Initial Analysis on the Sensitivity of BIOMASS P-band Quad-Pol SAR Images to Agricultural Crops

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Abstract

P-band quad-pol images acquired by the recently launched BIOMASS mission over a region in Colombia (mostly dedicated to sugarcane cultivation) has been used to check the potential sensitivity of such data to the crop status and growth. The analysis of these images demonstrates certain relationship between the radar response (in terms of scattering mechanisms) and the stage in the growing season. Typical polarimetric features, such as the backscattering coefficient at different channels, the correlation and the ratio between the co-polar channels, and a radar vegetation index, have been computed to interpret the response of sugarcane at P-band. Results suggest that P-band quad-pol data from the BIOMASS mission is well suited for monitoring the growth of this crop type.

1 Introduction

The main objectives of the ESA BIOMASS mission are to measure forest biomass and height globally to improve understanding of the carbon cycle and climate change. It aims to create the first comprehensive 3D maps of forest structure, track changes over time, and quantify carbon stored in forests to support climate policy. The mission will also use its unique P-band radar to observe subsurface geology and monitor changes in dry and frozen regions like glaciers.

Although agricultural crops are not among the priority land scenarios to be studied with BIOMASS, P-band radar could take advantage of its large wavelength (70 cm) to penetrate the vegetation canopy and provide information about both soil and vegetation. This would be particularly useful for crops like corn, sugarcane, cocoa, millet, etc., which exhibit dense canopies and usually reach large vegetation heights (above 2 m). In fact, it is well-known that higher frequency bands, such as C- and X-band, exhibit a saturated sensitivity to the development of crops when they are very tall and/or very dense. In such situations, the characteristic short wavelength of C- and X-band (3–6 cm) limits their penetration into the vegetation volume, hence producing a response coming mainly from the upper canopy. As a result, the monitoring potential of these bands is restricted to the early growth stages. The use of low frequencies such as L- and P-band allows us to overcome this limitation thanks to the penetration capabilities of long wavelengths [1]. In the past, the main examples of the use of P-band data for agricultural crops were focused on crop classification, for which multi-frequency datasets gathered by an airborne system were exploited [2, 3].

In this work we explore the first sets of images gathered by the BIOMASS mission for the Cal/Val activities during the Commissioning phase, some of which were acquired in agricultural areas. In particular, we initially focus on the Cauca Valley (Colombia) which is a wide area dedicated to the cultivation of sugarcane. In the past, sugarcane has been monitored with Earth observation satellites, also including radar images at different frequency bands (L-, C-, and X- band), but not at P-band [4, 5, 6].

The analysis of the BIOMASS data has been carried out by first extracting polarimetric features and comparing them to biophysical variables that characterise the condition of sugarcane fields. In situ data gathered in the framework of the EU-funded DINOSAR project [7] are used for evaluating the sensitivity of the BIOMASS data to sugarcane biophysical variables, like biomass and plant height. Moreover, a large dataset of polygons, available thanks to the ESA-funded CC4SC project [8] is also exploited to evaluate the sensitivity of the data to the *day of season*, which is a key variable to interpret the phenology of this crop.

2 Test Site, Datasets, and Processing

The main study site of this work is located in the Cauca Valley, Colombia, where most of its surface (around 237,000 ha) is dedicated to sugarcane cultivation (see **Figure 1**). The climate conditions in the Cauca Valley allow for year-round cultivation of sugarcane, with no distinct harvest seasons. This means that, at any time, one can find fields with sugarcane at any growth stage, from sowing (or ratooning) to harvest.

The typical duration of the cultivation cycle at each field is between 12 and 15 months, being the harvest decided on the basis of the management of mills and further sugar processing steps. Sugarcane is a crop of class C4 that accumulates biomass continuously if conditions are favourable.

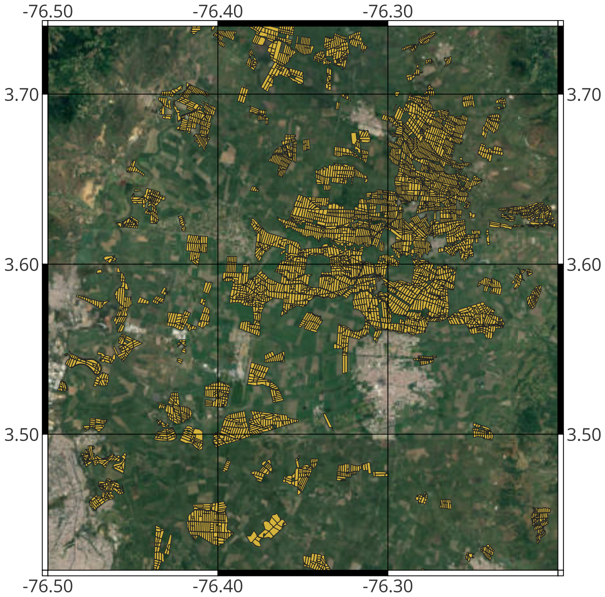


Figure 1 Optical image of the study area, located in the Cauca valley (Colombia), with the position of sugarcane fields employed in the CC4SC project.

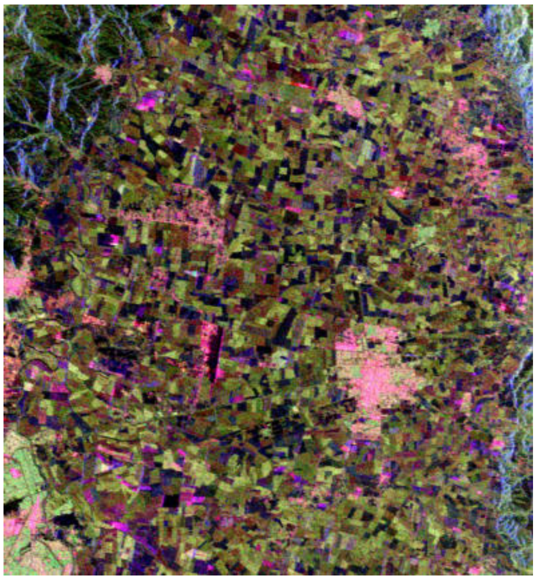


Figure 2 Pauli RGB composite of the BIOMASS image acquired at 05-06-2025 over the Cauca Valley (Colombia). Colour code: R = HH-VV, G = 2VH, B = HH+VV.

Plants typically reach heights above 3 m in most cases. However, there is a noticeable variability in the growth (in terms of biomass and plant height) among fields and also within some fields, due to the influence of soil conditions and farming practices [9].

A stack of 6 images acquired by BIOMASS between 05-Jun-2025 and 20-Jun-2025, with a 3-day revisit period, has been used in this work. The stack of images is processed to L1C level. All images are co-registered to a primary image, and look-up-tables for radiometric calibration and for interferometric processing are provided with the images. The images were acquired with swath S1, characterised by an incidence angle from 23 to 27.8 degrees. The spatial resolution of the images is 24 m x 7.5 m (slant-range x azimuth) approximately.

Starting from the L1C products, the processing carried out consists of the following steps:

- Read the SLC images (amplitude and phase) of the three polarimetric channels (HH, VV and VH), where VH denotes the cross-polar channel (and VH = HV due to reciprocity).
- Apply the radiometric calibration to convert the image values of all channels to backscattering coefficient γ_0 as complex values.
- Compute the polarimetric covariance and coherency matrix, for which a 10x2 boxcar filter was used.
- Geocoding to geographical coordinates (lat/lon).

3 Results

Figure 2 shows a false-colour RGB composite of the main study area, for which the backscattering coefficient of the three channels of the Pauli basis has been used for the primary colours. The use of the Pauli basis, where Red channel corresponds to HH-VV, Green to 2VH, and Blue to HH+VV, enables a first and quick interpretation of the main physical scattering mechanisms in the scene. On the lower left part of the image we can identify in green and pink colours a portion of the city of Cali, whereas the town of Palmira appears more centred in this image. Urban areas are usually represented in reddish colours because of the dominance of double-bounce scattering, and streets and buildings rotated with respect to the incidence direction usually create a green colour due to the strong response in the cross-polar channel produced by such rotated elements. The mountain ranges at the left and right sides of the image define the West and East limits of the Cauca Valley.

From the point of view of agricultural applications, the most interesting aspect of **Figure 2** is the diversity of colours (both in hue and intensity) found in the cultivated area. Dark areas indicate low backscattered power from the soil, which in principle correspond to fields in the early growing season, during which the plants have not grown enough yet. Some of the (not so) dark areas show a blue colour, which means that surface scattering is dominant in that fields. Moreover, there are some sparsely distributed fields represented in dark pink or purple colour, which denotes a dominant double-bounce scattering mechanism (likely produced by the interaction between stems and ground), but with much lower intensity than in the case of buildings. Finally, most of the sugarcane fields are represented in green colour, showing a wide range of intensities which we can associate with the amount of volume scattering coming from the vegetation canopy at different growing stages.

In the rest of this section we present the images of some polarimetric features which are useful to start understanding the radar response of sugarcane fields at P-band. The backscattering coefficient of the three linear channels (HH, VH, and VV) is shown in **Figure 3**. We can observe that the VH channel exhibits the lowest values in the overall scene, but there is a wide dynamic range in the cultivated area. Contrarily, the VV channel is very homogeneous all over the cultivated area, showing much less contrast between early- and late-season fields. Regarding HH, it shows the highest backscatter values, and its dynamic range in the cultivated are is in between the other two channels.

A specific polarimetric feature that can be derived from quad-pol data is the complex co-polar coherence, which has recently proved its usefulness for crop monitoring with airborne L-band data [10, 11]. The amplitude and phase of the coherence between HH and VV channels is represented in **Figure 4**. Coherence amplitude is relatively low at most fields, which correspond to the expected response in presence of a vegetation volume. Such a low coherence is in agreement with the theoretical response of an ideal random volume of scatterers (without radar backscatter from underlying ground), which would produce a coherence value of 1/3 [12]. As expected from surface scattering, the fields in the early season (which appeared dark in **Figure 2**), for which backscatter is dominated by the ground response, exhibit a much higher coherence amplitude. The phase difference between HH and VV is consistently around zero for the early-season fields, which is characteristic of surface scattering. Nonetheless, the fields with low coherence (assumed dominated by volume scattering) mostly exhibit a phase around $\pm 180°$. Such a phase is typically associated with double-bounce scattering in the literature, as it is the phase expected from a pure metallic dihedral [13]. In this case, the reason of such a value over grown sugarcane fields is to be investigated, as may be characteristic of the P-band large wavelength. A detailed analysis of this aspect is ongoing.

Another feature derived from the two co-polar channels is the ratio of their backscattering coefficients (HH/VV), which is represented in **Figure 5**. Such a ratio is high in presence of a dominant double-bounce scattering mechanism, as a consequence of the Brewster angle influence at the two surfaces of the dihedral, which affects only the VV channel. In this scene, the town of Palmira is characterised by a large HH/VV ratio. As for the sugarcane fields, the ratio values are positive overall, but not very high as could be expected from the double-bounce mechanism.

As a final feature analysed for this contribution, we inspect the quad-pol radar vegetation index (RVI) defined as [14]:

$$\text{RVI} = \frac{8\text{VH}}{\text{HH} + \text{VV} + 2\text{VH}} \quad (1)$$

The image of RVI is shown in **Figure 6**. It seems to represent well the amount of vegetation canopy associated with the sugarcane fields, but a quantitative comparison is still to be carried out.

4 Conclusions

The first qualitative results shown in this work using a quad-pol P-band image acquired by BIOMASS mission

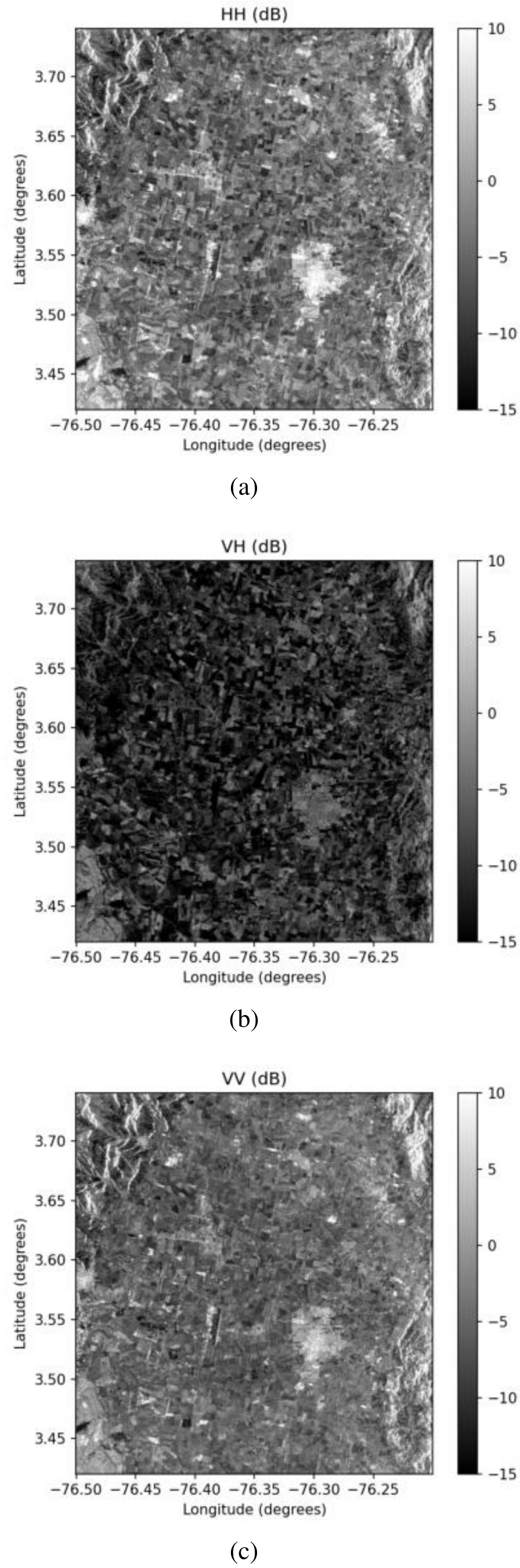
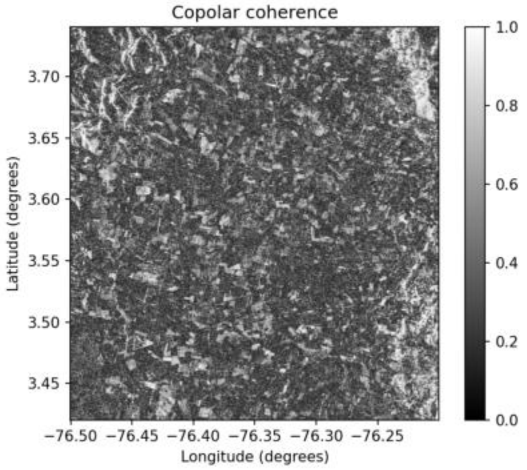
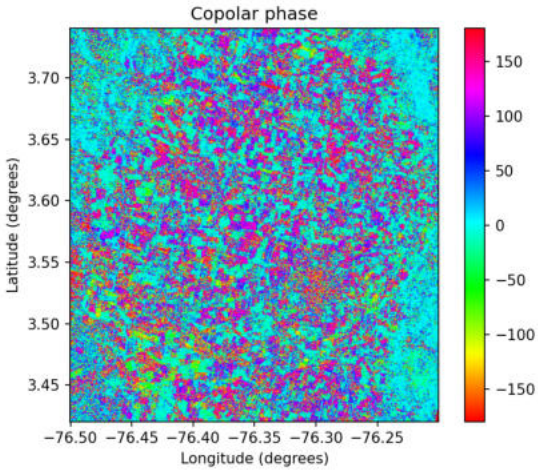


Figure 3 Backscattering coefficient (γ_0) at the linear channels for the BIOMASS image acquired at 05-06-2025 over the Cauca Valley (Colombia). (a) HH, (b) VH, and (c) VV.



(a)



(b)

Figure 4 Complex co-polar coherence for the BIOMASS image acquired at 05-06-2025 over the Cauca Valley (Colombia). (a) Amplitude, and (b) phase.

over a scene dominated by sugarcane fields in Colombia have demonstrated the presence of sensitivity in the data with respect to the physical features of the fields. Despite the very large wavelength of this radar, the signature of the crop fields is evident in the images. Thanks to the diversity of growth conditions in this area, a single-date image can be used to analyse the radar response of the sugarcane fields along their cultivation cycle. An in-depth analysis of this response, including a quantitative validation with in-situ data (e.g. plant height and biomass) is being carried out and will be presented at the conference.

Although the BIOMASS mission is mainly centred on forest studies, this initial analysis suggests the potential use of P-band for other land applications in the view of possible future SAR missions focused on agricultural crops.

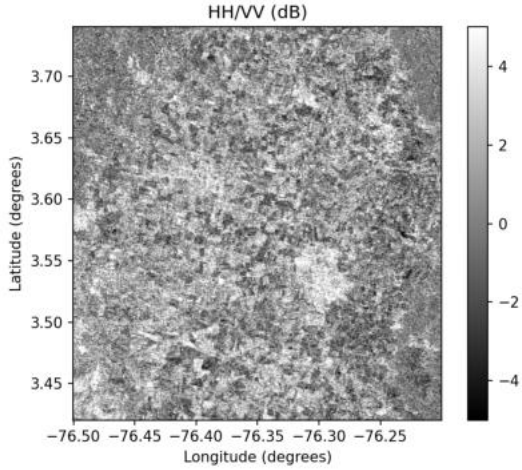


Figure 5 Ratio of the backscattering coefficient of the copolar channels (HH/VV) for the BIOMASS image acquired at 05-06-2025 over the Cauca Valley (Colombia).

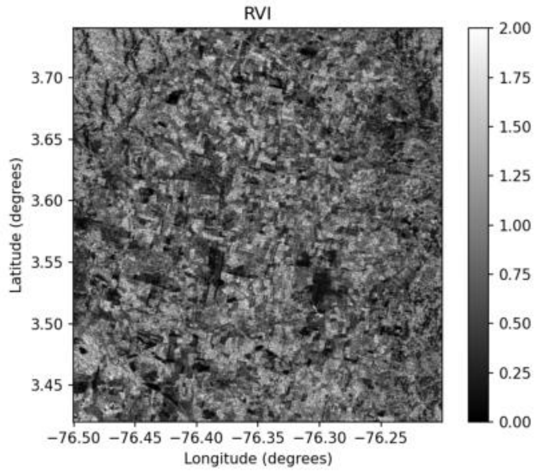


Figure 6 Radar vegetation index (RVI) for the BIOMASS image acquired at 05-06-2025 over the Cauca Valley (Colombia).

Acknowledgement

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