SAR tomography for the retrieval of forest biomass and height: Results from two tropical forests in French Guiana

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By exploiting **SAR Tomography (TomoSAR)**, we are able to transform the multi-baseline stack of SAR images into a multi-layer stack of SAR images, where each image represents the complex reflectivity associated with a layer at a certain height above the ground [1].

The main goal is to improve forest biomass and height retrieval methods by addressing 2 questions:

- main scattering mechanisms (SMs) at forest and ground level
- SMs changes across the global forest biomes
The retrieval of forest biomass has been demonstrated at the Paracou forest in French Guiana [1], [3].

1. The backscatter from the layer at 30 m above the ground level is significantly correlated to tropical forest Above Ground Biomass (AGB).

2. Tropical forest height can be estimated as 4m accurate or better.
Goal:
To assess the robustness of the method, the analysis is performed at Nouragues forest with strong topography and high AGB (up to 600 t/ha).

French Guiana

Problem:
Phase calibration, to be carried out in order to recover the interferometric ground phase, is difficult for the harsh hilly terrain.
Phase calibration solution:

- Retrieval of an initial guess for ground phases by Capon spectra for HH channel;
- Correct the original data using this ground phase;
- Re-retrieval of ground phases by Sum of Kronecker Products (SKP) model.

Initialization

\[
\phi_n^{initial} = \frac{4\pi}{\lambda r \sin \theta} B_n z_g^0
\]

where:

\[
z_g^0 = \arg \max_z \{ S_{Capon}(z; HH) \}\]
SKP Decomposition [4]

Multi-polarimetric multi-baseline covariance matrix can be expressed:

\[ W = \sum_{k=1}^{K} \lambda_k C_k \otimes R_k \approx C_g \otimes R_g + C_v \otimes R_v \]

Assuming 2 main Scattering Mechanisms - ground and volume scattering:
- The best LS approximation of \( W \) is obtained by retaining the first 2 terms of the SKPD
- The matrices \( R_g, R_v, C_g, C_v \) can be determined from the terms of the SKPD via a linear transformation
Tomography processing

Retrieval of the ground phases

\[ \varphi_{n}^{\text{ground}} = \frac{4\pi}{\lambda r \sin \theta} B_{n} z_{g} + \eta_{n} \]

\[ \varphi^{\text{ground}} = [\varphi_{1}^{\text{ground}}, \varphi_{2}^{\text{ground}}, ..., \varphi_{N}^{\text{ground}}], \text{ can be obtained by :} \]

\[ \varphi^{\text{ground}} = PL(R_{g}) + \varphi^{\text{initial}} \]

Phase calibration is carried out by removing the ground phase value of the original SAR images.

By this way, we get two advantages:

- The removal of the propagation disturbances, which allows a correct focusing along the vertical direction by exploiting the Fourier Transform.
- The removal of terrain topography, resulting in the contributions from the terrain to be automatically focused at 0m, independent of the actual topography.
After phase calibration based on the ground profile, most of phase center are located on the ground.

Even if the topography is very harsh, the SKPD makes it possible to retrieve the ground phases for phase calibration, which allows a correct focusing along the vertical direction.
Contributions from the ground level beneath the forest are observed. However, significant scattering contributions are observed at the canopy level in HH polarisation, whereas this volume scattering contribution is dominating in HV polarisation.

The scattering mechanisms in tropical forest shown by these results are quite different from those in boreal forests where for all polarisations the dominating contribution was observed to be associated with the ground level.
Forest biomass retrieval

The backscatter from the layer at 30 m above the ground level is significantly correlated to tropical AGB in both tropical forests in French Guiana.

- Training on stratified subset of Nouragues data.
- Performance assessed on data from Paracou.

\[ \text{RMSE} = 57.17 \text{ (t/ha)} \]
\[ r_p = 0.77 \]

\[ \text{RMSE} = 50.86 \text{ (t/ha)} \]
\[ r_p = 0.88 \]
Forest height retrieval

The retrieval of forest height has been assessed through a direct investigation of the shape of the 3D backscattered power distributions at each location.

The estimation appears to be reliable for vegetation layers ranging from 20m to 40m. For this range height, standard deviation is about 4m.

The relative error has been evaluated as:

\[ \left| H_{\text{tomography}} - H_{\text{LiDAR}} \right| / H_{\text{LiDAR}} \]
Conclusions

- TomoSAR can be used to improve our knowledge on scattering mechanisms of different forests.
- TomoSAR can be used to retrieve forest biomass and forest height: the robustness and transferability of the tomographic method have been demonstrated for 2 tropical forests.
- Hence, TomoSAR results could be used as references to fine tune PolSAR and PolInSAR methods (model approximation, model parameterisation...)
- The feasibility under the 6 MHz bandwidth constraint by frequency allocation at P band has been proved in Paracou [3]. Future work will extend the BIOMASS simulation to the Nouragues site.
REFERENCES


ACKNOWLEDGMENTS

The authors would like to thank Dr. Pascale Dubois-Fernandez, along with the whole TropiSAR 2009 team. We also acknowledge the CIRAD for in situ data availability in Paracou.