MONITORING FOREST ABOVE-GROUND BIOMASS FROM MULTIFREQUENCY VEGETATION OPTICAL DEPTH: A PRELIMINARY STUDY

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ABSTRACT

Vegetation Optical Depth (VOD) is highly sensitive to Above-ground Biomass (AGB), particularly at L-band, as this band is more sensitive to the canopy layer and has greater capacity to penetrate the vegetation. However, higher frequencies, such as C- and X-bands are more related to smaller vegetation structures. Then a combination of these three bands is expected to be relevant to accurate AGB retrievals. This study presents a comparison of three VOD products at three bands and evaluates the performance of a multi-frequency VOD combination by applying a Principal Component Regression (PCR) to Forest biomass. Results show that L-band VOD captures the 84% of the biomass and the PCR is built, mainly, for this band meaning that higher frequencies do not contribute substantially to the AGB retrieval in this study, still they do not affect the retrievals negatively.

Index Terms**—** Vegetation optical depth, multi-frequency microwave remote sensing, forest biomass, SMOS, AMSR2

1. INTRODUCTION

Above-Ground Biomass (AGB) is an Essential Climate Variable and an Essential Biodiversity Variable. Monitoring AGB and its changes is needed to quantify gains and losses in vegetation carbon stocks resulting from natural and anthropogenic processes. Such changes impact on the interaction between terrestrial ecosystems and the atmosphere. In particular, vegetation is a sink for more than 25% of anthropogenic carbon emissions. Hence, quantifying AGB changes is paramount to develop climate change mitigation strategies to reduce atmospheric CO2. Satellite remote sensing is probably the only technique able to monitor vegetation characteristics (e.g., AGB) globally and on a regular basis. In particular, passive observations of vegetation optical depth (VOD) capture the attenuation of the soil and vegetation microwave emissions as they pass through the vegetation canopy. The VOD depends on the combination of the canopy structure, biomass, and vegetation water content [1], and is used as a proxy of AGB. Various studies have applied VOD products to analyze forest dynamics and biomass using long- term series of VOD at different frequency bands (L-, C-, X- and Ku-bands; e.g., [2, 3, 4])., Importantly, the sensitivity of VOD to biomass increases with decreasing frequencies because lower frequencies provide information from deeper canopy layers [3, 5]. In that sense, multi-band VOD products such as the recently presented VOD Climate Archive (VODCA) allow preserving the characteristics of each frequency with respect to the canopy structural elements, and to study the VOD dynamics from different and complementary information sources [6]. Still, to the authors' knowledge, the combination of VOD from different bands to retrieve AGB has been addressed only in few studies [2], and further research is needed to include the lowest available frequency band (L-band) in this approach. To fill this gap, this study presents a comparison of VOD-AGB relationships from two VOD products at three frequencies (1.4 GHz, 6.9 GHz, 10.7 GHz, i.e., L-, C- and X-bands, respectively), and evaluates the performance and sensitivity of the combination of these frequencies to study AGB.

2. DATA AND METHODS

2.1. Data

2.1.1. Study area

The study area is Catalonia (NE Spain) (Figure 2). The region spans through 32,000km^2 with altitudes varying from the sea level to over 3000 m. It presents a Mediterranean climate with mild winters, and warm and dry summers. The Pyrenees create topographical- gradients from Mediterranean-type biomes to temperate, sub- alpine and alpine-type regions. Approximately the 60% of Catalonia is covered by shrublands and forests dominated by Pinus sp. and Quercus sp. species [7].

2.1.2. Vegetation Optical Depth: L-, C- and X-VOD

VOD products at L-band (L-VOD; 1.4 GHz), C-band (C-VOD; 6.9 GHz) and X-band (X-VOD; 10.7 GHz) are used in this study. The L-VOD is derived from the ESA'S Soil Moisture and Ocean Salinity (SMOS) mission. In particular, the SMOS-IC product is applied. It is produced by INRA- CESBIO and the retrievals of soil moisture and VOD are based on the L-MEB model inversion and performed over pixels considered entirely homogeneous [8]. The products are provided on the EASE (Equal Area Scalable Earth) Grid version 2 (EASE2) with a spatial resolution of 25 x 25 km at 30∘ of latitude [9]. The C- and X-VOD products are derived from the Advanced Microwave Scanning Radiometer 2 (AMSR2). They are retrieved using the LPRM V5 [10]. Their native resolutions are 35x62 km and 24x42 km, respectively, which are re-gridded to provide a final product at 25 x 25 km. In this work, C- and X-VOD have been linearly interpolated to match the EASE2 25 km grid of L-VOD.

2.1.3. Catalan Forest Inventory

The Catalan Forest Laboratory is a joint initiative by the Centre for Ecological Research and Forestry Applications (CREAF) and the Forest Science and Technology Centre of Catalonia (CTFC) [11]. The laboratory maps are based on information from the Forest National Inventory version 3 (IFN3), which is a database of circular sampling plots distributed across Spain at a density of one plot per km2. In Catalonia, the inventory includes observations on 95 tree species, mainly pines (Pinus sp.), oaks and holm oaks (Quercus sp.), maples (Acer sp.) and beeches (Fagus sp.) for the period 2000-2010. The Forest Laboratory processes the IFN3 raw data to obtain maps of several forest attributes, such as carbon stock, tree density, biomass, etc. Since this study analyzes the sensitivity of VOD to AGB, the variable Aerial Biomass (i.e., synonym to Above-Ground Biomass; AGB) is used as the AGB bench-mark data. Figure 1 shows the AGB map from the Catalan Forest Laboratory.

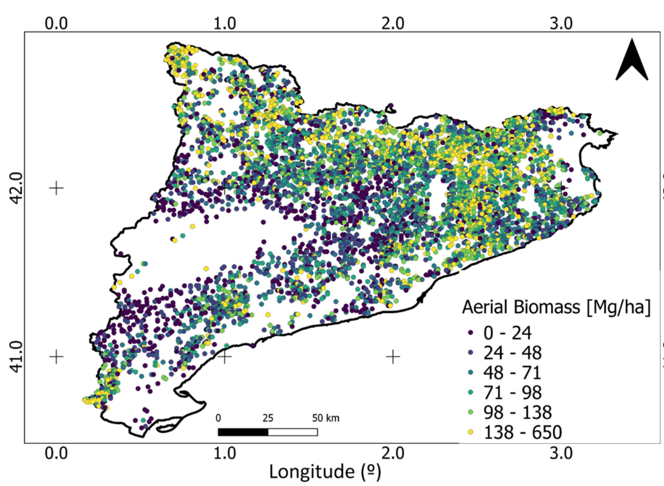

Fig. 1. Aerial biomass [AGB; Mg/ha] in Catalonia: Observations taken during the period 2000-2010. Plots of $1km^2$

2.1.4. International Geosphere Biosphere Program (IGBP) Land Cover

The International Geosphere Biosphere Program (IGBP) divides the land cover of the Earth into 17 land classes [12]. The IGBP pixels have been resampled to the spatial EASE grid version 2 by allocating to each pixel the dominant class. Only forests are considered in this study, keeping only homogeneous pixels with a dominant fraction of forests classes higher than 60%. Pixels characterized by a fraction of open water body and urban areas larger than 5% are excluded.

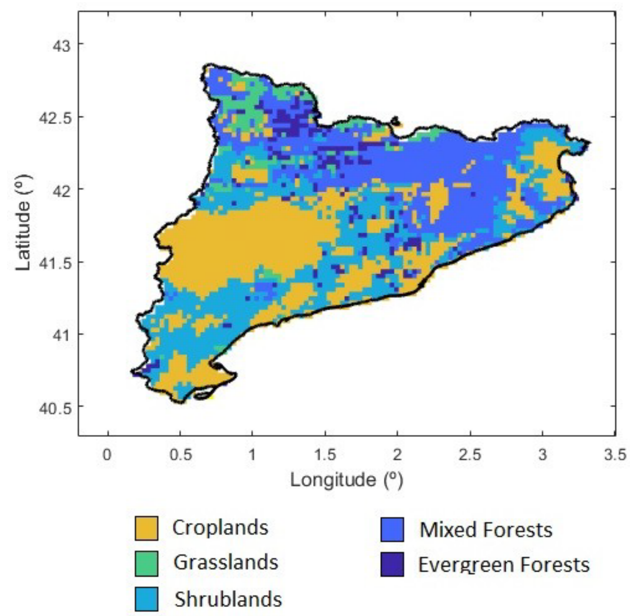

Fig. 2. IGBP Land Cover

2.2. Methodology

Daily L-VOD values were filtered by removing strong topography, frozen ground, and polluted scene by radio-frequency interference (RFI). Also, SMOS brightness temperatures with RMSE more than 8 K were eliminated in order to remove poor quality data. VOD products were then yearly averaged using both the ascending and descending orbits to remove the VOD diurnal variations due to its sensitivity to the vegetation water content, and rain interception. The differences between raw VOD data and smoothed VOD data, by applying a moving-average window of 30 days, have been used to exclude outliers, removing the data lower/higher than the 10th/90th percentiles. Then, the filtered data of the ascending and descending passes was averaged into one VOD dataset by product. Consequently, the sample used is 22 forest pixels in Catalonia. The sensitivity of the three bands to AGB is analyzed by means of the Pearson's correlation coefficient (R). Then, in order to detect multicollinearity between the variables, the

Variance Inflation Factor (VIF) was computed for the three VOD products. Since the variables were correlated and show multicollinearity (see Section 3), a Principal Component Regression (PCR) was proposed. Also, a L-VOD linear regression was computed in order to compare the sensitivity of this band to the PCR. The VOD and principal components (PC) values were scaled between 0 (equivalent to minimum value) and 1 (equivalent to maximum value) in order to ease comparisons.

3. RESULTS

Table 1 shows coefficients of correlation for VOD bands and PCs. L-VOD is the product most correlated to AGB, as it presents very high Pearson's correlation coefficient (r = 0.84), while the C- and X-VOD show significantly higher dispersion and lower coefficients (Table 1 and Figure 3). Since these variables are moderately correlated and present (VIF = 1.6), a combination of them using a PCR is appropriate in this study. Table 2 shows the correlation of every VOD product to every principal component and their percentages of explained variance. These components are the linear combination of the L-, C- and X-VOD values for the selected pixels. While PC1 is dominated by C- and X-VOD and explains the 87.56% of the total VOD variance, L-VOD shows the highest coefficient in PC2 and dominates its variability. Individually, these two components (PC1 and PC2), which explain the 99.3% of the VOD data, are less correlated to AGB than L-VOD, although more correlated than C- and X-VOD (Table 1).

Considering PCR and L-VOD linear regressions, Table 3 shows the regression coefficients of both models, as well as their significance (p-value). The R2 coefficients are similar, meaning that both models are highly capable to explain the observed AGB. The PCR can be explained as a multiple linear regression of PC1 and PC2, where the effect of PC2 to the dependent variable (AGB) is stronger than the effect of PC1, as its coefficient is higher than the PC1 coefficient (Table 3).

Estimator	R	RMSE
PCR	0.85	295.3
PC1	0.62	332.2
PC2	0.59	663.7
L-Band	0.84	258.3
C-Band	0.55	601.8
X-Band	0.50	647.1

Table 1. VOD and PC relationships to the AGB

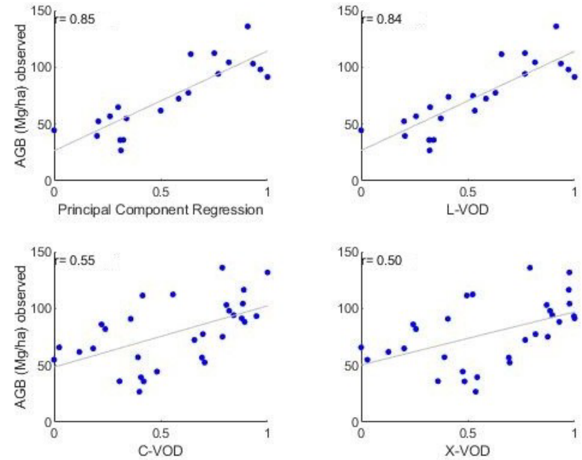

Fig. 3. L-,C-, X-VOD and PCR relationships to the AGB

Band	PC1	PC2	PC3
L	0.33	0.94	-0.01
C	0.69	-0.25	-0.68
X	0.65	-0.22	0.73
pt Variance	87.56	11.73	0.72

Table 2. Principal Components coefficients

4. DISCUSSION AND CONCLUSIONS

The results presented in this study show that the sensitivity of VOD to forest AGB increases as the frequency decreases. This is consistent to previous work comparing different frequency VODs with AGB [4] in agreement with the fact that lower frequencies have greater capacity to penetrate the vegetation. In this sense, PC1 and PC2 obtain different information, as PC1 is mainly correlated to C and X-VOD and they are capturing more information of the higher part of the canopy: leaves and small branches, with more variability in the signal than the obtained by larger structures, such as trunks. On the other hand, PC2 is very correlated to L-band, which is more sensitive to the trunk structure and other non-green vegetation, much more homogeneous and static structures. Thus, the higher weight of PC2 in the regression explains the similarity of the PCR model to L-VOD in terms of their goodness of fit with AGB. This, as well as the strong influence of L-band in the PCR model, show that the complementary of L-VOD with higher frequencies is not improving AGB modelling in this area. Still, the multifrequency combination applied does not decrease the strength of the relationship between VOD and AGB. Therefore, as the sample used is low and only forests have been considered in the analysis, future studies are necessary to reach more conclusions on the suitability of L-, C- and X-VOD combinations for accurate

Model	Coefficients		R^2	p-value
PCR	Intercept	-0.93	0.73	0.000
	PC1	75.53		
	PC2	197.38		
L-VOD	Intercept	3.39	0.72	0.000
	L-VOD	215.89		

Table 3. Statistics of the principal component regression and L-VOD linear regression

AGB modelling. In particular, further analysis will be carried out to include other vegetation types with lower canopy density (e.g., shrublands or grasslands) in order to understand whether, as suggested by previous works, higher frequency bands could be complementary to L-VOD in low-density vegetation regions [5]. Therefore, this study presents a first step towards the development of regional models to estimate forest biomass from multiple passive microwave frequencies. Enhanced models including shrubland and cropland/grassland vegetation classes will be presented at the conference to determine the ability of complementary VOD products to derive improved AGB estimates.

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