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Tree density estimation in a tropical woodland ecosystem with multiangular MISR and MODIS data

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Abstract

In this paper we evaluate the potential of spectral, temporal and angular aspect of remotely sensed data for quantitative extraction of forest structure information in tropical woodlands. Moderate resolution imaging spectroradiometer (MODIS) multispectral data at 500-meter spatial resolution from different dates, multiangle imaging spectroradiometer (MISR) bidirectional reflectance factors (BRF) and normalized difference angular index (NDAI) derived from MISR data at 275-meter spatial resolution were used as input data. The number of trees per hectare bigger than 20cm in diameter at breast height was taken as variable of interest. Simple and multiple ordinary least square regressions and artificial neural networks (ANN) were tested to understand the relationships between the various sources of remotely sensed data and the output variable. An experimental design technique, followed by a classification of the input variables and a factor analysis were implemented in order to understand the structure, reduce the dimensionality of the data and avoid the overfitting of the neural network. The results show that there is a significant amount of independent information in the angular dimension, and this information is highly relevant to the estimation of tree densities in the study area. The MISR NDAI indexes improved the performance of the MISR BRF. The non-linear ANN outperformed the linear regressions. The best results were obtained with the ANN after selecting the input variables according to the results of the experimental design, the classification and the factor analysis, with a 0.71 correlation coefficient against the 0.58 of the best linear regression model.

Keywords: MODIS; MISR; Neural networks; Band selection; Tropical woodland

1. Introduction

Land cover change can be examined from a number of perspectives including the type, duration, magnitude, and rate of change (Gong & Xu, 2003). Foody et al. (2001) divided magnitude land cover changes into land cover conversion and land cover modification. Most of the land cover change studies with medium resolution passive remote sensing have focused on forest cover conversion. Since Tucker et al. (1985), several initiatives have developed static regional and global land cover products using advanced very high-resolution radiometer (AVHRR) data (DeFries et al, 1998; Hansen et al, 2000; Mayaux & Lambin, 1997). More recently MODIS and VEGETATION sensors on board of Terra/Aqua and SPOT-4/5 platforms respectively have provided improved capabilities for land cover and vegetation mapping (Bartholomé and Belward, 2005; Fensholt, 2004; Frield et al, 2002; Mayaux et al, 2004; Townshend & Justice, 2002; Zhan et al, 2000). Less research has focused on land cover modification. Land cover modification includes subtle changes that affect the character of the land cover without changing its overall classification (Lambin, 1999). These very dynamic processes are usually difficult to monitor with discrete land cover units, as they usually generate heterogeneous and mixed spatial distributions that take place at subpixel scale. As a consequence, degradation of forest cover,

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biomass, density and structure of the regrowth have proven extremely difficult to monitor from space (Asner, 2000).

Monitoring forest modifications requires the measurement of continuous biophysical attributes of the surface, and only a representation of land cover as a continuous field can lead to an accurate detection of forest degradation (Gong & Xu, 2003; Lambin, 1999). Some initiatives are already working in this direction. For instance, the MODIS 500-meter Global Vegetation Continuous Field product (VCF) is a data intensive approach that combines multispectral and multitemporal remotely sensed data (Hansen et al, 2003). This product includes basic layers for percent tree cover, percent herbaceous/shrub cover and percent bare ground. The VCF has been generated using multitemporal metrics and a regression tree algorithm from 8-day composites spanning 14months, and its validation is still a work in progress (Hansen et al, 2002).

The potential of multiple view angle (MVA) remote sensing for the characterization of vegetation canopies has been presented in previous works (Diner et al., 1989; Diner et al., 2005; Gobron et al., 2000; Martonchik et al., 1998; Braswell et al., 2003). At landscape level, variations in the anisotropic reflectance signature of forest vegetation are controlled by the spatial distribution and shape of individual canopies (Asner, 2000). Consequently medium resolution MVA can play an important role in the improvement of the estimation of continuous canopy information. Despite its potential, the angular domain of remotely sensed data has not been fully developed due mainly to the lack of consistent multiangular data. This situation has changed since the launch of the Multi-angle Imaging SpectroRadiometer (MISR) sensor on board of the Terra platform. Several studies present MISR data as a promising alternative to obtain structural information of land surfaces (Gobron et al., 2002; Pinty et al., 2002; Widlowski et al., 2001).

However, the integration of spectral and directional information raises the question of how much independent information can be found in remotely sensed MVA data that is not found in multispectral channels. Studies about this issue are still limited and they mainly focus on high-resolution data. Some works have indicated the presence of non-redundant directional information, opening the gate for a significant improvement in information extraction (Barnsley et al, 1997; Hyman & Barnsley, 1997). More recently, Su et al. (2007a,b) combined medium resolution MVA data from MISR and multispectral data from MODIS and MISR for recognition of vegetation types in arid ecosystems. Su et al. (2007a) found that, while multispectral bands contained a larger share of the information, the addition of MVA data from MISR off-nadir bands and from semiempirical Bidirectional Reflectance Distribution Function (BRDF) model parameters greatly improved the results of the classification. Also for arid environments, and moving towards a more quantitative variable, Chopping et al. (2006) combined medium resolution MVA and multispectral data from MISR in a canopy reflectance model to estimate fraction of woody plant cover.

Another path to the improvement of the estimation of continuous biophysical parameters is the application of more suitable models. Since the relationship between remotely sensed data and the continuous vegetation variables are not necessarily linear, the application of linear empirical models does not usually produce successful results. Neural networks (NN) have the ability to learn patterns or relationships from given training data, and to generalize from such data (Anderson & Rosenfeld, 1988; Gong, 1996). Since neural networks make fewer assumptions about the data than multiple regressions they are an attractive non-parametric alternative (Foody et al., 2001) and provide a more powerful and adaptive non-linear mechanism than traditional linear and simple non-linear analysis (Kimes & Nelson, 1998). These attractive characteristics have led several authors to explore the application of ANN for the extraction of continuous vegetation variables. Kimes et al. (2002) and Abuelgasim et al. (1998) used ANN to estimate several canopy biophysical parameters from the inversion of canopy models using simulated data. Gong et al. (1999) retrieved leaf area index (LAI), and leaf angle distribution from simulated multi-angle reflectance. Working with real field data, Foody et al. (2001) applied ANN to estimate biomass of tropical forest from Landsat TM data, observing stronger correlations than with traditional vegetation indices.

In this study, we explore the potential of multiangular remotely sensed data and its combination with multispectral and temporal data for quantitative extraction of forest density in tropical woodlands. We also investigate the application of artificial neural network models to capture the non-linear relationship between the tree density and the remotely sensed data.

2. Data

2.1. Study site

The study site is located in the province of Zambezia, in Central Mozambique (longitude 35° 10′/39° 10′; latitude −15° 00′/−18° 50′). The area covers 400km from East to West and around 100km from South to North (Fig. 1). This area corresponds to the Miombo woodland formation of Southern Africa. Miombo is a deciduous woodland characterized by a clearly defined dry season spanning from May to November and the dominant presence of species from the family *Caesalpinaceae*, *Brachystegia*, *Julbernardia* and *Isoberlinia*. Miombo woodlands normally present low leaf area index values, ranging from 2 in the peak of the wet season to 1 in the peak of the dry season (Huemmrich et al, 2005). Low LAI values result in limited shade of lower crowns and ground. The availability of water both in the form of precipitation and as ground water resources is the main factor driving the distribution of the vegetation. This, together with an intense regime of natural and human-driven disturbances have conformed a heterogeneous woodland landscape that alternates dense and open forests, thicket, and grassland formations showing a wide range of tree densities (Campbell, 1996).

2.2. Satellite imagery (MODIS and MISR)

2.2.1. MODIS

MODIS Surface Reflectance at 500-meter spatial resolution for bands 1, 2, 3, 4, 6 and 7 (620–670nm, 841–876nm, 459–479nm, 545–565nm, 1628–1652nm, 2105–2135nm,