INVESTIGATIONS ON THE FULL POLARIMETRIC PALSAR DATA TO DISCRIMINATE MACROPHYTES SPECIES IN THE AMAZON FLOODPLAIN WETLAND

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1. INTRODUCTION

The objective of the present work was to evaluate the use of coherent and incoherent attributes derived from full polarimetric radar imagery to discriminate macrophyte species in Monte Alegre Lake (Amazon, Brazil), using PALSAR/ALOS L band data. As radar backscatter is sensitive to surface geometry, this research assumes that the discrimination among the species is possible due to the varying plant morphology.

There are several parameters in the literature used to investigate the full polarimetric radar data for wetland characterization. In the 1990s, the phase difference between the HH and VV polarization was the most used [4]. Then, the Cloude-Pottier’s [5] and the Freeman-Durden’s [1] incoherent target decomposition became a popular approach. Nowadays, the newest available technique is the Touzi decomposition, which has as its main advantage the capacity to better describe asymmetric scattering. Among the Touzi parameters, there are: 1) the “complex” entity (magnitude (α_s) and phase ($\Phi_{\alpha s}$)), which are required for an unambiguous description of target scattering; and 2) the helicity (τ), applied to assess the symmetric nature of target scattering [4].

In order to assess the suitability of these parameters, the floodplain region of the Monte Alegre Lake, in the state of Pará, Brazil – Amazon region was selected as a test site. Floodplains are wetlands of key importance for the global carbon cycle, as large recyclers of atmospheric CO_2 and one of largest natural sources of methane [2]. In the Amazon floodplain, macrophytes are responsible by the highest rates of methane emission, and exhibit very fast growth rates and high productivity [6]. As both productivity and growth have been shown to be species dependent [7], it is extremely important that tools be developed that allow proper discrimination of aquatic plant species.

2. METHODS AND DATA

A full polarimetric image, L band (~23 cm) was obtained on March 25th, 2009 from the ALOS/PALSAR sensor system. The image was acquired in PLR mode, with an off-nadir angle of 21.5º, ascending orbit, at processing level 1.1 (complex data in slant range). Fieldwork was carried out in April, 2009 in order to measure the following macrophyte morphological variables: emergent stem length, emergent stem diameter, leaf width, leaf length, number of leaves per stem (Figure 1), and number of stems in a 0.25 m² quadrat (Figure 2). A total of 65 samples were taken.

Besides the aforementioned variables, additional morphological measures were derived from the original field data: emergent stem volume, total leaf area per stem, plant biomass. The plant biomass was computed for each sample using the phenometric models of [7], described on Eq. 1 for all pooled species and Eq. 2 for *Hymenachne amplexicaulis* specifically. These models have been developed specifically for plants occurring in the Monte Alegre Lake:

$$B_i = 0.24 + 0.05\ V_{stem} + 0.01\ A_{leaf} \qquad \text{(Eq. 1)}$$

$$B_i = 0.55 + 0.07\ V_{stem} \qquad \text{(Eq. 2)}$$

where, Bi = biomass (g), V_{stem} = emergent stem volume and A_{leaf} = total leaf area.

The emergent stem volume was computed as a cylindrical volume ($V_{stem} = L_{stem} \times 0.25 \times \pi \times D^2_{stem}$, where L_{stem} is the length of the stem, and D_{stem} is the average stem diameter); and total leaf area was computed as the sum of the areas of a triangle ($A_{leaf} = \sum^{n}_{i=0}(0.5 \times L_{leaf} \times W_{leaf})$, where L_{leaf} is the average leaf length, W_{leaf} is the average leaf width and n is the total number of leaves per stem [7].

Prior to correlating macrophyte morphological variables to the coherent and incoherent radar attributes, it was necessary to register image and ground samples to the same reference system. As orthorectification can modify the complex part of the SAR image, the extraction of the radar attributes from each sampled location was done by projecting the sample element from the cartographic reference system (orthorectified image) into the ground range image.

The scattering matrix was then converted into a covariance matrix with a spatial average of 7x1 (azimuth by range, respectively) pixels to extract the coherent and incoherent attributes. The spatial averaging converts pixel spacing from 3.59 m in azimuth x 9.37 m in range for a slant range image to 23.04 m in azimuth x 25.12 meters in range for the ground range image. Finally, in order to reduce the effect of image speckle, the covariance matrix was filtered by the Refined Lee Filter, with a 3x3 pixel window. The incoherent attributes extracted were: sigma nought (σ^0_HH, σ^0_HV and σ^0_VV), span transformed to dB and intensity ratio transformed to dB. The coherent attributes extracted consisted of all the parameters from the Cloude-

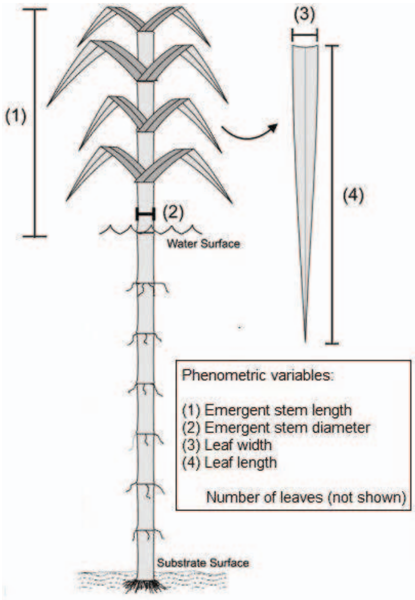

Figure 1. Macrophyte diagram, showing the measured morphological variables. Adapted from [7].

Figure 2. Example of sampling unit, showing the quadrat used to delimit the 0.25 m² area for stem counting.

Pottier's, Touzi's and Freeman-Durden's decompositions, plus the phase difference between the HH and VV and the magnitude of the complex correlation coefficient. A total of 31 attributes were extracted.

For each sample, the average of the attributes was computed for a 50 m x 50 m square area, which corresponds to the average size of the homogenous macrophyte stands. Correlation analysis was performed to assess the sensitivity of the various polarimetric attributes to the selected macrophyte shape variables. The morphological variables selected for testing were: emergent stem length (L_{stem}), emergent stem volume (V_{stem}), total leaf area per stem ($A_{leaf/stem}$: area of a single leaf multiplied by the total number of leaves per stem), biomass per m² (B(g/m²): plant biomass multiplied by the number of stem per square meter) and number of leaves per m² (N_{leaf}/m^2: number of leaves multiplied by the number of stem per square meter). A Box-Cox transformation was applied to these variables in order to normalize them and to increase the correlation to the radar attributes.

3. PRELIMINARY RESULTS

The main species found in the study site were *Paspalum repens* (n=41), *Hymenachne amplexicaulis* (n=15), and *Panicum elephantipes* (9). Plant density ranged from 12 stems/m² for *P. elephantipes* to 272 stems/m² for *P. repens*. Emergent stem length ranged from 10 cm to 120 cm, respectively for *P. elephantipes* and *H. amplexicaulis*. Stem diameter ranged from 0.3 to 1.6 cm, with the lower values found for *H. amplexicaulis* and the highest values for *P. repens*. The number of leaves ranged from two to nine. Leaf length and leaf width were 9-72 cm and 1-3.3 cm, respectively.

The highest correlation between the morphological variables and the radar image attributes occurred for seven incoherent and four coherent attributes: sigma nought for HH and HV (σ^0_hh, σ^0_hv); BMI (biomass index) and CSI (canopy structure index) developed by [3]; co-polarized and cross-polarized intensity ratio (VV/HH, VV/HV); span; alpha and anisotropy (Anis.) from the Cloude-Pottier decomposition; volume scattering mechanism (Fr_Vol) from the Freeman-Durden decomposition; and alpha 1 (Tz_alfa1) from the Touzi decomposition. All correlation values can be seen on Table 1.

Table 1. Correlation matrix for macrophyte morphological variables (L_{stem}, V_{stem}, $A_{leaf/stem}$, B(g/m²), N_{leaf}/m^2) and incoherent (σ^0_HH, σ^0_HV, BMI, CSI, VV/HH, VV/HV, span) and coherent (Alpha, Anis., Fr_Vol, Tz_alfa1) radar attributes. Values in bold correspond to $p < 0.05$.

	Macrophyte shape variables					Incoherent attribute							Coherent attribute			
	L_{stem}	V_{stem}	$A_{leaf/stem}$	B(g/m²)	N_{leaf}/m^2	σ^0_hh	σ^0_hv	BMI	CSI	VV/HH	VV/HV	Span	Alpha	Anis.	Fr_Vol	Tz_alfa1
L_{stem}	1	**0.59**	**0.52**	**0.68**	**0.57**	**0.38**	**0.47**	**0.33**	**-0.42**	**-0.42**	**-0.44**	**0.31**	**0.39**	**-0.34**	**0.47**	**0.33**
V_{stem}		1	**0.77**	**0.79**	**0.45**	**0.48**	**0.54**	**0.44**	**-0.26**	**-0.26**	**-0.33**	**0.47**	**0.28**	**-0.36**	**0.55**	**0.27**
$A_{leaf/stem}$			1	**0.71**	**0.39**	**0.49**	**0.56**	**0.43**	**-0.30**	**-0.32**	**-0.36**	**0.48**	**0.29**	**-0.36**	**0.57**	0.24
B(g/m²)				1	**0.84**	**0.51**	**0.55**	**0.44**	**-0.45**	**-0.45**	**-0.42**	**0.45**	**0.41**	**-0.40**	**0.55**	**0.43**
N_{leaf}/m^2					1	**0.42**	**0.45**	**0.39**	**-0.37**	**-0.37**	**-0.35**	**0.35**	**0.35**	**-0.35**	**0.44**	**0.36**
σ^0_hh (dB)						1	**0.84**	**0.87**	**-0.43**	**-0.43**	**-0.28**	**0.97**	0.17	**-0.42**	**0.83**	**0.25**
σ^0_hv (dB)							1	**0.69**	**-0.50**	**-0.49**	**-0.65**	**0.81**	**0.49**	**-0.65**	**0.99**	**0.36**
BMI								1	-0.11	-0.10	-0.01	**0.91**	-0.05	-0.21	**0.65**	0.00
CSI									1	**0.99**	**0.81**	-0.22	**-0.79**	**0.59**	**-0.55**	**-0.87**
VV/HH (dB)										1	**0.81**	-0.22	**-0.79**	**0.60**	**-0.55**	**-0.87**
VV/HV (dB)											1	-0.13	**-0.91**	**0.72**	**-0.69**	**-0.75**
Span (dB)												1	0.02	**-0.36**	**0.79**	0.07
Alfa													1	**-0.55**	**0.53**	**0.89**
Anis.														1	**-0.70**	**-0.47**
Fr_Vol															1	**0.41**
Tz_alfa1																1

The results suggest that the use of polarimetric information could be used to discriminate between plants species based on morphology, and that estimates of plant biomass and productivity could be improved by the use of polarimetric information. Continuation of the present research will aim to further investigate: 1) the development of reliable proxies of species shape; and 2) the use of multiple linear regression approaches to model plant morphology and biomass based on radar polarimetry attributes.

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