South Korea

[8] F. Garestier, "Evaluation du potentiel de la technique PolInSAR pour l'estimation des paramètres physiques de la végétation en conditions spatiales", PhD thesis manuscript, 2006

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