Day-Night Tropical Forest Phenomenology through Tomographic Imaging: Paracou results

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Abstract. This work aims at studying day-night phenomenology in a tropical forest illuminated by P-band radar signals. The analysis is carried out based on data set from the ground-based ESA campaign TropiScat, which aimed at evaluating the temporal coherence in a tropical forest in quad-polarization and at different heights within the vegetation layer. The experiment has been successfully set up and operated since October 2011 at the Paracou field station, French Guiana.

Thanks to the 15 minutes time sampling of the system, we were able to provide the first ever tomographic movie capturing the forest daily change, at least to our knowledge. Tomogram analysis revealed a diurnal vertical motion of the forest center of mass. This phenomenon is strongly related to daily temperature variations, which suggests a connection with forest transpiration phenomena.

Concerning daily temporal coherence, the most relevant phenomenon is the coherence drop during daytime, due to the effect of the wind moving the forest canopy. This result already appears to provide a very useful input concerning the forest space borne, i.e. BIOMASS mission, as it suggests that performance over tropical forest could be optimized by gathering acquisitions at dusk or dawn time. Furthermore, this result indicates that the

BIOMASS space borne will be able to provide useful information on the evapotranspiration of tropical forests, which has a central role in the water cycle.

Keywords: Day-night, center of mass, temporal decorrelation, TropiScat, tomography

1. Introduction

The candidate Earth Explorer Core Mission BIOMASS is actually foreseen to be operated in a Tomographic Phase during approximately the first two months of mission lifetime (Le Toan et al., 2011). For this purpose, the TropiSAR experiment (Dubois-Fernandez et al., 2012) has been conducted in 2009 over the tropical rain forest at Paracou, French Guiana, for studying the vertical structure of the vegetation, which would be one of the key elements for the assessment of the forest biomass (Ho Tong Minh et al., 2012a). In order to complement the airborne TropiSAR dataset in producing a well-controlled dataset in various seasons and weather conditions, the TropiScat ground based experiment had been proposed to acquire intensity and complex coherence in quad polarization, together with a vertical imaging capability (Ho Tong Minh et al., 2012b). In order to illuminate the forest from the top, a set of 20 antennas was installed on top of the Guyaflux tower (55 m high) at the Paracou test-site, to radiate P to L band signals to the forest below. Such an equipment is intended to provide 2D (ground range - height) resolution capabilities through the coherent combination of the signal from different antennas via tomographic techniques. By comparing, again coherently, tomographic images taken at different times it is possible to gain access to the variation of temporal coherence with respect to forest height.

Results so far indicate that there is a diurnal vertical motion of the forest center of mass and this phenomenon is strongly related to daily temperature variations, which suggests a connection with forest transpiration phenomena. We find that the temporal coherence daily drops during daytime and therefore it suggests that BIOMASS performance over tropical forest could be optimized by gathering acquisitions at dawn or dusk time.

The paper is organized as follows: section 2 presents the main features of tomographic array; results are shown in section 3; conclusions are finally drawn in section 4.

2. TropiScat tomographic mode

The TropiScat tomographic array has been designed and implemented as shown in Figure 1. This system has been designed to provide fully polarimetric vertical resolution capabilities, gather data continuously for about a year, and provide a sufficient number of looks for reliable coherence evaluation at several height levels. The system is characterized by 20 antennas, each of which is operated either as a transmitter or a receiver. The array extent is 2.4 x 4.4 m in the horizontal and vertical direction, respectively. The minimum distance between antennas equals 0.8 m, which ensures reduction of coupling effects.

Figure 1. TropiScat tomographic mode

Figure 1 shows that the vertical locations of the real array antenna is irregular. However, by employing multiple transmitting–receiving pairs, a uniform equivalent monostatic array is formed along the vertical direction for each polarimetric channels, resulting in the same tomographic imaging properties in all four channels. This design has been optimized for a central frequency of 500 MHz. The resulting virtual array aperture and spacing are, respectively, Az = 2.8 m; dz = 0.2 m. This vertical spacing yields at P-band (500 MHz) an ambiguous return appearing at an angle close to 135° from the target, well distinguished from the forest. Furthermore, the virtual array aperture results in the vertical resolution in far range (70m) being about 7.5m in P-band and proportionally higher at higher frequencies (Ho Tong Minh et al., 2012b). The temporal sampling for tomographic imaging at P-Band is 15 minutes, resulting in 96 samples per day. This allows to study both the short term temporal coherence and its seasonal variations within the forest.

3. Experiment results

3.1 Tomographic movie

Figure 2 reports a few snapshots from the "tomographic movie" obtained over time at P-Band. Each panel has been generated in slant range - height coordinates, and flattened so as to bring terrain level at 0 m, so as to help visualization and interpretation of the results. It is however important to note that terrain topography in the illuminated area is characterized by a strong back-slope (i.e. the terrain is tilted away from the tower). This results in the absence of scattering contributions from ground-trunk interactions, differently from other areas within the TropiSAR data-set (Ho Tong Minh, 2012c). As visible, acquisitions collected during day time are often characterized by a lower intensity with respect to night hours. This phenomenon is due to the fact that time required for each tomographic acquisition is about 4 minutes, which makes the imaging quality sensitive to wind gusts.

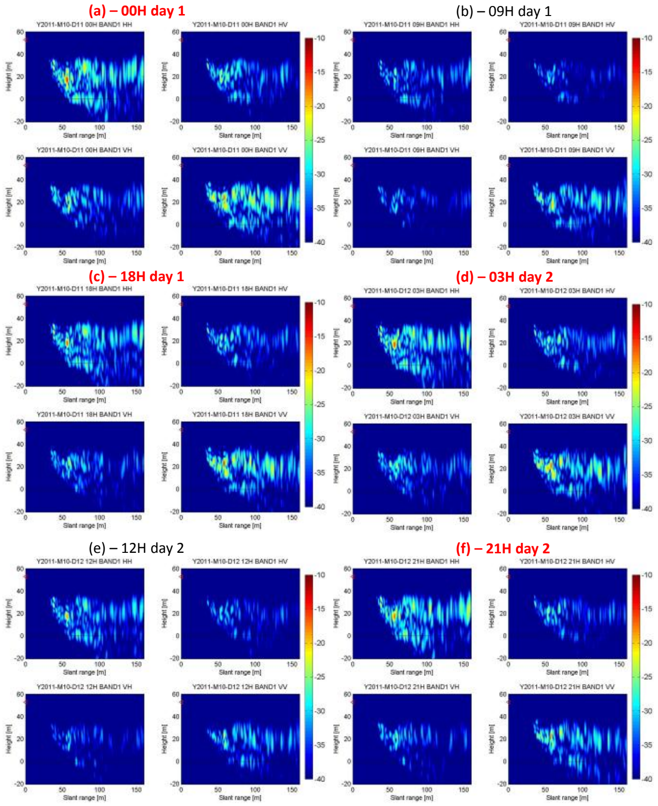

Figure 2. Tomographic movie

3.2 Day-Night tropical forest phenomenology

We found that the location of the forest center of mass, which is the center of the vertical reflection, is observed to go up and down by more than 1 m during day hours at all polarization, as shown in Figure 3.

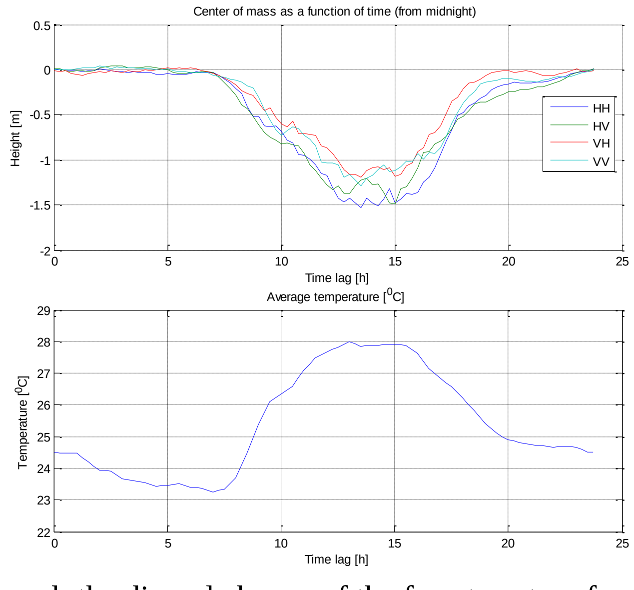

Figure 3. Upper panel: the diurnal change of the forest center of mass. Bottom panel: temperature variation over one day.

This result has been obtained by considering dry day acquisitions from November 2011 to February 2012. The strong correlation with temperature variation over one day seems to suggest that this phenomenon may be connected to water content within the vegetation layer. The stored water clearly plays a biologically significant role. One possible explanation considers transpiration phenomena (Campbell and. Norman, 2000). There is heat and mass transfer between forest organisms and their surroundings. With changing temperature, the exchange of oxygen and carbon dioxide between leaves and the atmosphere varies. In fact, in a photosynthesis process, it uses light energy to convert CO_2 into carbohydrates. The basic equation may be written (Landsberg and Sands, 2011) :

$$H_2O + CO_2 + \text{light energy} \rightarrow O_2 + CH_2O \tag{1}$$

where CH_2O is a generic carbohydrate. This then leads to changes of the water content inside forest organism in response to foliage air vapor pressure gradients. Indeed, the loss of water content depends on the changes in stomatal aperture and hence stomatal conductance, which depends on changes in turgor pressure in the guard cells (Landsberg and Sands, 2011). These are specialised epidermal cells on either side of the aperture, hydraulically linked to surrounding epidermal cells. If the turgor pressure in the guard cells falls, the cells tend to become flaccid and stomatal apertures are reduced (Jones, 1992). However, this is a level too far down for our purposes, and we are simple based on observations at the phenomenological forest level in this paper.

As a matter of fact, there is a considerable delay (about 6-hours) between water loss from foliage and water uptake by the roots (Helkvist et al., 1974). Hence, there exists a period when the balance of water content of the forest is positive or negative. It is positive if the loss from foliage is lower than the gain from roots.

During the morning hours, the water balance is negative (Cermak at el., 2007). We observed the mass, a manifestation of stem volume, goes down. The balance becomes positive at noon time when input into the stem at roots is greater than output at foliage and hence the mass is going to shift up. The mass is returning in the afternoon and at night until the early morning hours of the next day when transpiration resumes. Accordingly, stored water is depleted mostly during morning hours and then replenished during the afternoon.

The day-night forest phenomenology can be divided into distinct phases of depletion and recovery pattern. Diurnal changes in stem mass are strongly related to changes in the quantity of water removed from storage. Stem mass decreases with increasing transpiration (and water depletion from storage) early in the day and increases with decreasing transpiration (and gradual refilling of storage) later in the day. Despite its variation, the stem mass goes back during the night. This suggests growth or a net day-to-day increase in volume mass occurred only at night time when transpiration approached zero and internal storage compartments had been mostly refilled. This phenomenology is also confirmed with the previous work (Cermak at el., 2007).

3.3 Day-Night temporal decorrelation

Figure 4 shows HV coherency matrices over one day at the ground layer (0 m), and at 10 m and 20 m above the ground. Each entry in the three matrices has been obtained by taking the interferometric coherence between two different acquisition times at one particular location within the forest. Coherence evaluation has been carried out by employing an averaging window of 5m x 40m (height-range), corresponding to about 50 looks. We notice a regular decline of coherence moving away from the main diagonal, which corresponds to increasing time lag. However, the most relevant phenomenon is the coherence drop during daytime, which confirms the effect of the wind moving the forest canopy observed in the previous section. It is worth noting that this phenomenon is partly observed at the ground level as a resulting of defocused contributions from the rest of the vegetation layer.

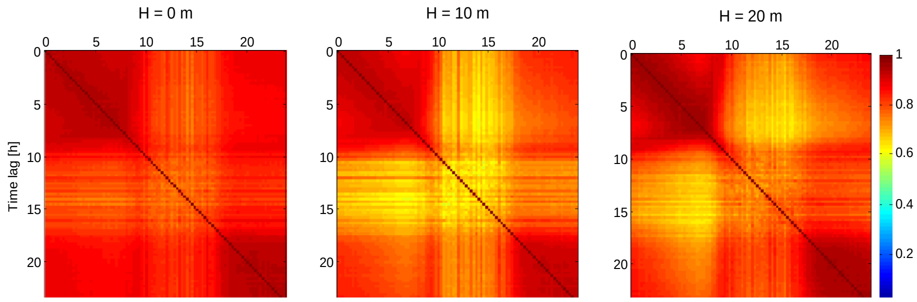

Figure 4. HV day-night temporal decorrelation as a function of height.

Multi-baseline multi-polarimetric data allows to identify the sources of forest scatter. The same principle can be developed with multi-temporal multi-polarimetric (MTMP) tomographic data (Ho Tong Minh, 2012c). In detail, the MTMP covariance matrix may be expressed as a Sum of Kronecker Product (SKP). As a consequence, we can decompose the stable and varying components which are associated with KP 1 and KP 2 respectively.

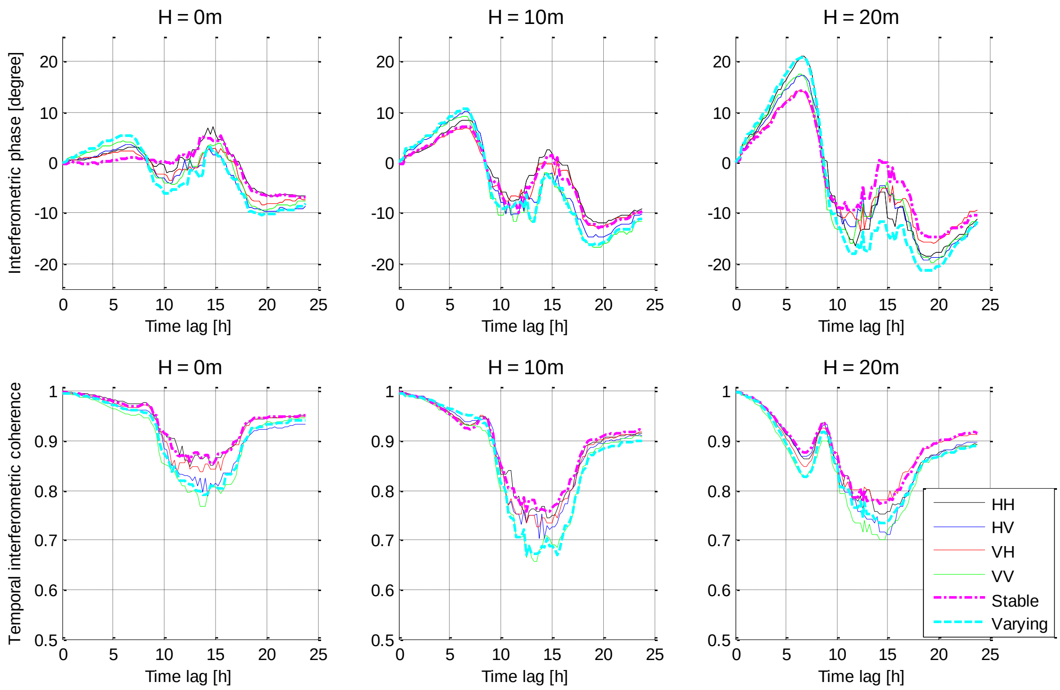

Figure 5. Amplitude and interferometric phase of day-night as a function of height.

In Figure 5, all polarizations are shown, as well as the stable and varying components. The temporal interferometric coherence amplitude and phase variation during day and night as a function of height can thus be observed. At the ground layer, the coherence amplitude and phase are the most stable. In summary, night hours are most stable for data acquisition due to the high coherence.

4. Conclusions

A successful TropiScat ground based radar experiment for tomographic imaging has been presented. Thanks to the fine time sampling, the first ever tomographic movie capturing the forest daily change has been produced, at least to our knowledge. Tomogram analysis revealed a diurnal vertical motion of the forest center of mass. This phenomenon is strongly related to daily temperature variations, which suggests a connection with forest transpiration phenomena.

Concerning the short time temporal coherence, the most relevant phenomenon is the coherence drop during daytime, due to the effect of the wind moving the forest canopy. The sum of Kronecker products has been proposed as a model to represent and provide a reasonable description of the structure of the covariance matrix of the multi-polarimetric and multi-temporal data. This result already appears to provide a very useful input concerning the BIOMASS mission, as it suggests that performance over tropical forest could be optimized by gathering acquisitions at dusk or dawn time.

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