Retrieval of Tropical Forest Height by means of SAR Tomography

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ABSTRACT

Forest height is one of the important parameters for assessing forest biomass at local scale for resource monitoring and at global scale for the global forest carbon stocks, which plays a key role in the global carbon cycle and hence in the global climate. While airborne LiDAR is used routinely for measuring forest height for local applications, there is a need to define spaceborne systems well adapted to forest height at global scale, particularly for tropical forests.

In this paper, we present an approach based on SAR Tomography to retrieve tropical forest height. SAR Tomography enables to observe the whole forest vertical structure directly by exploiting the 3D nature of the forest data volume. It can separate the ground contribution in the radar backscatter measurements, can image the vegetation layer by layer and thus can reduce the topographic effects. The experiment results are based on the P-band polarimetric multi-baseline data, collected by ONERA over Paracou, French Guiana, in the frame of the TropiSAR ESA campaign. We compare the forest height retrieved from SAR Tomography with LiDAR measurements. While results are based on the airborne campaign data, the potential of the future spaceborne P-band SAR on board the BIOMASS mission with tomographic capability is prominent to provide high accuracy tropical forest height maps for global forest carbon monitoring.

1. INTRODUCTION

Longer wavelength Synthetic Aperture Radar (SAR) imaging is an important tool for forestry investigations, by virtue of the capability of lower frequency microwaves to penetrate the vegetation layer down to the ground. The availability of multiple baselines provides in addition an important advantage of this technique, which is the possibility to see the vertical structure of the vegetation through SAR Tomography (TomoSAR) (Reigber and Moreira, 2000). For this reason, TomoSAR techniques have been assessed in the last years over vegetated areas, as witnessed by papers recently published in this field (Tebaldini and Rocca, 2012; Ho Tong Minh et al., 2012a; 2012b).

In this paper, we propose a new approach of tomography for the retrieval of the forest height. The experiment results are based on the P-band fully polarimetric data set collected by ONERA in Paracou, French Guyana, during the ESA campaign TropiSAR (Dubois-Fernandez et al., 2012).

This paper is structured as follows. In section 2 the basic principles of SAR Tomography imaging are briefly recalled and the method for forest height retrieved is presented; in section 3 results are reported and discussed. Finally, conclusions are drawn in section 4.

2. TOMOGRAPHY METHODOLOGY

2.1 From multi-baseline to multi-layer images

A complete procedure for this processing was discussed and validated against the same data-set analyzed in this paper in (Ho Tong Minh et al., 2012a). The procedure is just briefly summarized here for sake of clarification.

The basic principle of TomoSAR is relatively simple and well known. By flying the radar along multiple flight paths nearly parallel to each other it is possible to create a 2D synthetic aperture, resulting in the possibility to focus the signal not only in the range, azimuth plane, but in the whole 3D space (Reigber and Moreira, 2000). In formula, assuming that each image within the data stack has been resampled on a common master grid, and that phase terms due to platform motion and terrain topography have been compensated for, the following model holds, (Reigber and Moreira, 2000):

$$y_n(r,x) = \int P(\xi,r,x) e^{+j\frac{4\pi}{\lambda r} b_n \xi} \, d\xi \qquad (1)$$

where: $y_n(r,x)$ is the pixel value at the range and azimuth coordinates (r,x) in the n-th Single Look Complex (SLC) image of the data stack; b_n is the normal baseline relatively to a common master image; λ is the carrier wavelength; ξ is the cross range coordinate; $P(\xi,r,x)$ is the average scene complex reflectivity within the slant range, azimuth resolution cell. It follows after eq.1 that the SAR multi-baseline data and the scene complex reflectivity within each resolution cell constitute a Fourier pair. Hence, the latter can be retrieved by Fourier transforming the data along the baseline direction (Reigber and Moreira, 2000), i.e.:

$$P(\xi,r,x) = \sum_n y_n(r,x) e^{-j\frac{4\pi}{\lambda r} b_n \xi}. \qquad (2)$$

Hence, SAR Tomography processing allows us to retrieve the cross range distribution of the scene complex reflectivity at each range-azimuth location, therefore providing fully the 3D imaging capabilities. The final conversion from cross range to height is then obtained through straightforward geometrical arguments. It follows that a multi-baseline SLC data can be converted through TomoSAR into a multi-layer SLC data, i.e.: a new stack of SLC images, each of which representing scattering contributions associated with a certain height above the ground.

2.2 Forest height estimation

The retrieval of forest height has been assessed through a direct investigation of the shape of the 3D backscattered power distributions from the multi-layer SLC at each location. This is a slice of the multi-layer data stack corresponding to a constant azimuth or slant range value.

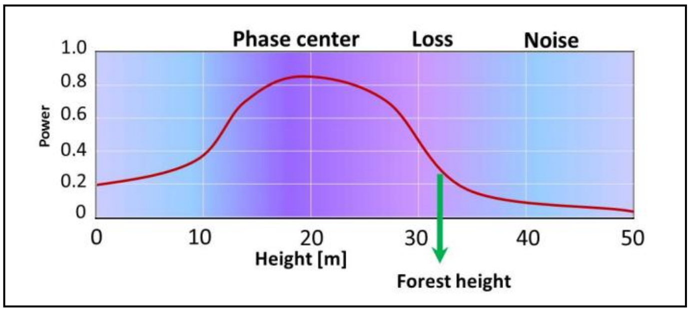

Figure 1. Criterion for the retrieval of forest height.

The criterion adopted in assessing forest height follows after the basic assumption that the shape of the backscattered power distribution as a function of height can be roughly divided into three zones, see fig.1. The major zone is found in correspondence of the phase center location, where most of the backscattered power is concentrated. In the lower zone the backscattered power undergoes a loss due to both the point spread function of the tomographic processors and the tapering of the forest density. In the highest zone, the backscattered power is mostly contributed by noise, not to be likely associated with physically relevant components. Accordingly, forest height has been retrieved by evaluating the power loss from the phase center location (Tebaldini and Rocca, 2012).

3. EXPERIMENT RESULTS

3.1 TropiSAR data

The Paracou experimental site is located in a lowland tropical rain forest near Sinnamary, French Guiana. Slopes range from 25% to 50%. The forest in Paracou is classified as a low land moist forest with 140-200 species per ha, specified in the forest census of all trees with diameter at breast height >10 cm. The SAR system used in the TropiSAR campaign is the ONERA airborne system SETHI. The P-band SAR has a bandwidth of 335-460MHz and the resolution is about 1 m in slant range and 1.245 m in azimuth direction (Dubois-Fernandez et al., 2012). The whole TropiSAR data-sets including in-situ data, are available through the archive of the European Space Agency (ESA). Details on access to campaign data can be found at the ESA EOPI portal (http://eopi.esa.int), under the campaigns link. In this paper, we use the Paracou tomographic data-sets which consists of 6 fully polarimetric SLC images at P-band acquired on 24 August 2009. The baselines have been spaced vertically with a spacing about 15 m (50ft). The trajectory flown is lower than the reference line (13000ft / 3962m) with a vertical shift of 50ft, 100ft, 150ft, 200ft and 250ft respectively.

3.2 Multi-layer images and tomographic profile

The multi-baseline SLC data has been converted into a multi-layer SLC data according to the procedures discussed above, each layer representing the scene reflectivity associated with a certain height above the ground. We note that the implemented phase calibration procedure automatically steers ground contributions at 0 m (Ho Tong Minh et al., 2012a). Hence, we refer to each image within the multi-layer data stack simply by the associated height (i.e.: 10 m layer, 20 m layer,...), or as ground layer for the image focused at 0 m regardless of the actual topography.

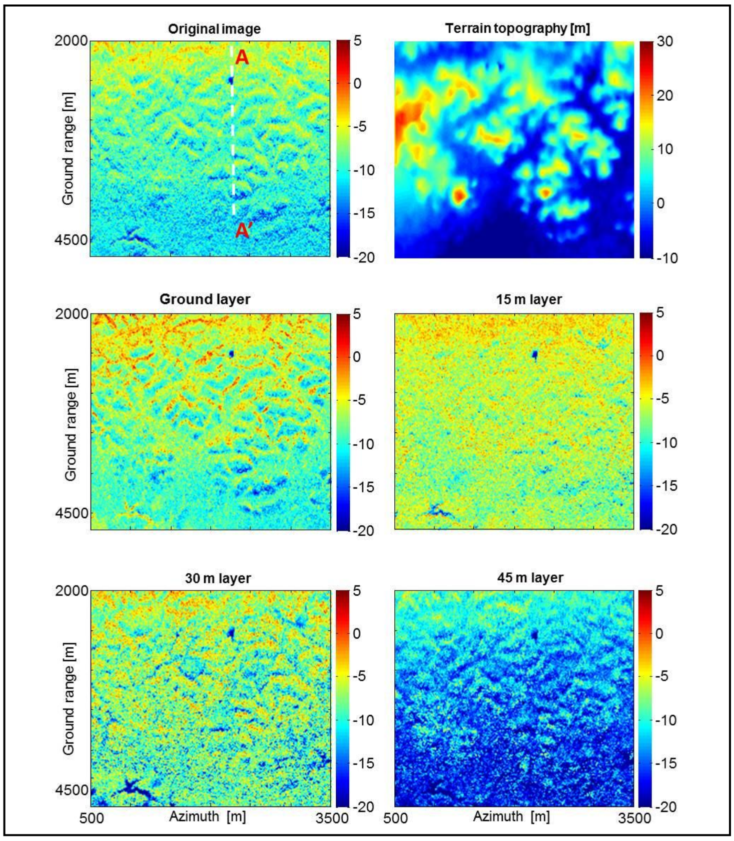

Figure 2. Tomographic results over the Paracou study site: HV backscattered power for four tomographic layers associated with four different heights above the ground 0 m (ground layer), 15 m, 30 m and 45 m. The top left panel presents the original HV image. The top right panel is the terrain topography.

Fig.2 shows the HV backscattered power for layers at 0 m (ground layer), 15 m, 30 m and 45 m. The backscattered power relative to one image from the original multi-baseline data-stack (i.e. non-tomographic) is shown in the top left panel of fig.2 to provide a comparison and the terrain topography is shown as well in the top right panel. The four tomographic layers are observed to be different in their information content. In particular, the ground and the top (45 m) layers show strong topographic effect, whereas the middle layer images appear much less affected by topography.

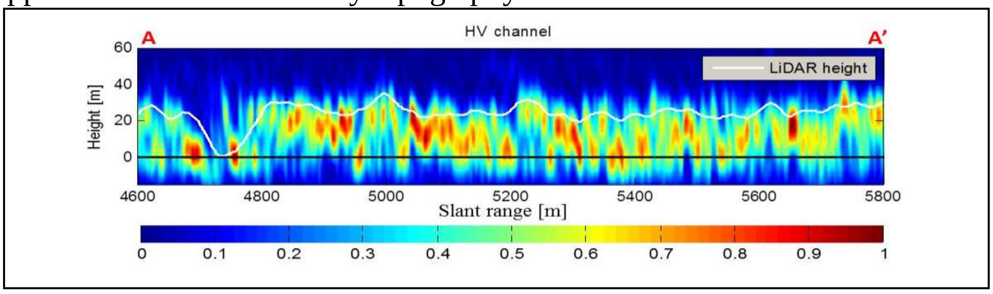

Figure 3. Tomographic reconstruction along the azimuth cut AA' (see fig.2) in HV. The while line denotes the LiDAR height measurements. The panel has been normalized in such a way that the sum along height is unitary.

Fig.3 presents the tomographic profile of a constant azimuth section AA' (x=2270 m, see fig.2) at HV. The panel has been normalized in such a way that the sum along height is unitary, in order to help visualization. The white line denotes forest top height derived from LiDAR measurements. The figure indicates that in tropical forests, the contributions from the canopy are important, whereas the contribution from the ground are also present, even for forest height of 30-35 m.

3.3 Forest height retrieval

The analysis of the forest vertical structure is expected to provide direct estimation to forest height. At both linear and circular polarizations, namely HH, HV, VV, LL, LR and RR, it was found that they share a similar behavior (Ho Tong Minh et al., 2012c). However, HV channel is the most sensitivity to volume scatterings. Therefore, we produce a forest height map by examining the HV tomographic profile from TomoSAR technique.

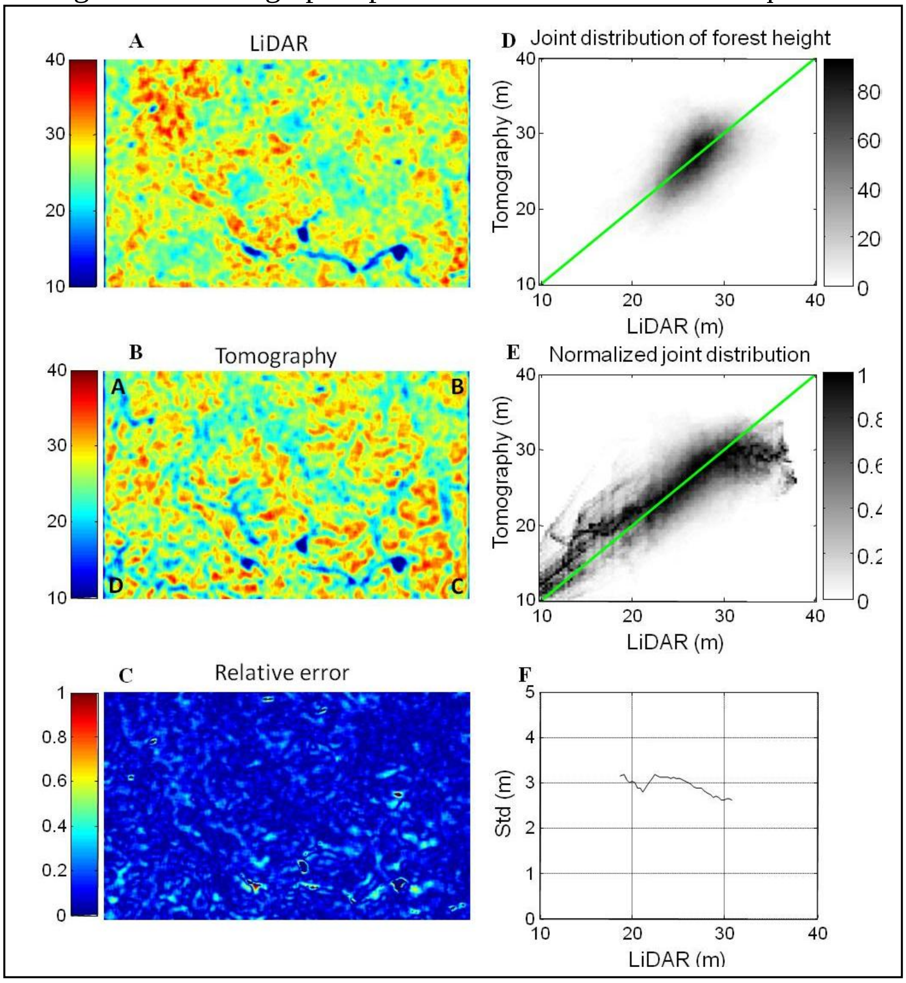

Figure 4. Retrieval of forest height. Range increases from bottom.

The LiDAR forest height H_{LiDAR} available is shown in fig.4**A** to facilitate the interpretation of the results. In fig.4**B**, an agreement of tomographic forest height $H_{tomogaphy}$ with the LiDAR measurements is observed at an intensity loss of 2 dB with respect to the phase center location. Both LiDAR and tomographic forest height are filtered by an average window of 50 x 50 m. The joint distribution of forest height is shown in fig.4**D**. The joint distribution has been normalized such that the maximum is unitary along each column in fig.4**E**. The relative error has been evaluated as : $|H_{tomogaphy} - H_{LiDAR}|/H_{LiDAR}$ and is shown in fig.4**C**. The average value is 0.092 (9.2%). Fig.4**F** shows the standard deviation of $H_{tomogaphy}$ with respect to H_{LiDAR}. The estimation appears to be reliable for vegetation layers ranging from 19 m to 31 m. For this range height, standard deviation has been assessed in about 3 m.

4. CONCLUSION

In this work SAR Tomography has been exploited for the retrieval of forest height in dense tropical forests based on TropiSAR 2009 data-sets. The tomography methodology to derive the forest height information has been described.

Our study demonstrates a method that can map detailed spatial variability in a primary tropical rainforest height with high resolution and high accuracy. While results are based on the airborne campaign data, the potential of the P-band spaceborne SAR on board the future BIOMASS mission with tomographic capability is prominent to provide high accuracy tropical forest height maps for global forest carbon monitoring (Le Toan et al., 2011).

5. REFERENCES

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