TROPICAL FOREST BIOMASS MAPPING FROM DUAL FREQUENCY SAR INTERFEROMETRY (X AND P- BANDS)

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ABSTRACT:

Radar sensors operating with different wavelengths and polarizations have been widely used for large-scale forest mapping and monitoring. The interferometric phase obtained by microwave sensors contains additional information on the three-dimensional structure of the scattering targets in the image. An experiment was performed in the Brazilian Amazon (Tapajós National Forest and surroundings) to provide airborne SAR data at X- and P- bands over tropical rain forest. In a first step of the presented research the regular radar backscatter results are joined with an interferometric height model to establish a statistical relationship to forest biomass (primary and secondary vegetation). Subsequently, that model is applied for generation of a thematic land cover map. Backscattering of P-band waves mainly occurs on the ground surface, and can be used for interferometric generation of a Digital Elevation Model. The X-band is reflected by dossel, and thus relates to the forest canopy in a Digital Surface Model. The difference between both models has been shown to represent height of vegetation. Care was taken in establishing statistical models that relate dendrometric parameters from forest types to both P-band backscatter and interferometric height. A best biomass model [**biomass = 44.965 + 13.887 × h** $_{int}$ **+ 10.556 ×** $\sigma°_{HH}$] was established after comprehensive testing of a range of specific allometric equations to achieve statistically high precision in biomass prediction. A segmentation algorithm (hierarchical region growth) was applied to the remote sensing dataset to provide means for application of the biomass model to homogeneous landscape units with similar biophysical characteristics and site histories. A final mapping result displays forest biomass, and accounts for different successional stages and primary forest in intervals.

1. INTRODUCTION

With the advance of remote sensing technology, SAR data are available to supply and/or to complement the information level obtained by optical sensors, referring to monitoring land cover in Amazonia region. For certain specific studies, such as e.g. the estimation of biophysical parameters of vegetation cover, radar data present limitations inherent to the frequencies used (Wegmüller and Werner, 1997). In this context, a scientific experiment was performed in the Brazilian Tapajós region, to provide airborne interferometric X and P-band SAR data over tropical rainforest. The objective of this study is to analyze and map the biomass variation of primary forest and secondary succession using dual frequency SAR interferometry. This interferometric approach demonstrate a potential to improve knowledge of forest structure and the estimation of its' biophysical parameters (Cloude et al., 2000; Balzter, 2001).

2. MATERIALS AND METHODS

2.1 Test-Site Description

The area under study is located at the lower Tapajós River region (Pará State, Brazil), between W 54° 53' to 55° 06' and S 03° 03' to 03° 12' close to the São Jorge village, along highway BR - 167 Cuiabá - Santarém. The yearly rainfall varies between 1,750 and 2,000mm. The distrofic yellow latossol (oxisol) soil type predominates in two textural classes: clay and medium clay. These are normally deep soils, found over hilly to strong hilly terrain, covered by dense forest of lowlands and sub-montane. Human occupation is related mostly to subsistence agriculture (rice, cassava, maize, beans, pepper) and specially to huge areas for extensive cattle raising.

2.2 Remote Sensing and Ground Data

The airborne SAR images were obtained by a system developed by AeroSensing RadarSysteme GmbH Company, that acquires both P (polarimetric) and X- band interferometric data. This radar system provides P band (λ= 72 cm), obtained with a middle frequency of 415 MHz, band-width of 70 MHz, depression angle of 45°, range resolution of 1.5 m and azimuth resolution of 0.7 m, for 1 look slant range image. The X band imagery have a pixel up to 0.5 m of ground range resolution, with HH polarization, middle frequency of 9.6 GHz and 400 MHz band-width.

The radar tracks were radiometrically corrected according to the antenna pattern using a function based on homogeneous extended areas; and afterwards, the polarimetric calibration was done for each polarization (slant range mode), based on the 8 corner reflectors (placed in the field along the flight strips using differential GPS measurement). In this study only HH polarization at X and P band was analyzed. The longer wavelenghts (P-band) pass through the forest cover and were used to generated a Digital Elevation Model (DEM). The short wavelenghts (X band) are reflected from the top of forest canopies and are used to generate a Digital Surface Model (DSM). Both models are calibrated and have a spatial resolution of 2.5 m. The difference between the DSM and DEM is considered to represent height of vegetation cover, thus providing in form of an image a so-called “Interferometric Height Model” (DHM). This image was afterwards segmented using an algorithm based on hierarchical region growing. This algorithm start out degrading the image to pyramidical levels with increasing spatial resolution and performs an initial region growing based on a mutual nearest neighbor criterion of grey level values between pixels (Souza Jr. et al. 2003). On each sucessive level, firstly a border correction by edge detection is applied. Subsequently, an F-test for homogeneity provides a criterion for decision on whether to split polygons and grow regions again. The procedure works successively at six pyramidical levels. In the final results, polygons below 2,500 m^2 are eliminate in order to provide a degree of segmentation that would sensibly reflect a minimum landscape unit in the study area. After the image segmentation, the interferometric height value from each polygon is extracted, which corresponds to the localization of each sample plot properly georeferenced, where the forest inventory was done.

Using this procedure, interferometric height values for both primary and secondary forest areas were obtained, which are need to setup a biomass prediction model and consequently allow the thematic mapping, based on the adjusted equation.

During the field survey, biometric features (DBH > 5 cm, total tree height) for the primary forest and secondary sucession, including the botanical identification were collected in several samples, with measurements in plots of 2,500 and 1,000 m^2 respectively (Santos et al., 2003). Secondary succession inventories were collected to represent three stages of succession (at initial, intermediate and advanced level). The stratification considers both the age of the natural regrowth, certain structural characteristics, and floristic composition.

These data allow for the computation of structural forest parameters for diameter, total basal area and various height measures (mean height, predominant height, i.e. the arithmetic mean of tree height of the upper vegetation stratum), and biomass was derived by allometric equations from Nelson et al. (1999) and Chambers et al. (2001).

3. RESULTS AND DISCUSSION

3.1 Interferometric Height versus Ground Data

Interferometric height ($\mathbf{h}_{int}$) for primary forest is a measure of the height of some predominant collective of the tallest trees, excluding the under-story. The interferometric height for secondary growth is a measure of the height of some sub-emergent individuals that excludes the tallest trees (upper stratum), and only consists in the smaller ones. Therefore average height (considering DBH>5cm) was used for secondary succession and predominant height (mean height of the tallest 200 individuals per hectare) was used for primary forest, according to Neeff et al. (2004).

A linear function was fitted to the combination of mean and predominant forest heights as derived from ground data versus interferometric height as derived from remote sensing data (Figure 1). The coefficient of determination attained a value of $R^2 = 0.87$ on this regression analysis. Thus, the interferometric height is a valid measure of forest stand height from a remote sensing dataset.

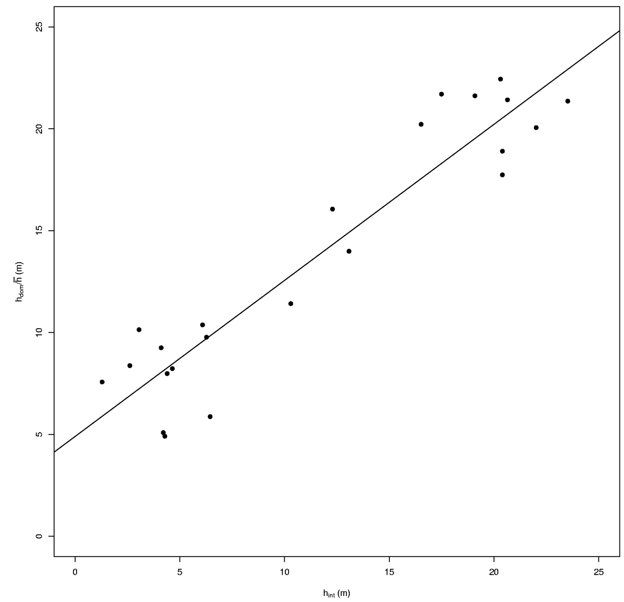

Figure 1. Scatterplot of forest height from ground measurements versus interferometric height derived from X and P-band SAR data. Source: Neeff et al. (2004).

3.2 Interferometric SAR Data and Biomass

Initially, the biomass stocks variable was logarithmically related to P-band backscatter data in HH polarization, showing a coefficient of determination of $R^2 = 0.66$ according to Santos et al. (2003). Using the same dataset at Tapajós region, considering a polynomial function, these authors reported that the best fit was produced using the HH polarization ($R^2 = 0.77$) when comparing to HV and VV polarization. Afterwards, the interferometric height, i.e. the difference between DSM and DEM, was taken to represent vegetation height and was individually related to biomass, whose relation is linear and yields a determination coefficient of $R^2=0.87$.

Finally, integrating the variables mentioned, both P-band HH backscatter ($\sigma°_{HH}$) and interferometric height ($\mathbf{h}_{int}$) were fitted to biomass levels, and the precision was slightly increased to $R^2 = 0.89$ for the calculation of standing biomass in primary and secondary forests. The intercept is not significantly different from 0 at level $\alpha = 0.05$, however, there is no reason to drop the intercept from the model. This biomass model (Neeff et al., 2004) was established for all types of forest occurring in this area; ranging from initial regrowth with biomass levels below than 5 t/ha to primary forest with biomass levels up to ca. 350 t/ha:

$$\mathbf{biomass = 44.965 + 13.887 \times h_{int} + 10.556 \times \sigma°_{HH}} \quad \mathbf{(1)}$$

The model in Equation 1 is linear and thus not affected by saturation of backscatter response with increasing biomass levels that has been reported as a general problem of forest monitoring by radar (LeToan et al. 1992; Imhoff, 1995; Santos et al. 2002).

Despite some difference in the response curves of the logarithmic and exponential functions when relating biomass and radar backscatter values, the P-band signal alone would saturate around 100 ton/ha, as reported by Santos et al. (2003); since here we also count with interferometric height (Equation 1), saturation of the radar response signal as a problem for tropical forest biomass estimation does not occur any more.

In Figure 2 the variance of the forest biomass estimate is graphically displayed in function of the observed data range of interferometric height ($\mathbf{h}_{int}$) and backscatter radar ($\sigma°_{HH}$). The standard errors range between ca. 20-40 ton/ha. The biomass estimates obtained by applying equation 1 are superior to common approaches, because they are not only based on backscatter signals, and because the variance of the estimate does not increase exponentially with high quantities of biomass.

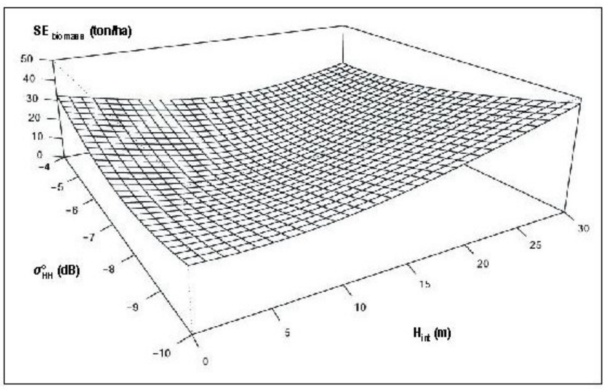

Figure 2. Variance of biomass estimation as fuction of height interferometry and basckscatter.

The segmentation of the DHM yields a division of the study area in landscape patches by polygons, that would reflect individual forest stands or management units of farms. As described above, the mean interferometric height and mean P-band radar backscatter are calculated for all polygons. A simple binary classification is performed to distinguish forest cover and agricultural/pasture areas. All polygons with mean interferometric height ≥ 2.6 m are classified as secondary succession or primary forest; all polygons with $\mathbf{h}_{int}$ < 2.6 m are taken to correspond to nonforest landuse, i.e. agriculture, pastures, etc.

Nevertheless, the biomass map was realized based on equation 1, which describes only SAR data signals from the primary and secondary vegetation. Polygons with nonforest classes are masked out. The procedure yields a map that display the spatial disctribution of standibng alive above ground biomass in forest cover at the test-site in the Tapajós region (Figure 3).

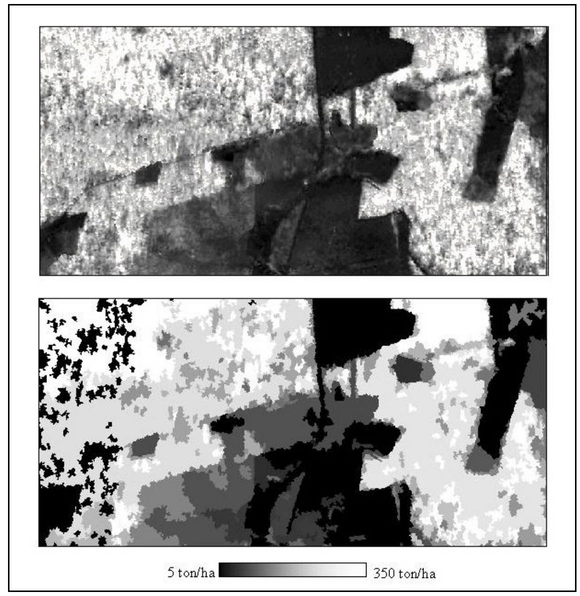

Figure 3. Section of SAR interferometric height image and biomass distribution map of land cover classes in the Tapajós region. In the above figure, the dark areas correspond to deforested areas (mainly pastures), the brightest grey levels are primary forest, intermediate variations in tone reflect forest successional stages.

4. CONCLUSIONS

This work shows a new approach to mapping and inventory tropical forest biomass, which has become possible by improved data quality related to the SAR data (considering both backscatter signals and interferometric data). It largely enhances biomass model precision due to the integration of interferometric height measurements. It was also observed that an adequate calibration of DSM and DEM is important for height inferences, this is particularly true for initial and intermediate successional stages, because the heights to be measured are lower than for advanced stages. The segmentation approach based on hierarchical region growth (representation by pyramidal levels) applied on the DHM image demonstrated potential for analysis and improvement of thematical stratification by regions. The general problem of excessive image segmentation, frequently observed in radar imagery, does not occur when using the segmentation approach adopted here.

This study is a contribution to the Governamental Program "Science and Technology for the Management of Ecosystems" from the Ministry for Science and Technology (MCT), which is looking for alternatives (remote sensing data) and for the improvement of technological knowledge which might help in the inventory and monitoring of forest resources in Brazil.

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