TROPICAL FOREST STRUCTURE OBSERVATION WITH TANDEM-X DATA

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ABSTRACT

TanDEM-X forms together with TerraSAR-X the first single-pass polarimetric interferometer in space. This allows for the first time the acquisition and analysis of Single-, Dual-, and Quad-Pol-InSAR data without the disturbing effect of temporal decorrelation globally. For this reason, the exploration of TanDEM-X data for forestry is constantly increasing especially concerning forest height estimation, biomass classification and structure characterization.

This paper reports the results of recent experiments aimed at investigating the potentials of TanDEM-X in characterizing quantitatively the spatial variability of the canopy top and phase center height, which is a proxy to horizontal structure. It is shown that such characterization can allow to differentiate among e.g. different successional and / disturbance stages in tropical forests.

Index Terms— SAR, interferometry, TanDEM-X, forest structure, canopy texture.

1. INTRODUCTION

Since 2010, the TerraSAR-X and TanDEM-X platforms have been acquiring single-pass X-band interferometric SAR data in single-, dual- and fully polarimetric configurations. Without the disturbing effect of temporal decorrelation, the demonstration of a number of single and multibaseline polarimetric interferometric (Pol-InSAR) techniques for forest applications was possible from space.

X-band has - when compared to lower frequencies - a reduced penetration capability that makes it a sub-optimal choice for vegetation 3-D structure observation. Nevertheless, although depending on forest site and seasonality, TanDEM-X interferometric coherences indicated a sufficient high penetration and dependence on polarization to allow the inversion of forest structure parameters as forest height [1]-[2], classify biomass [2], and to infer forest structure properties [3]-[5].

Concerning the quantification of forest structure, it has to be remarked that fully tomographic experiments are possible only in a few test sites, as only there the necessary baseline variation is provided (see [5] for a first example). The characterization of forest structure at a larger scale and for different ecosystems with TanDEM-X data has therefore to be carried out using a reduced observation space. Thus, it is worth exploring the information content of interferometric complex coherences, taking into account the limited penetration capabilities of X-band. The extraction of information about the top vegetation layer (i.e., a sort of top canopy texture) could be feasible with TanDEM-X data.

Following this line of investigation, the purpose of this paper is to report about results obtained in the characterization of the canopy horizontal structure by quantifying the spatial variation of the canopy top height and phase center. These experiments have been carried out over a test site in the Tapajos national forest, located in the Amazon basin in northern Brazil beside the Tapajos River. The region of Tapajos is fairly flat and predominantly vegetated by undisturbed primary rainforest, with also younger secondary forest stands. In this analysis, we processed TanDEM-X dual-pol data acquired in bistatic mode on 5th December 2012, with height of ambiguity around 60m. For processing and validation purposes, fine-beam Lidar first (top canopy height) and last return (digital terrain model, DTM) acquired in July 2012 are available.
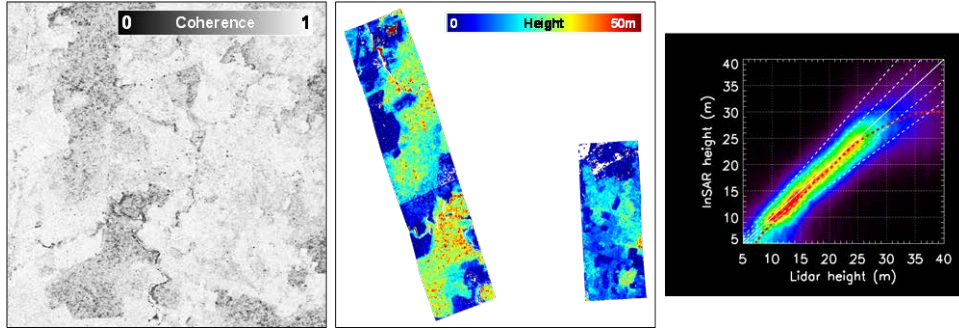
Fig. 1. Tapajos test site, from left to right: (a) TanDEM-X HH InSAR coherence (range on the horizontal axis); (b) TanDEM-X InSAR forest top height; (c) validation plot. The coherence map covers an area of around 5 × 5 Km on ground. Forest height was inverted only where the Lidar DTM was available.
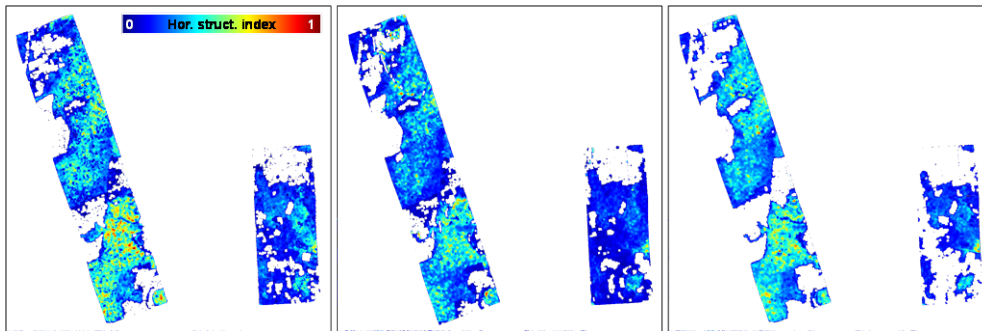

Fig. 2. Tapajos test site, HS indicators in radar coordinates calculated for (from left to right): (a) Lidar top heights (first return); (b) TanDEM-X InSAR forest top height; (c) TanDEM-X HH phase center heights above the Lidar DTM. CHP scale: 10m; HS scale: 50m. Bare soils have excluded from processing.

Finally, polygons on ground corresponding to primary and secondary (initial, intermediate and advanced stages) forest stands were sampled and delimited according to an analysis of ground inventory data and visual identification from photographs.

2. FOREST HEIGHT ESTIMATION

The estimation of forest height is by far the most assessed application of TanDEM-X data in forestry. Several techniques have been developed in the past years for single-baseline forest height inversion, depending on the number of available polarization channels and/or penetration until the ground [1][2]. In the case at hand, due to the limited penetration and the reduced polarimetric diversity [1], forest height could be inverted in a Random-Volume-over-Ground framework just with single polarization data (HH or VV) by using the Lidar DTM and by assuming the absence of ground scattering [1].

In Fig. 1 (utmost left), the TanDEM-X HH interferometric coherence is shown calculated with a square multilook cell with 15m side length on ground. The maximum coherence (higher than 0.85) is obtained in correspondence of the bare areas, while lower values are over forest areas. These coherence where then used to invert

forest height with the above mentioned assumptions (Fig. 1, mid panel). When validated against the Lidar top canopy height (Fig. 1 utmost right), the large majority of the estimated heights present estimation errors within the 10%, with a global root mean square error around 4m. Some underestimation is observed for taller stands essentially due to the non-optimal spatial baseline (too long) for the given height variation. Processing the VV data provided similar results with negligible differences.

3. QUANTIFYING FOREST STRUCTURE FROM FOREST HEIGHT

Once a height map is available, a way to characterize forest horizontal structure is to characterize the variability of forest height. A direct approach is discussed in [10]. According to it, a horizontal structure indicator (called hereafter HS for brevity) can be calculated from canopy height profiles (CHP) derived from the height map. The CHP's are computed at a fine scale, and then aggregated at the desired larger HS scale. The defined HS for each cell is proportional to the product $NP \times H_{max}$, where NP is the number of peaks of the aggregated CHP's above a fraction T of the maximum height H_{max} in the same cell. The larger HS, the larger the forest heterogeneity.
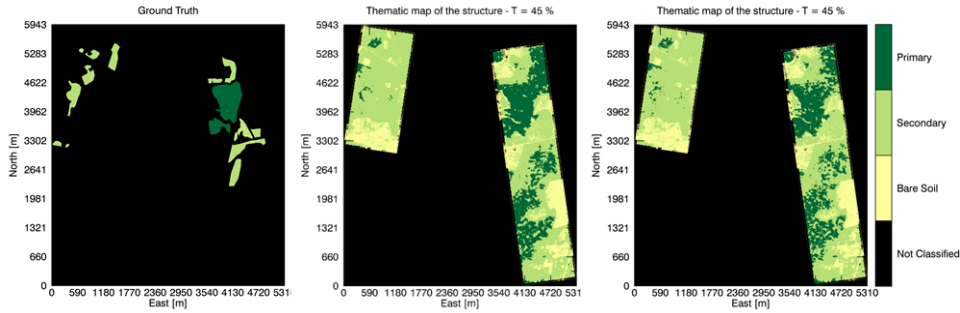
Fig. 3. Tapajos test site, from left to right: (a) Ground polygons delineating primary and secondary forest areas (UTM coordinates); (b) TanDEM-X classification by using HS calculated from HH phase center heights with respect to the Lidar DTM; (c) TanDEM-X classification by using HS calculated from phase center heights with respect to their minimum in the HS cell. *CHP* scale: 10m; HS scale: 50m; *T*=0.45; multilook cell side on ground: 5m.
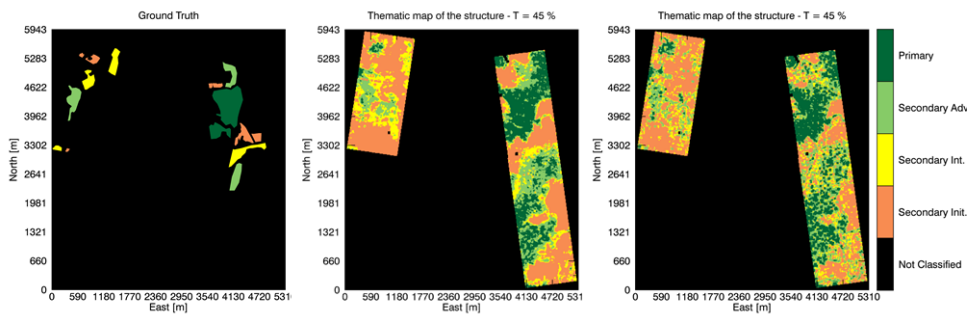

Fig. 4. Tapajos test site, from left to right: (a) Ground polygons delineating primary forest and 3 successional stages in the secondary forest areas (UTM coordinates); (b) TanDEM-X classification by using HS calculated from phase center heights with respect to the Lidar DTM; (c) TanDEM-X classification by using HS calculated from HH phase center heights with respect to their minimum in the HS cell. CHP scale: 10m; HS scale: 50m; *T* = 0.45; multilook cell side on ground: 5m.

The HS obtained over the Tapajos area of interest by using the Lidar and the TanDEM-X HH top forest heights, and the TanDEM-X HH phase center heights over the Lidar DTM are shown in Fig. 2. They have been calculated with a CHP scale of 10m and a HS scale of 50m. HS has been normalized to 1 for simplicity. In all of the three maps, spatial gradients are apparent. Increases and decreases of HS are very similar for Lidar and TanDEM-X. Notice also that similar height levels can have different HS levels, as it is reasonable to expect. Moreover, trends in the TanDEM-X HS from forest height are visible also in the HS from phase centers. It is worth noting that TanDEM-X HS presents a lower dynamic than the Lidar one. This is due to the multilook cell size (15m) used. Indeed, it is bigger than the CHP scale and therefore it limits the information content in terms of heterogeneity. This parameter is optimized in the following. More importantly, by comparing these maps with ground polygons, it has been seen that areas with larger HS values match well with primary forest areas. This indicates that HS is a parameter that can be used for instance for classifying different successional and/or disturbance stages.

4. USING HORIZONTAL STRUCTURE FOR DISTINGUISHING SUCCESSIONAL STAGES

From the experiments of Section 3, it is apparent that using a TanDEM-X phase center height map over the (Lidar) DTM has the same information content in terms of horizontal structure as forest height. Therefore, phase center heights have been used in the experiments reported in the following aiming at classifying the different forest successional stages. A simple one-dimensional classification approach has been performed by thresholding HS. Optimal thresholds have been set empirically by maximizing the classification accuracy basing on the histograms of HS on the ground polygons. Clearly, the classification accuracy depends on the parameters that concur in the determination of HS, namely both HS and CHP scales, the multilook cell side, and the height threshold *T*. In what follows, we fixed the CHP scale to 10m.

In the two-class case, i.e. primary and secondary forest, it has been seen that for a HS scale equal to 50m, a classification accuracy larger than 80% can be achieved independently of *T* for both classes, and for multilook cell sides below 10m. If *T* is fixed to 0.45, then the accuracy is

maximized and results larger than 90%. The resulting thematic map is shown in Fig. 3 (mid panel). The accuracy slowly degrades for larger T especially for the primary forest. Increasing the HS scale from 50m up to 200m has a "smoothing effect", and primary forest areas become less distinguishable from secondary ones.

The four-class case, i.e. primary and 3 stages in the secondary forest (initial, intermediate and advanced) is definitely more challenging. Again, we fixed the CHP scale to 10m and the HS scale to 50m. Interestingly, also in this case the classification accuracy is maximized for $T = 0.45$, but it is sensitive to small changes of T. For the optimal value (Fig. 4, mid panel), the classification accuracy is larger than 70% for all classes. Secondary intermediate and advanced forest stands are the ones with lower accuracy. HS scales larger than 50m reduce abruptly the classification accuracy.

Finally, it is of interest to understand the sensitivity of HS and the consequential classification to the knowledge of the ground topography. A non-compensated ground topography may indeed induce artifacts [7]. The phase center height have thus been calculated with respect to their minimum in the HS cell. In this case, using a 5m multilook cell is of crucial importance. Accepting a reduction of accuracy, it preserves information about propagation through smaller gaps, that would be lost for larger cells. The classification results are reported in Figs. 3 and 4 (right panel). A slight degradation of the performance can be noticed in the two-class case. The degradation increases instead in the four-class case, where for instance intermediate and advanced secondary forest stands are more difficult to be recognized even at a 50m scale. This situation worsens when larger HS scales are employed.

5. CONCLUSIONS

The experiments reported in this paper show that it is possible to characterize structural differences by means of TanDEM-X data even in dense tropical forest environment like Tapajos. The characterization of vertical structure is limited by the reduced penetration capabilities of X-band waves. On the other hand the characterization of the horizontal structural allows distinguishing between different successional and/or disturbance stages. For instance, primary and secondary forest could be clearly distinguished. Three TanDEM-X features play a key role: (1) the high spatial resolution that allows to explore and evaluate (statistically) a large range of scales; (2) the limited penetration capability that increases the sensitivity to the top canopy surface variability and which now becomes an advantage; (3) the ability to estimate the phase center and top height accurately due to the single-pass InSAR implementation. Investigations are ongoing to confirm these capabilities in different tropical forest test sites, and to investigate further the robustness and sensitivity to scale and threshold values. Eventually these investigations could also be extended to different ecosystems.

From a methodology point of view, it has been seen here that to distinguish between primary and secondary forest a (very) high resolution DEM may suffice. Still unexplored is the information content of the magnitude of the interferometric coherences. One could for instance evaluate the possibility to extract texture information from the coherence magnitude by means of Fourier-based methodologies [8]. In this case, no reference height would be needed.

7. REFERENCES

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