TreeSCAT: A Ground Based Polarimetric Scatterometer Experiment in temperate forests

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Abstract. This paper deals with a ground experiment related to the future spaceborne BIOMASS mission for global forest biomass estimation. The experiment is a ground based scatterometer that measured the evolution of intensity and coherency of HV during two periods of 3 weeks and 2 months. The evolution of polarimetric intensity and coherence was also measured while artificially watering the soil and then the tree.

Keywords: Remote Sensing, Radar, Scatterometer, temporal coherency, temperate forests.

1. Introduction and context

It is of great interest to determine the global quantity of biomass on earth. For this purpose, SAR images at P band look promising to perform this biomass retrieval over forests, and it is the primary objective of the BIOMASS project [1].

At the moment, two main strategies are advanced. On the one hand, the 'P-HV' method is based on the fact that for most trees HV intensity is increasing monotonously with biomass. However, previous studies have shown on the base of simulations that other parameters like branches moisture may also play a significant role in the intensity scattering. It looks then worth verifying this experimentally, which should induce also variations with time at various scales (intraday, daily, monthly, etc). On the other hand, the method based on POLINSAR rests on the assumption that biomass is generally proportional to height, and the latter may be derived from the knowledge of complex interferometric coherences in HH,HV and VV [2]. When using repeat pass interferometry, the temporal decorrelation may play a parasitic role in this strategy and therefore needs to be evaluated also.

To finely study these effects, a proximity experiment is the most convenient: the measured scene may be well characterized, the measurements may be repeated as frequently as wished and hopefully they may be linked to some physical characteristics like air pressure or wind velocity which may be measured as well synchronously. Such proximity experiment has been proposed here on ONERA premises. It consists in the observation of one tree with an emitter-receiver located on the roof of ONERA laboratory. This emitter-receiver is remotely controlled via Ethernet, and then a fine temporal survey of the radiometry and the phase scattered by a tree may be performed. Its goal is permitting to see if the radiometry is stable or not and to better understand the reasons why.

To begin with, the experiment is described, with a site and experiment description as well as the parameters considered for the measurements. This is done in section 2. Then, section 3 presents the results obtained in terms of time series as well as artificial changes of the scene, and section 4 gives a synthesis and an analysis of the results obtained.

2. Feasibility Study

The system was foreseen to be built up with existing instrumentation: horn P band antennas, log-P ones, Vector network Analyser, humidity probe, etc. However it soon appeared that specific components had to be acquired to make successful the experiment, since with existing antennas the ratio target to clutter was too bad. It also appeared necessary to acquire an autonomous system for acquisition of meteorological variables.

The experiment is based on standard reflectrometry. The power budget at the distances involved is highly above noise. However, some difficulties arise due to the configuration of the possible sites. Among these difficulties, one can cite the fact that the extent of the impulse response may not be long enough to provide a sufficient number of independent samples to correctly evaluate the radiometry and the coherence and also the possibility of unwanted contributions of the environment of the tree (roof, wall, gate…) which are only separated from the tree contribution by a discrimination in range and by the antennas diagram. Therefore it is to determine first which is the degree of reliability of the possible output data in a feasibility study of this experiment in this frame, and if they have to be degraded.

2.1 Site description

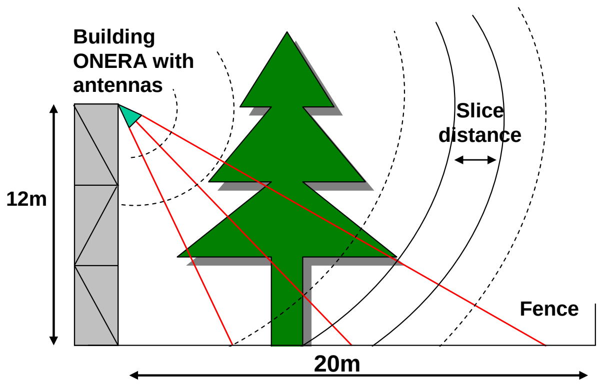

Figure 1. Diagram (left) and picture (right) of the scene.

The ground experiment has been installed on a building at ONERA, facing a temperate tree, a cedar (Fig. 1). Based on the use of a Vector Network Analyzer and adequate antennas, it may deliver P band polarimetric impulse responses.

2.2 Hardware

Antenna mounting is shown on Figure 2. They are attached to the rail overwhelming the building wall through a gliding support. RF cables connect both antennas to the ports of a VNA.


Figure 2. Mounting of the antennas on the roof and the VNA used for this experiment, respectively left and right.

Antennas are oriented vertically and horizontally, so that one can get at the same sequence : HV in transmission mode, HH and VV in reflection mode. They are Log-P type antennas, the radiation diagram is shown on Figure 3. One can see the dissymmetry of the planes E (50° 3dB aperture angle) and H (70°), nevertheless much smaller than those of the usual Log-P antennas.

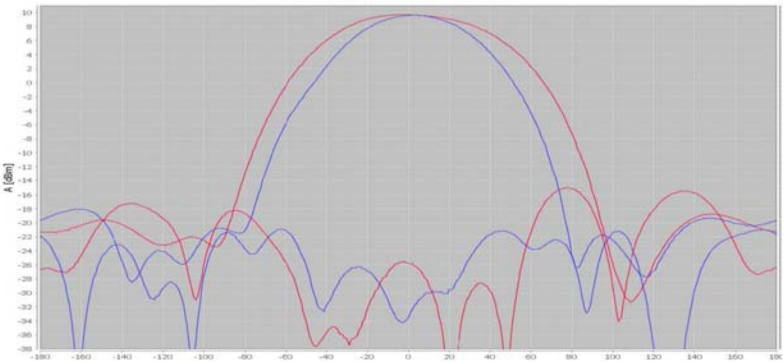

Figure 3. Radiation pattern in E and H planes, in co and cross polarization.

2.3 Software

The system proposed here is based on the use of a VNA as emitter-receiver. The fix antennas close to each other are located on the roof rail. The VNA, driven by a PC itself remotely driven with Ethernet, is located inside the building. In this case RF power is conveyed from VNA ports to antennas through RF cables of approximately 6 meters length .
The VNA operation is a step frequency one. At each frequency, the illuminated area obviously results from the antennas radiation (and reception) diagrams characterized by the 3dB aperture angles in elevation plane θ_{ele} and azimuth plane θ_{az} , and the antenna elevation angle θ_i . Elevation plane is defined by the beam pointing direction and the vertical axis, azimuth one is perpendicular to the latter and still containing the beam pointing direction. The antenna beam characteristics are intrinsic and roughly characterized by the 3 dB apertures in the principal planes: θ_E for the **E** plane parallel to radiated electric field and θ_H for the **H** plane perpendicular to the latter, both of them containing the antenna beam pointing direction. So in V polarization elevation plane is the **E** plane and azimuth plane is the **H** plane, whereas in H polarization elevation plane is the **H** plane and azimuth plane is the **E** plane. Furthermore, the antenna footprint depends on the height of the observation plane due to the volume effects of the forest (Figure 4), and is for example different for the soil and the foliage top height H_{cap} .

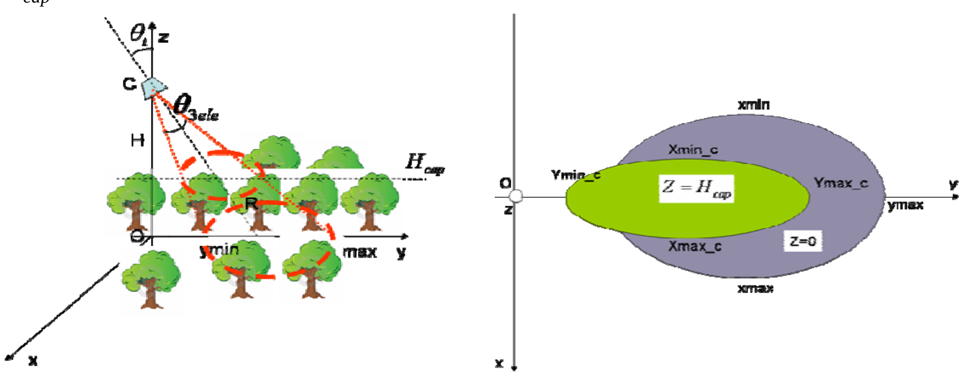

Figure 4 . Foliage and ground illumination at each frequency; right: projection on the horizontal plane.

Antenna aperture has to be large enough to illuminate a sufficiently large footprint to be representative without being spoilt by remote or close parasitic echoes, and preferably has to be characterized by similar radiation patterns in both E and H planes. The antennas selected here present good trade-off in respect to these objectives.

Azimuth resolution is obtained with the limits of the antenna footprint, range resolution through inverse Fourier transform of frequency domain data obtained with the frequency 'ramp' (Figure 5). If Δf , ∂f are respectively the frequency bandwidth and the frequency step ($\Delta f = (Nf - 1) \times \partial f$), then the range resolution is $dr = \frac{c}{2\Delta f}$ and the unambiguous range $D = \frac{c}{2\delta f}$.

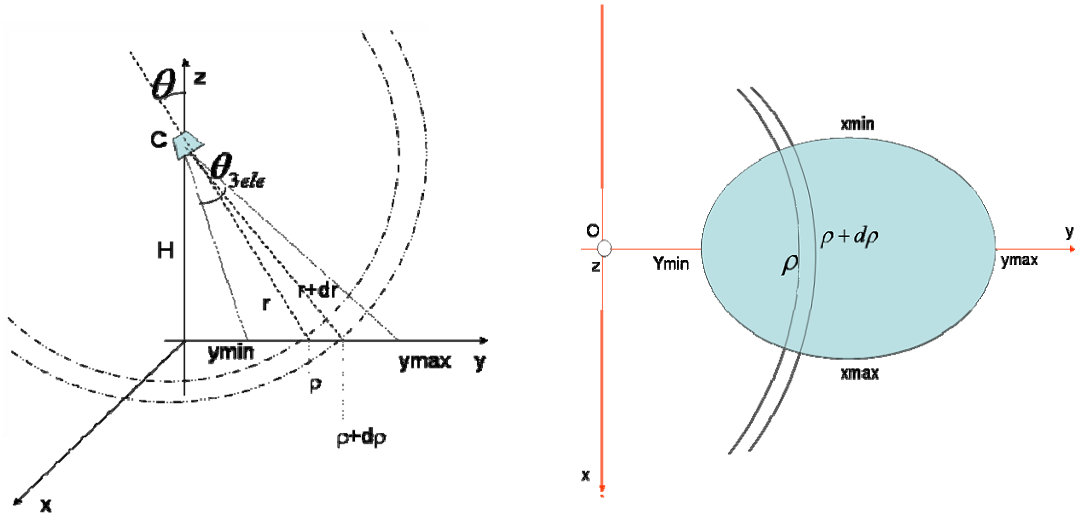

Figure 5 . Ground illumination after range gating; right: projection on the horizontal plane.

Actually, as here only one tree is observed, the range cells do not correspond to an identical volume. However, we will not consider this particularity. For the volume zone, we will consider a volume clutter distribution, and for the remainder a surface area.

2.4 Acquisition parameters

For all the experiments presented in the sequel, the configuration parameters are the following:

- Frequency band of measurement: 400 MHz – 1 GHz. However, the results presented in the paper have been processed at P-band only (400 MHz- 600 MHz).
- IF filter is set to 10 kHz.
- Main beam pointing angle of the antennas is set to 45°.
- Full S parameters is measured so as to obtain full polarization measurement at every acquisition.
- Acquisition and data storage are made fully automatic.

The corner reflectors, either trihedral for HH and VV, or dihedral for VH, were located on the scene to check the correct behaviour of the system.

3 Measurements series

3.1 Time series

Two periods of acquisition took place. The first one had a duration of 3 weeks: from May the 5th to May the 25th, with a periodicity of 5 minutes. The second one was between September the 16th up to November the 5th, with a periodicity of 5 minutes. On the 4 channels, the 4001 frequency complex data have been acquired at each time interval, and stored on the personal computer driving the experiment by Ethernet. In this section, only the response of the volume, trunk and soil in HV will be exploited.

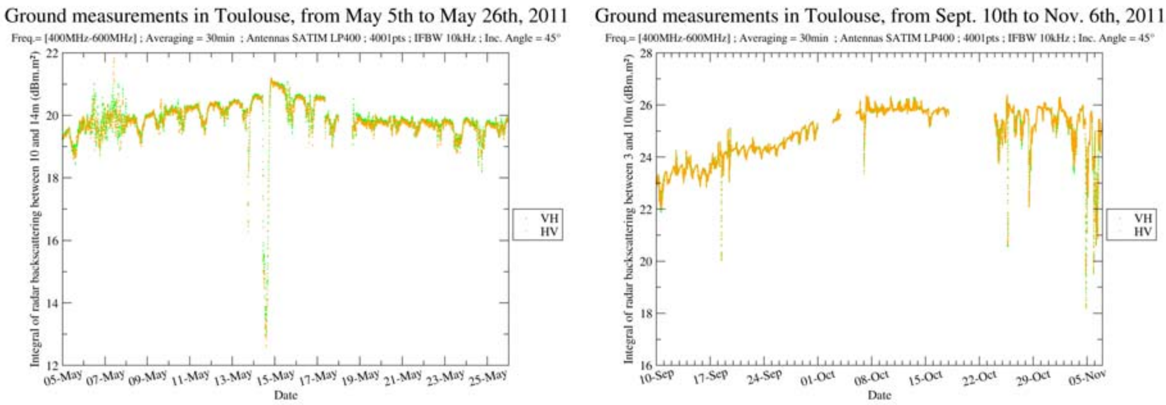

Figure 6. HV volume scattering over both periods, at P-Band.

The number of independent samples in each impulse response is significant but still limited. Actually, it was increased by considering together all the impulse responses contained in a time interval of 30 minutes. This time grouping should have no effect if the scene is steady, and should reduce speckle effects if short term movements are present, in particular due to the wind. This process was applied to the computation of the temporal coherence as well.

The intensity results are displayed on Figure 6, and the coherence results on Figure 7, both for P-band.

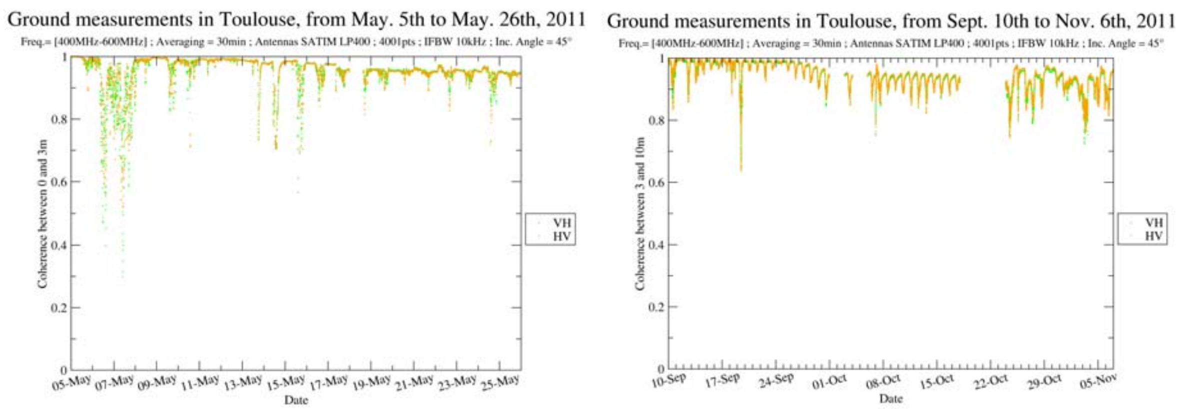

Figure 7. HV volume coherence over both periods.

At the time of these acquisitions, the personal meteorological acquisition system was not yet furnished, and so the meteorological data of the neighbouring station of Rangueil, 3 km away from the monitored tree, are used and reported. Then, one can find wind velocity, air moisture content, temperature and pressure on Figure 8.

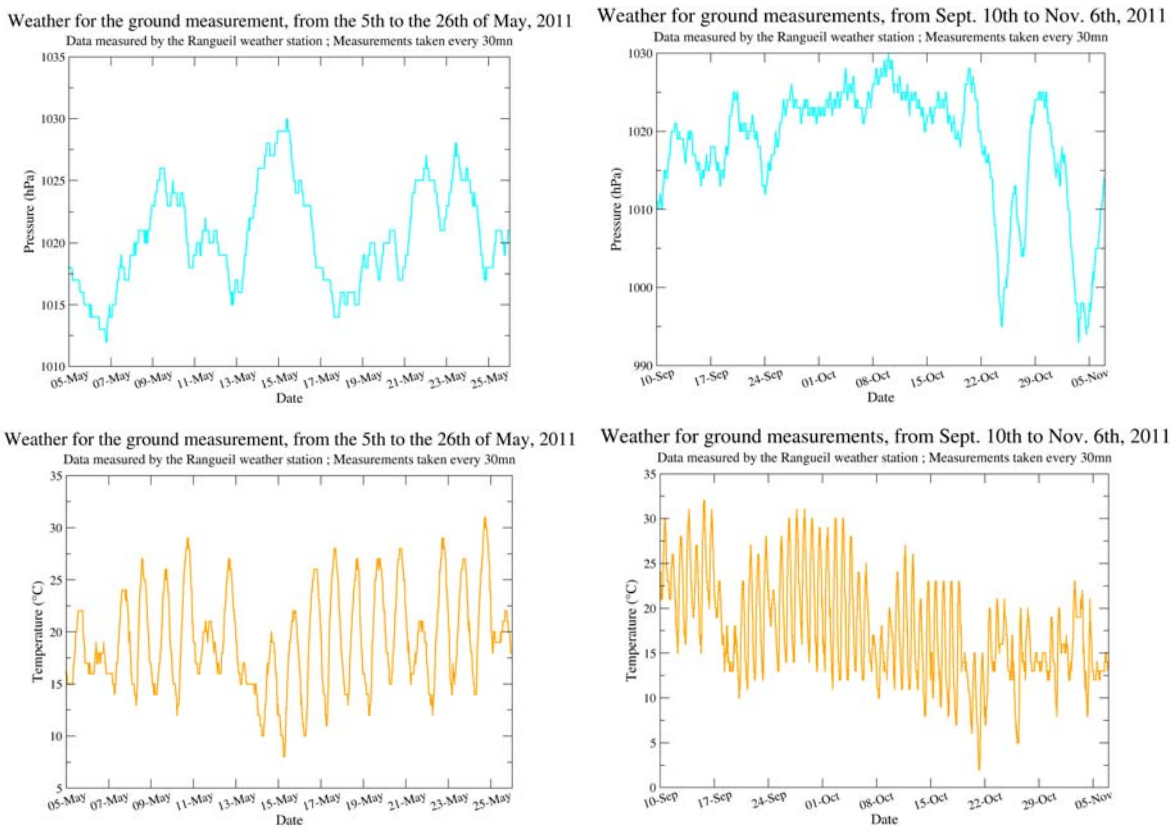

Figure 8. Air Pressure (top) and air Temperature (bottom) measured for both periods.

3.2 Artificial watering

After the second period, an artificial rain of the scene was considered (Figure 9).

Figure 9. Artificial watering of the soil (left) and the volume (right).

On Figure 10, one can see the evolution of the intensity and the coherence for HH, HV and VV during the artificial watering of the scene. The watering was performed during a dry period of summer, around 8:00 a.m. The soil began to be watered at the grey vertical line. Then when the soil was completely wet, at the purple line, the volume began to be watered, until the pink line. After this line, no mare watering was performed. The acquisitions have continued during the whole day, until dusk, and are displayed on Figure 11.

Note that the watering was stopped during the acquisitions.

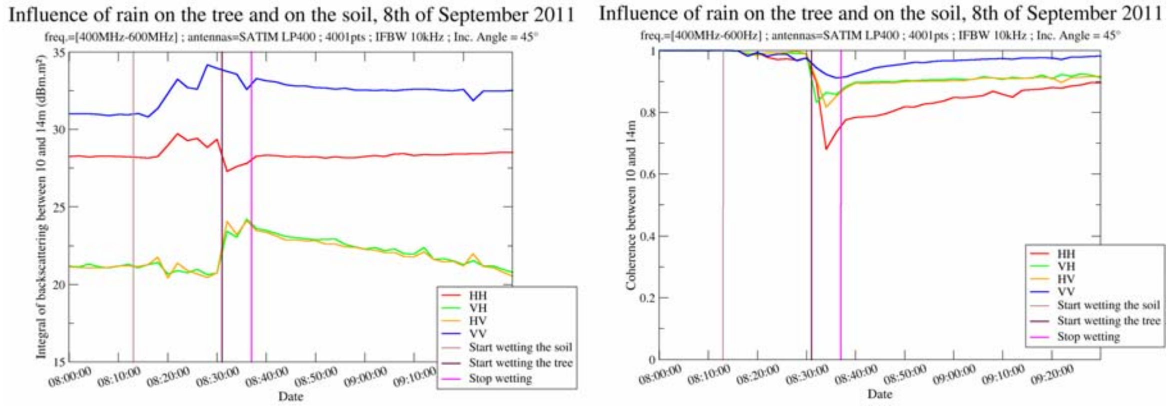

Figure 10. Evolution of the polarimetric intensity and coherence during the artificial watering.

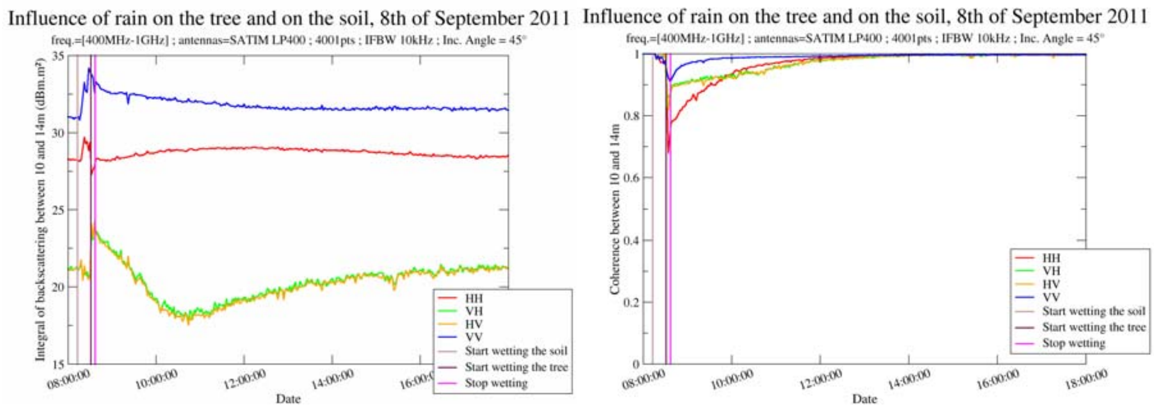

Figure 11. Unzoom of the polarimetric intensity and coherence displayed in Figure 10.

4. Analysis

First, one can see clearly on the plots of intensity a diurnal cycle. Though very regular, it is relatively limited: in the order of 1.5 dB for May, less than 1 dB in the second period. The maxima appear approximately at 9 in the morning, the minima at 6 in the afternoon. This cycle is clearly related to the evapo-transpiration of the tree, then subject to change with the season. Note that this diurnal cycle appears for all meteorological indicators.

A longer time scale appears also. Indeed, in the first period, a change of the envelope of 1 dB over 10 days may be observed. Grouping both periods, a variation on the envelope of 4 dB may be observed. The meteorological indicator most related to this scale seems to be the mean temperature.

Both short and long term variations may be attributed to the evapo-transpiration. Indeed, it was shown in a previous study [3] that moisture content variation in the branches induce at P band a significant variation of the P-HV intensity. We have here a quantitative idea of the orders of magnitude for this phenomenon in temperate regions like the south of France.

Apart from these regular evolutions, abrupt meteorological changes occur during the two periods. A strong wind sequence appears at beginning of May. In spite of time averaging, speckle effect remain significant but the order of magnitude is preserved. Rain sequences appear and may be recognized with abrupt change in radiometry and unusual values. This behaviour has been more widely analyzed on the coupling zone, not displayed here, and make discard those values which are obtained just under the rain due to antennas problems.

One can note that HV is poorly influenced by previous rain : we observe lees than 1 dB variation on May the 15th. The artificial rain confirm this point.

In the coherence results, the diurnal cycles are retrieved but the long-term evolution seems of less importance than for the intensity. The envelope of coherence remains high, greater than 0.9.

For the artificial watering, when wetting the soil, HH and VV intensity are increasing and HV remain stable, because the HV phase center is located in the volume of the tree. During this time, the polarimetric coherence remains stable. When watering the volume, HV intensity is increasing of 4 dB and a decorrelation appears for all polarizations. After the end of the watering, HH and VV intensity are reaching the value they had before and the coherence is back to around 0.98. Note HV intensity is back to its previous value after a decreasing which is linked to the diurnal cycle of HV intensity.

5. Conclusion and future prospects

The system for radiometric and coherence observation for one tree at P band has been set up, and the software for continuous acquisition monitored through Ethernet has been developed and implemented. Design and validity tests have shown that the results for the volume in HV are reliable. Two time series over 6 months have reported and analyzed. It appears that the P-HV intensity follows diurnal and weekly to monthly changes , the latter being much more significant, both of them certainly linked to evapo-transpiration. In this experiment, it seems less sensitive to wind and rain, which was confirmed by artificial watering. Coherence remain high over both periods.

Future prospects should include supplementary time series acquisition and analysis, deeper interpretation of results with electromagnetic models in-situ meteorological acquisitions.

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