Use of ALOS satellite data to estimate volume and biomass in an eucalyptus plantation located in the state of Minas Gerais - Brazil

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Abstract. The objective of this study was to estimate the biophysical parameters volume and biomass in Eucalyptus plantations in the municipalities of Ipaba, Belo Oriente, Santana do Paraíso and Caratinga, State of Minas Gerais, Brazil, using Palsar sensor aboard ALOS satellite. The methodological procedures included the adjustment and selection of equations to estimate the dendrometric parameters (dependent variables) in function of variables generated from Palsar images (independent variables). Variables derived from sensor PALSAR were polarizations LHH, LHV, LVV and LVH, incoherent attributes Parallel Ratio, Cross-Ratio and Total Power and the vegetation indices VSI, CSI and BMI. With the application of the Stepwise regression model, the equations that best explained the parameters were selected. Results showed that the correlations of the variable volume with the data obtained by radar reached values of -69% and -54%, respectively, for the variables total power and LVH, being these candidates variables most likely to contribute to the regression model. These were also the variables that showed higher correlations with the variables biomass, with values of -68% and -64%, respectively, and also the candidates most likely to contribute to the regression model. This study reinforces the use of remote sensing techniques, particularly in orbital level, to estimate biophysical parameters of forest plantations, once it enables the performance of quantifications by utilizing non-destructive methods.

Keywords. Eucalyptus, sensor Palsar, biomass, volume, remote sensing.

1. Introduction

Satellite images are widely used in estimating biophysical properties of natural and anthropogenic vegetation. Currently, there are several options of orbital sensors that acquire images of the surface at different spectral, spatial and temporal resolutions. The most frequently used for mapping land resources and monitoring the dynamics of land occupation are optical sensors operating in the visible and infrared spectrum. Some examples include the IKONOS satellite, which operates four bands in multispectral mode with a spatial resolution of 4 meters and a panchromatic band at spatial resolution of 1 meter [1], the CBERS-2 CCD (Charge Coupled Device) that operates with five spectral bands and spatial resolution of 20 meters [2] and the Terra/MODIS, which operates with 36 spectral bands and spatial resolution ranging from 100 to 300 meters [3].

However, by operating at wavelengths relatively small, on the order of micra (µm = 10-6 meters), the optical imaging is dependent on the absence of clouds or smoke during the passage of the satellites, besides suffer interference from solar illumination conditions [4]. An alternative to these limitations is the use of sensors operating in the microwave region of the spectrum, like the Synthetic Aperture Radar (SAR) [5].

The use of radar for estimating biophysical parameters of forest cover has increased significantly in recent years, mainly due to the interaction of the microwave signal with the vegetation in several bands frequency and polarization as well as the technological improvements, including polarimetry and interferometry. Moreover, it presents independence of solar illumination conditions and provides imaging under several weather conditions, being little influenced by the presence of clouds or fog. The SAR has a capacity to penetrate canopies, as well as presenting a significant relationship between backscatter and vegetation structure and moisture [6]. Some examples of earth resources satellites carrying radar sensors are the Canadian RADARSAT-2, the European ENVISAT ASAR and Japanese ALOS / PALSAR.

The objective of this study was to estimate the biophysical parameters volume and biomass in Eucalyptus plantations through sensor Palsar aboard ALOS satellite.

2. Methods

The study area is located in the municipalities of Belo Oriente, Santana do Paraíso, Ipaba and Caratinga, State of Minas Gerais, Brazil. It is bounded by parallels 19°14'29.74" S and 19°34'45.24" S and meridians 42°32'48.06" W e 42°20'52.81" W (Figure 1).

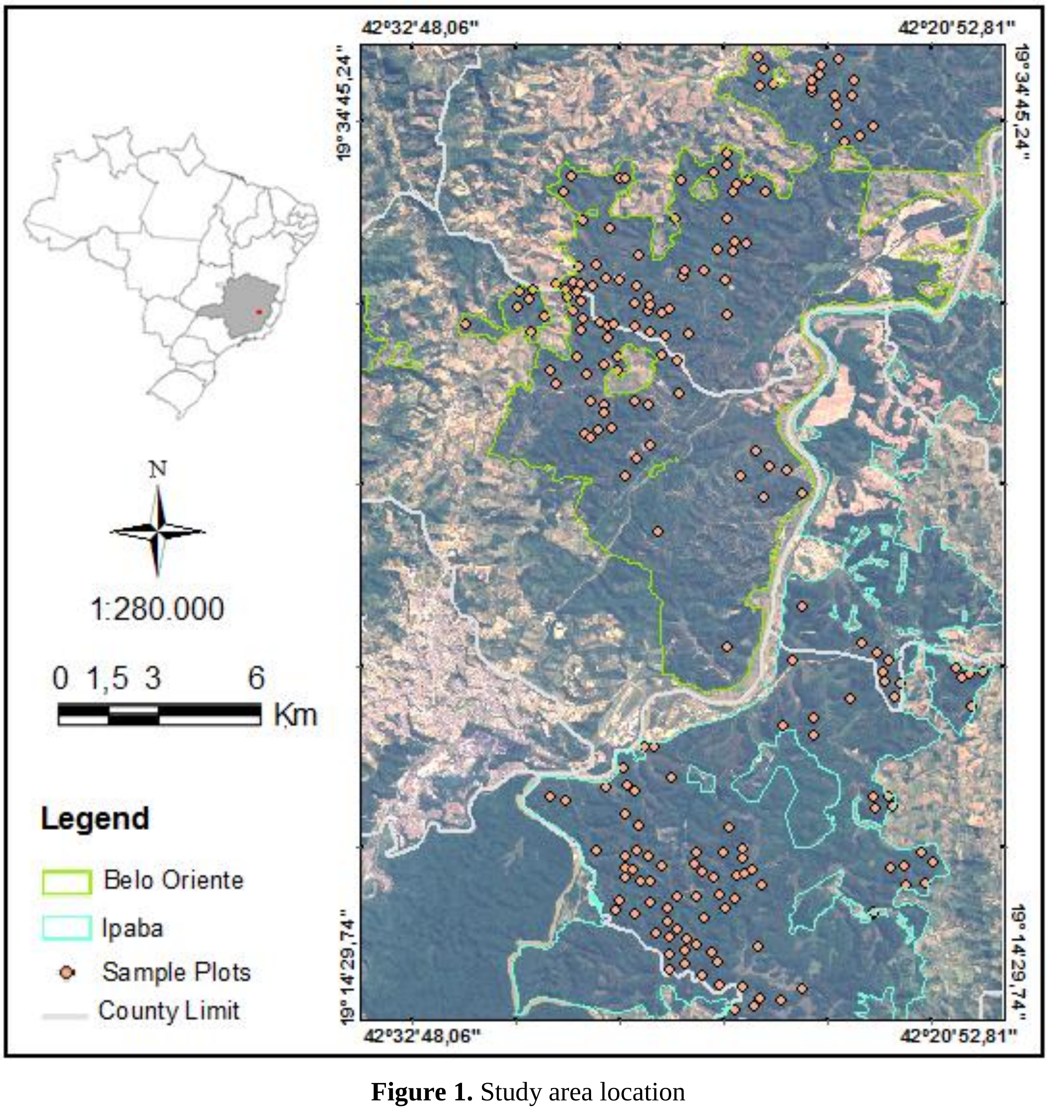

Figure 1. Study area location

The study area consists of stands of Eucalyptus, with a spacing of 3 x 2 meters, 4 to 8 years old, occupying an area of 837.12 km2. The forest inventory related to the study area was carried out by CENIBRA - Celulose Nipo Brasileira S/A, from February to September 2009, which included 206 sample plots of 340 m2. The variables volume and biomass were estimated by destructive method, derived from pre-selected trees representatives of the site. Digital data used were Palsar images with four polarizations, L-band and spatial resolution of 10 meters, obtained on 02 May 2009.

The digital values of the original images in the four polarizations (LHH, LHV, LVV and LVH) were converted to backscattering coefficient and subsequently used to generate the attributes: parallel ratio, cross ratio and total power and the following indices: biomass, canopy structure and volume scattering [7].

The conversion between amplitude (DN) and normalized radar cross section (dB) was performed using the equation (1) from Shimada [8]:

$$\sigma^{o} = 10 * \log_{10}\left[DN^{2}\right] + CF \tag{1}$$

where CF (conversion factor) = -83.0

In order to facilitate the integration and data analysis, it was generated a database based on a Geographic Information System (GIS) environment. This database contains the biophysical variables derived from forest inventory, which are used in the regression analyzes as dependent variables (volume and biomass) and the data corresponding to the independent variables extracted from PALSAR images (Table 1), besides the four polarizations LHH, LHV, LVV and LVH .

Table 1. PALSAR variables used in the regression models

Rp	Parallel ratio	$Rp = \frac{\sigma^{o}VV}{\sigma^{o}HH}$
Rc	Cross ratio	$Rp = \frac{\sigma^{o}HV}{\sigma^{o}HH}$
Pt	Total power	$Pt = \sigma^{o}HH + \sigma^{o}VV + \sigma^{o}HV + \sigma^{o}VH$
BMI	Biomass index	$BMI = \frac{\sigma^{o}VV + \sigma^{o}HH}{2}$
CSI	Canopy structure index	$CSI = \frac{\sigma^{o}VV}{\sigma^{o}VV + \sigma^{o}HH}$
VSI	Volume scattering index	$VSI = \frac{CS}{\left(\frac{\sigma^{o}HV + \sigma^{o}VH}{2}\right) + BMI}$

where $CS = \sigma^{o}HV + \sigma^{o}VH/2$

To evaluate the potential of sensor PALSAR to estimate dendrometric parameters, it was used the statistical method of regression analysis, based on the following equation (2):

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + ... + \beta_{p-1} X_{pi-1} + \varepsilon i \quad (2)$$

where Y_i is the value of the dependent variable in the i-th observation; β_o, β_1, β_2, ..., β_{p-1} are the model parameters; X_{i1}, X_{i2}, ..., $X_{i,\ p-1}$ are the values of p-1 explanatory variables in the i-th observation, and εi is a random error with mean E {εi} = 0 and variance σ2 = σ2 {εi}.

To determine the set of variables that contribute to the regression, it was used the criterion of F Stepwise method [9]. This procedure starts the computer analysis only with a constant, without any of the variables of interest, and at each step, after adding a new variable, it tests the possibility to withdraw from the model the variable whose partial contribution is not considered significant. Variables included in the model, at a given step, not necessarily remain until the end of the process.

3. Results

3.1. Regression model for the volume

Correlation analysis of the variable volume with the data obtained by the PALSAR sensor showed that the highest correlation (-69%) was obtained with the variable total power (Pt), followed by biomass index (BMI) with -65%, being these candidates variables most likely to contribute to the regression model (Table 2).

Table 2. Correlation matrix for the volume

	Volume	L_{HH}	L_{HV}	L_{VV}	L_{VH}	Rp	Rc	Pt	BMI	CSI	VSI
Volume	1	-0.59	-0.56	-0.58	-O.54	0.37	0.36	-0.69	-0.65	0.36	-0.24
L_{HH}		1	0.53	0.55	0.49	-0.87	-0.85	0.79	0.96	-0.87	-0.06
L_{HV}			1	0.82	0.47	-0.17	-0.02	0.74	0.69	-0.15	0.29
L_{VV}				1	0.44	-0.08	-0.17	0.73	0.78	-0.07	0.12
L_{VH}					1	-0.36	-0.31	0.88	0.53	-0.35	0.81
Rp						1	0.93	-0.54	-0.69	1.00	0.09
Rc							1	-0.50	-0.71	0.93	0.21
Pt								1	0.86	-0.53	0.50
BMI									1	-0.68	0.00
CSI										1	0.11
VSI											1

The statistical analysis for determining the variables that would compose the regression model to estimate the volume indicated that the variables Pt and L_{VH} were the best candidates, with p-values less than 0.926%. Table 3 shows the results of the regression.

Table 3. Results of the regression model.

	β	p-valor	SSE	R^2
Intercept	595.198	0.000%	99,038.4	49.10%
Pt	-187.586	0.000%		
L_{VH}	0.386	0.926%		

The regression model to estimate volume data from PALSAR sensor is showed below:

Volume (m^3/ha) = 595.196 + 0.386 * L_{VH} – 187.586 Pt

3.2. Regression model for the biomass

Correlation analysis of the variable biomass with the data obtained by the PALSAR sensor showed that the highest correlation (-68%) was obtained with the variable total power (Pt), followed by biomass index (BMI) with -64%, being these candidates variables most likely to contribute to the regression model (Table 4).

Table 4. Correlation matrix for the biomass

	Biomass	L_{HH}	L_{HV}	L_{VV}	L_{VH}	Rp	Rc	Pt	BMI	CSI	VSI
Biomass	1	-0.57	-0.56	-0.58	-0.54	0.35	0.34	-0.68	-0.64	0.34	-0.24
L_{HH}		1	0.53	0.55	0.49	-0.87	-0.85	0.79	0.96	-0.87	-0.06
L_{HV}			1	0.82	0.47	-0.17	-0.02	0.74	0.69	-0.15	0.29
L_{VV}				1	0.44	-0.08	-0.17	0.73	0.78	-0.07	0.12
L_{VH}					1	-0.36	-0.31	0.88	0.53	-0.35	0.81
Rp						1	0.93	-0.54	-0.69	1.00	0.09
Rc							1	-0.50	-0.71	0.93	0.21
Pt								1	0.86	-0.53	0.50
BMI									1	-0.68	0.00
CSI										1	0.11
VSI											1

The statistical analysis for determining the variables that would compose the regression model to estimate the biomass indicated that the variables Pt and L_{VV} were the best candidates, with p-values less than 1.36%. Table 5 shows the results of the regression.

Table 5. Results of regression model.

	B	p-value	SSE	R^2
Intercept	319.8117	0.000%	30,598.02	47.88%
Pt	-60.7025	0.000%		
L_{VV}	-0.5040	1,359%		

The regression model to estimate volume data from PALSAR sensor is showed below:

BIOMASS (t/ha) = 319.811 – 60.7025* L_{VV} + 1.28*Pt (3)

Analyzing the behavior of the regression models for estimating volume and biomass with those estimated from the forest inventory, it is noticed a good approximation in terms of results between them, as shown in Figures 2 and 3. This behavior indicated that the radar signal was able to estimate the volume and biomass of Eucalyptus.

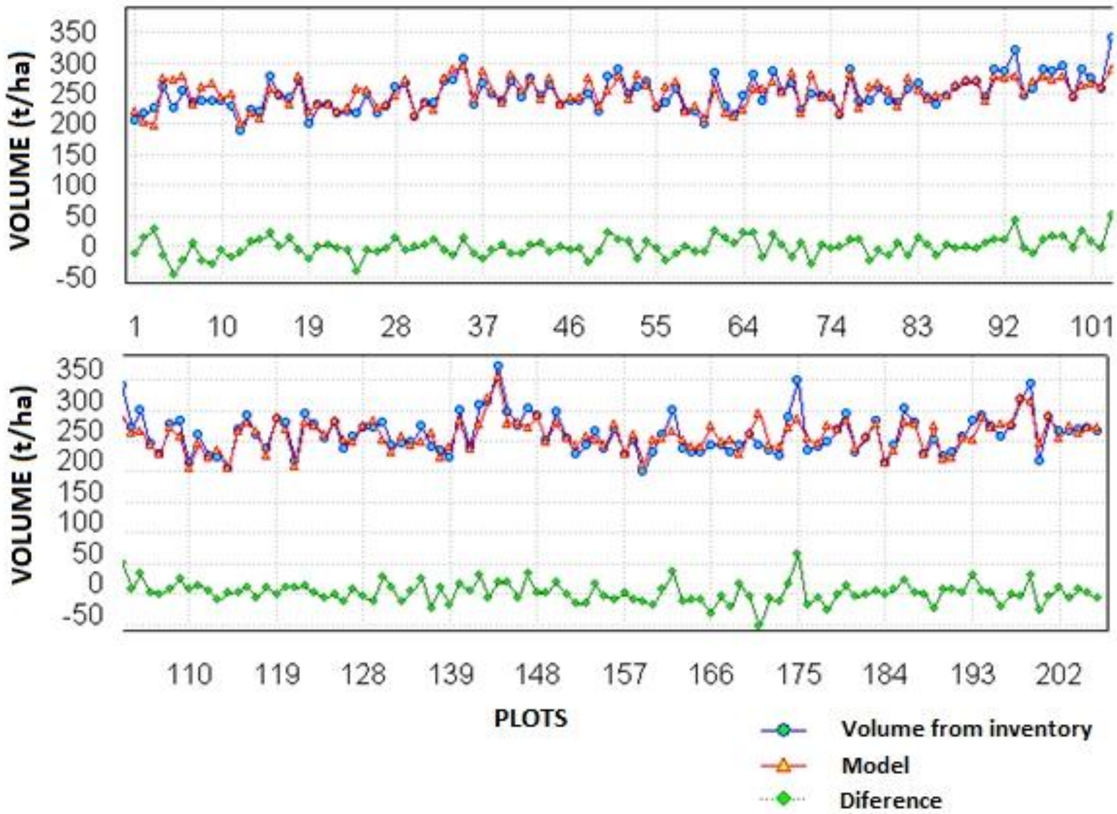

Figure 2. Comparative chart of volume estimated from inventory and by regression and their difference.

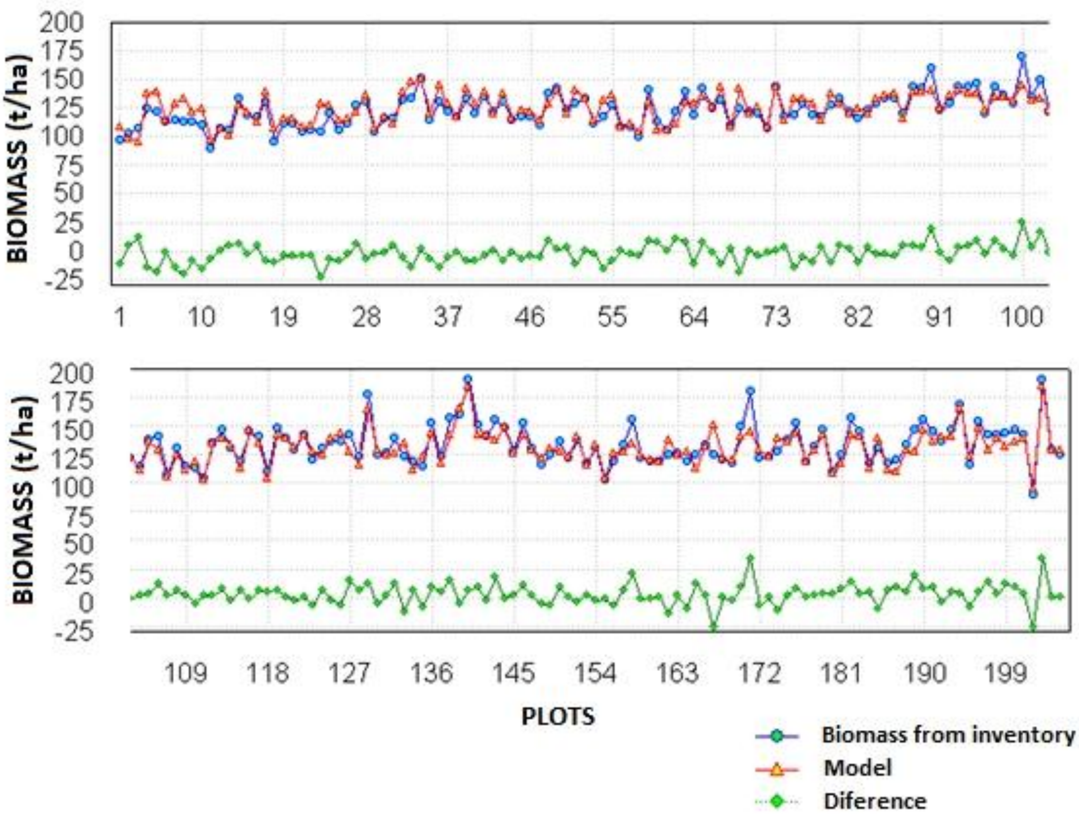

Figure 3. Comparative chart of biomass estimated from inventory and by regression and their difference.

4. Conclusions

The biophysical parameters, volume and biomass, estimated from a forest inventory showed good correlations with the Palsar data, especially with total power (Pt), LVV and LVH variables, indicating a great potential of using these data as support in inventories of large areas.

This study further reinforces the use of remote sensing techniques, especially in orbital level, to estimate biophysical parameters of forest plantations.

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