ADDRESSING TROPICAL FOREST STRUCTURE CHANGES WITH SAR TOMOGRAPHY: THE AFRISAR 2016 - GABONX 2023 CASE

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ABSTRACT

The ability of SAR Tomography (TomoSAR) in mapping forest structure changes in time by separating, quantifying and characterizing individual structural / dielectric change contributions has not been systematically characterized yet. In this work, such potentials are investigated in tropical forests sites in Gabon. This analysis is carried out by processing P-band tomographic data acquired by the DLR F-SAR platform during the AfriSAR and the GABONX campaigns in 2016 and 2023, respectively. Different types of structural changes are firstly identified by means of lidar acquisitions. Their mapping into both tomographic reflectivity reconstructions and related structure indices is then derived. Reasons for ambiguities are discussed, and possibilities for an improved change characterization investigated.

Index Terms— Forest structure, SAR, tomography.

1. INTRODUCTION

Forest structure changes reveal dynamic processes as growth, regeneration, decay and natural or anthropogenic disturbance. Knowledge about such processes is important for modelling the function and the development of forest ecosystems, and e.g. for developing accurate and robust forest biomass estimators [1]. While forest structure characterization traditionally relies on sampling techniques by means of field inventory plots or more recently by using terrestrial laser scanning techniques, any large scale estimation of forest structure requires the support of (spaceborne) remote sensing techniques. Long-wavelength (i.e. P- or L-band) Synthetic Aperture Radar (SAR) configurations are expected to play a critical role, as they provide penetration within forest volumes and continuous imaging capabilities with high spatial and temporal resolution.

In this context, tomographic SAR (TomoSAR) techniques allow to reconstruct vertical reflectivity profiles (equivalent to backscattered power) from a set of images acquired under slightly different angular directions along displaced tracks or orbits. TomoSAR reconstruction capabilities were demonstrated in a number of airborne experiments [2]-[8], and these results initiated the conceptualization of TomoSAR acquisition modes in future spaceborne SAR configurations [9]-[11]. For instance, the upcoming ESA's P-band BIOMASS mission will be able to acquire TomoSAR data in a dedicated mission phase in repeat-pass mode.

For the same wavelength, polarization and looking geometry, changes of vertical reflectivity profiles can be induced by changes of either the geometric scatterer structure (due to growth, thinning, mortality, etc.) or their dielectric properties (due to changes of vegetation water content induced by rainfalls, droughts, seasonality, etc.). Despite technological and experimental advancements, the parameterization of physical changes of different types and intensities in terms of reflectivity changes, together with the assessment of the possibility to separate, quantify and characterize the individual structural / dielectric change contributions in TomoSAR acquisitions repeated in time are critical missing aspects. This results into interpretation ambiguities of the spatial gradients and the temporal changes of the reconstructions in terms of physical processes. Systematic analyses of appropriate change data sets, as well as the development of dedicated models and methodologies are thus required.

First investigations in this direction were carried out by analyzing multi-temporal airborne TomoSAR L-band reflectivity reconstructions over a temperate forest site in [12], [13]. It was shown that structure indices derived from the reflectivity profiles [14] can follow structural spatial gradients and their evolution in time. However, temporal dynamics at local scale may be erroneously characterized due to e.g. limited vertical resolution and / or the presence of dielectric changes. The purpose of this work is to extend this analysis to selected structural changes on ground by comparing P-band reflectivity profiles derived over tropical forest sites in Gabon imaged during the AfriSAR and the GABONX campaigns in 2016 and 2023 respectively. Once more, this assessment is carried out by considering not only TomoSAR reflectivity reconstructions, but also available structure indices derived from them.

2. THE AFRISAR 2016 AND GABONX CAMPAIGNS

The AfriSAR campaign was successfully carried out in 2015 and 2016 as a joint effort among space agencies (ESA,

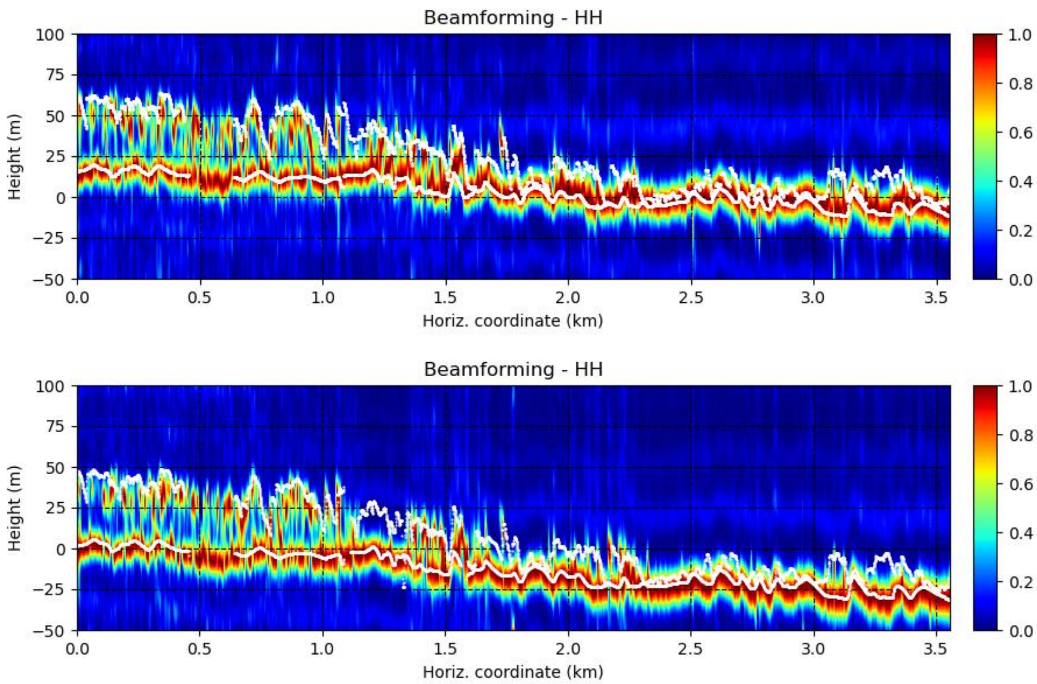

Fig. 1 Mondah site (Gabon). Beamforming TomoSAR profiles (HH polarization) along a north-south transect obtained from the AfriSAR 2016 (top panel) and GABONX 2023 data (bottom panel). Slant range increases from left to right. The white dashed lines correspond to the LVIS lidar ground topography and RH100 measured in 2016. The apparent height difference between 2016 and 2023 is just a constant shift induced by the preliminary tomographic calibration of the GABONX data.

NASA, ONERA, DLR and AGEOS) over African tropical forest sites of Gabon [15]. The objective of the campaign was to acquire polarimetric interferometric and TomoSAR data sets, lidar full waveforms and ground measurements for the development, calibration and validation of tropical forest structure and biomass estimation algorithms.

The GABONX campaign is the ESA-supported successor to AfriSAR 2016, and it was carried out from May to July 2023. GABONX aims to detect and quantify changes that have occurred since the acquisitions in February 2016. To this end, DLR's F-SAR sensor acquired fully polarimetric L- and P-band TomoSAR data over three forest sites (Mondah, Lopé, Mabounie) out of the original four in the same flight geometry as in 2016. P-band data were acquired and processed with an off-nadir angle range between 20° (near-range) and 50° (far-range). The radar was operated with a 50 MHz bandwidth centered at 435 MHz (equivalent to a wavelength of 69 cm). The flight level of 20000 ft (6096 m) of the reference acquisitions was chosen to ensure an above-the-clouds operation in order to reduce turbulences. For each TomoSAR acquisition, 10 tracks were flown with a vertical displacement of [-80m, -60m, -40m, -20m, 10m, 20m, 40m, 60m, 80m] with respect to the master acquisition. These displacements lead to a vertical resolution of around 15 m and a non-ambiguous height interval of around 250 m, both calculated at mid range.

3. TOMOGRAPHIC PROFILES: FIRST RESULTS

A first comparison between representative profiles has been attempted in the Mondah test site. Mondah is a partially flooded area containing mangrove and mahogany woodlands in northwest Gabon. The north-western part is a primary forest taller than 50 m, with dense and homogenous stands, while the southern part is secondary forest. The topography is fairly flat within the site.

Two beamforming (Fourier-based) HH P-band profiles along a representative 3.5 km north-south transect are shown in Fig. 1, obtained after flattening the TomoSAR data to the mean test site ground height. It is apparent that the distribution and intensity of the profile sidelobes is very similar for the two data sets. This was confirmed by the corresponding TomoSAR point-spread functions, practically ruling out the presence of profile differences induced by differences in the realized track displacements. The ground and top canopy height (RH100) measured in 2016 by means of NASA's LVIS (Land, Vegetation and Ice Sensor) lidar acquisitions [16] is reported as a reference. Neglecting the height shift, in both cases the ground scattering is generally well visible and well located around the lidar ground. At the same time, in many tall stands the canopy reflectivity peak seem to move closer to the canopy top from 2016 to 2023. However, there are also cases (e.g. around 1.2 km horizontal coordinate) in which the canopy contribution disappears.

4. OUTLOOK

In the full paper, a more systematic analysis will be presented. For this, LVIS lidar data acquired in May 2023 still in the frame of GABONX will be used to identify the types of physical structure changes and the areas in which they occur. The mapping of this changes on both TomoSAR profile reconstructions and structure indices will be assessed, and reasons for ambiguities explored. The focus will be not only on the capability to detect changes, but also to distinguish their type. It is expected that this new set of results will complement previous ones in different ecosystems in the characterization of TomoSAR potentials for forest structure change observation, and to conclude on future investigation directions.

5. ACKNOWLEDGEMENT

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