Using Fraction Images to Study Natural Land Cover Changes in the Amazon

Conference Paper · September 2006

DOI: 10.1109/IGARSS.2006.544 · Source: IEEE Xplore

USING FRACTION IMAGES TO STUDY NATURAL LAND COVER CHANGES IN THE AMAZON

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***Abstract* - Satellite data such as the vegetation indices are a crucial tool for studying vegetation phenology patterns from regional to global scales. In this study, we investigated the relationship of the fraction images, derived from the linear spectral mixture model, with the NDVI and EVI, the most used indices to evaluate the phenological response using remote sensing data from the MODIS sensor. Our objectives were to understand how the vegetation indices are related with the vegetation fraction and to evaluate if the information provided by the shade and soil fraction images can be used to explain the vegetation indices behavior. We used a temporal series data of the MOD13A1 product for the 2002 year, the precipitation data from 125 meteorological stations, and a land cover map generated based on the 2002 images. We studied two different vegetation physiognomies to analyse if the fraction images were landscape dependent. Our results showed that for the Open Tropical Forest, the vegetation fraction image presented a significant correlation with the EVI (r^2=0.84) but not with the NDVI. For the Cerrado grassland landscape, the vegetation fraction image presented high correlation with the NDVI (r^2=0.93) and EVI (r2=0.98). Significant correlations were also found for the shade and soil fraction images for the land cover studied, showing that these additional information are a useful source of data to understand the vegetation canopy structural changes and to analyze the responses provided by the vegetation indices correctly.**

Keywords: *Phenology, Fraction images, Vegetation indices, MODIS.*

I. INTRODUCTION

Vegetation distribution and phenology are largely associated with climate factors, landscape characteristics and human actions. Phenological response studies in regional and global levels are important to understand the relationship between different natural, agricultural and urban ecosystems and how the climate acts over the biosphere in a temporal scale and how the climate are influenced by the terrestrials ecosystems, playing a major role in regional ecosystem simulation models.

The exchanges of energy and CO2 between the biosphere and atmosphere by the biogeochemical cycles are strongly influenced by the phenology due to the onset and offset and the length of the growing season [1], i.e. the period when the canopy is photosynthetically active and there are an increase of the biomass, which is a major component in the dynamics of terrestrial primary productivity and the global carbon cycle.

The vegetation index images are the most used data to monitor these natural alterations. In the last decades, this monitoring for regional and global scales has been made with the Advanced Very High Resolution Radiometer (AVHRR) sensor by the Normalized Difference Vegetation Index (NDVI) data [2], [3].

In this study, we investigated the utility of fraction images in monitoring the seasonal dynamics of different vegetation physiognomies on an intra-annual basis. Previous studies have demonstrated that images modeled by endmember selection in mixture models are sensitive to detect changes in vegetation behavior [4]. Here we analyzed the relationship between the MODIS vegetation indices and fraction images derived from the same sensor data. Our objectives were to understand how the vegetation indices are related to the vegetation fraction cover and if this relationship is characteristic of the land cover type. We also investigated the influence of shade and soil fractions derived from the Linear Spectral Mixing Model on the MODIS vegetation indices responses.

II. STUDY AREA

The study area comprises the state of Mato Grosso, located on the southern extent of the Brazilian Legal Amazon between the coordinates 06º 00′ and 19º 45′ south latitude and 50º 06′ and 62º 45′ west longitude, with a territorial extension of 900,000 km^2. It has a natural model of complex biodiversity, resulting in different vegetation type classes (Fig. 1a), due to variations such as climate, precipitation pattern (Fig. 1b), terrain features (Fig. 1c) and length of the dry season.

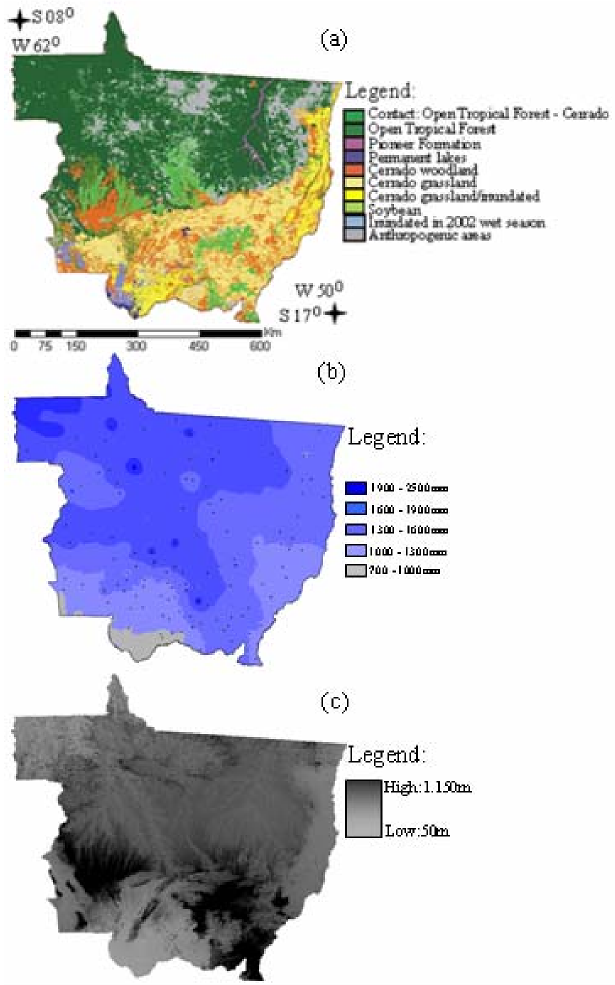

Figure 1. Characterization of the study area. (a) 2002 Land cover classification for Mato Grosso based on annual signatures in NDVI, EVI and fraction images time series. (Source: Anderson et al., 2005); (b) Cummulative precipitation map generated with 125 field station for 2002 year; (c) Elevation map based on the SRTM data.

III. DATA

The satellite images used in this study were the Terra/MODIS product MOD13A1, acquired for the whole 2002 year. This product contains: 250m 16-day NDVI, EVI, NDVI Quality, EVI Quality, average view zenith angle, average sun zenith angle, average relative azimuth angle. In addition, it is available the red (band 1, centered at 640 nm), NIR (band 2, centered at 858 nm), blue (band 3, centered at 470 nm), and MIR (band 7, centered at 2130 nm) reflectance bands.

The land cover map for the study area was generated based on the same multitemporal data series [5]. The map (Fig. 1a) presents the following land cover classes: Open Tropical Forest, Cerrado grassland, Cerrado grassland/inundated, Cerrado woodland, Pioneer formation, Contact between Forest and Cerrado, anthropogenic areas and soybean areas. In this study we analyzed the Open Tropical Forest and Cerrado grassland, due to the lower confusion presented in the validation of the land cover map with field measurements [6].

We also used the precipitation data acquired from the Agência Nacional de Energia Elétrica (ANEEL) provided daily and monthly from 125 meteorological stations in Mato Grosso.

IV. ANALYSIS

A. Generating monthly images

The 138 16-day composite NDVI, EVI and the reflectance bands were mosaic to generate 23 16-days images for the study area. Monthly composites images were generated based on the maximum NDVI pixel value.

B. Applying the linear spectral mixture model

Based on these monthly composite images, we generated and applied a spectral mixing model for each month, which was used to characterize the spectral mixture of targets in each pixel. In this approach, the response of the pixel in any spectral wavelength can be considered as a linear combination of the responses of each component in the mixture. The linear spectral mixing model estimates the proportion of each component within pixels by minimizing the sum of squares of the errors [7]. The model was run using 3 endmembers: vegetation, soil and shade, based on the red, NIR, blue and MIR spectral bands. The proportion of each one of the components varies from 0 to 100 percent. These endmembers were selected directly from the image [8]. By using this image endmember approach for MODIS data, it was assumed that there is at least one pure pixel for each component due to the study area characteristics, as large areas of agriculture or bare soil on the dry season and large water bodies. The vegetation pixel was selected from homogeneous vegetation cover; the soil pixel was selected from bare soil areas; and shade pixel was selected from pure water bodies considering the spectral similarity between shade and water targets. With the 12 spectral mixing models, it was selected the 3 best endmembers response to generate a unique annual model to be applied to the whole temporal series. The soil and shade endmembers were selected from dry season months and the vegetation endmember was selected from a wet season month. In this study, we hypothesized that the pure endmember is a pseudo-invariant target, and thus the changes observed on the proportion of the components is due to the vegetation phenology.

C. Generating the precipitation surface

The 125 meteorological stations points were plotted spatially and a monthly mean were generated by each month. From the point values, we generate a regular grid by an interpolation using a weighted average considering the Z-values and quadrant regions algorithm (Fig. 1b).

D. Statistical Analyses

Linear regression analyses were carried out to compare the monthly mean value from the land cover classes of the vegetation indices images with the fraction images [3].

Significant correlation between vegetation fraction and the vegetation indices indicates that they are related. Significant correlation for the different vegetation physiognomies indicates that it is land cover dependent. A global relationship between rainfall and the dependent variables, as the vegetation indices and fraction images were also analyzed.

V. RESULTS

A. Comparison between vegetation types

The fraction images showed a seasonal behavior that can explain the phenology of the land cover types analyzed in this study by a combination of the components. In general we can observe three main points on the fraction images (Fig. 2): a) It is observed that the shade fraction presents its higher values in March (61%) for the cerrado grassland, and 52% during May and June for the Open Tropical Forest ($p<0.05$). These higher values occur in the end of the wet season, due to the heterogeneity of heights on the canopy layers, e.g., the deciduous and semi-deciduous trees on the Open Tropical Forest are green and on the Cerrado grasslands the sparse trees, shrubs and the grasses are forming different layers, increasing the shade proportion. b) It is observed a peak in the soil fraction on August on the two vegetation formations (35% and 1.6% on Cerrado grassland and Open Tropical forest, respectively). It is also observed that in August there were the lower NDVI and EVI values for Cerrado grassland (NDVI=0.50 and EVI=0.27). The NDVI and EVI lower's values for the Open Tropical Forest were NDVI= 0.83 in July and EVI= 0.47 in May and June. c) The vegetation fraction has its higher values for the Open Tropical forest on September (62%), as well as the EVI. The vegetation fraction was significantly correlated with the EVI for the vegetation physiognomies boarded in this study, but the NDVI had significant correlation just for the Cerrado grassland ($p<0.05$).

a. Open Tropical Forest

The Open Tropical Forest is considered a transition on the Amazon Tropical Forest in its south's limits. It's adapted to more than 60 days of dryer per year (Fig. 2c), and its structure can change based on latitude and altitude. The EVI and the vegetation fraction seem to be sensitive to changes within the canopy during the dry season (April to September), particularly in the months of August and September, increasing its values (Fig. 2a). This pattern corresponds to a structural change in the canopy: the deciduous and semi-deciduous species lose their leaves and the canopy became more homogenous, corroborated with the decrease of the values on the shade fraction image. There were no significant relationship between the EVI and the precipitation pattern, but we found an r^2= 0.66 for the NDVI versus one month lag's precipitation and for the shade fraction with 3 months precipitation lag: r^2= 0.75 ($p<0.05$). For the NDVI this relationship is even stronger if we do not consider the December month that is clearly affected by cloud's cover (r^2= 0.90). The NDVI decreases from a maximum value of 0.89 in January to a minimum value of 0.83 in July and then starts to increase with some variations due to the beginning of the wet season and cloud cover. The annual mean of the NDVI in this research (0.86) is higher than the values founded by [2] (0.53). The difference between the results in both studies can be due to two components: the temporal serie analyzed and the sensor/data characteristics.

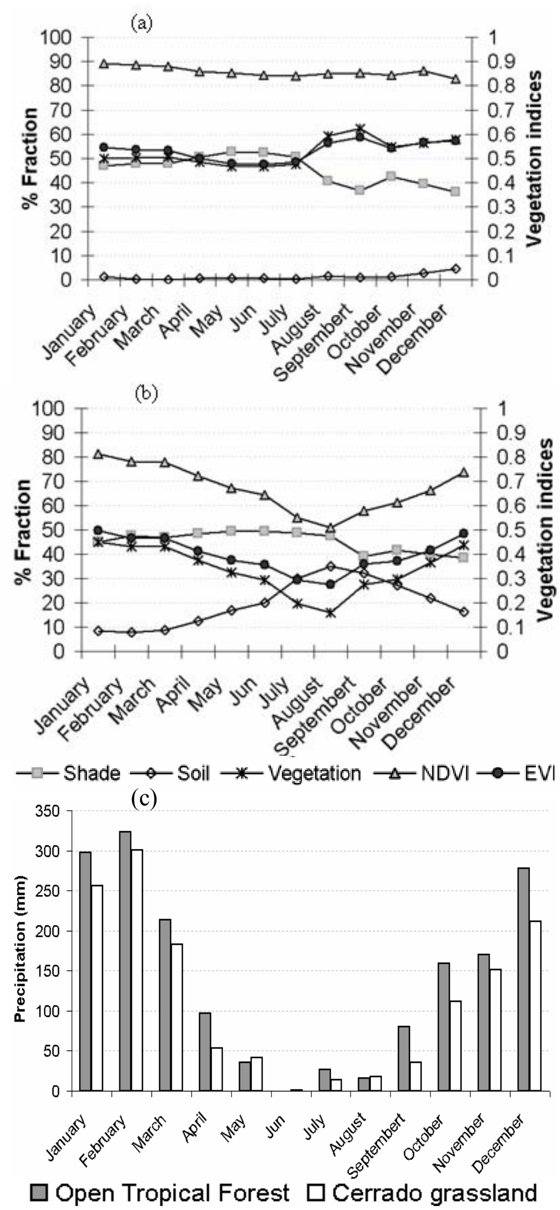

Figure 2. The monthly mean of the intra-annual seasonality curves derived from the linear mixing model (soil, shade and vegetation fraction images) and the vegetation indices NDVI and EVI for the land cover classes. (a) Open Tropical Forest; (b) Cerrado grassland; (c) Precipitation pattern for 2002 by land cover types.

[2] used data from 1981 until 1991 (ten years monthly mean), which included two El Niño years (1982/83 and 1986/87), that affected the precipitation pattern. The other component is that they used data provided by the AVHRR sensor, which is 1 km spatial resolution, and also it can have had sensor's degradation along the period, navigation's error and atmospheric attenuation influencing their results [9]. The results for higher NDVI values founded in this study can also be related to the better spatial and spectral characteristics of the spectral bands of the MODIS sensor, and also the systematic

atmospheric correction with more accurate parameters for these data.

b. Cerrado grassland

The Cerrado grassland region is strongly related to the rainfall pattern. The soil is shallow and the edaphic water is the most important factor associated with the distribution of the Cerrado formations [10]. Its composition is grasses and shrubs predominantly with sparse trees. In the Fig. 2b is presented the vegetation indices and fraction images curves of this formation. [2] found minimum NDVI value of 0.36 and a maximum of 0.41 for 10 years monthly mean; [3], using the AVHRR data from rainy season period for 1993/94, 1994/95 and 1995/96 found a minimum value of 0.02 and a maximum of 0.4 on the NDVI's for the Namibia savannas region. In this study we found a higher annual mean (0.67) for NDVI: minimum value of 0.50 in August, and a maximum value of 0.81 in January. The EVI had an annual mean of 0.40, with a maximum of 0.49 in January and a minimum of 0.27 in August. The NDVI values for the wet season had a maximum value in January of 0.81 decreasing to 0.72 in April. The maximum value founded was 0.67 in May and the minimum was 0.5 in August during the dry season. The EVI variation on the wet season is a maximum of 0.49 in January and a minimum of 0.41 in April. During the dry season, the maximum value founded was 0.37 in May and a minimum of 0.27 in August. All the maximum and minimum values found for the vegetation indices and vegetation fraction occurred during the same months, for both seasons. The shade fraction curve shows an increase until June (44% in January to 49% in June) and then its starts to decrease (48% in July to 38% in December). The maximum value founded for the wet season was 48% in April, and the minimum value were 44% in January. During the dry season, the shade fraction varied from a maximum of 49% in June to a minimum of 38% in September. During all the year its values are higher than the other fractions values, due to the layers formed by this vegetation structure. The soil fraction image presents its lower values during the wet season (8% in January to 12% in April), when the vegetation is more vigorous, and it increases during the dry season: 16% in May to 35% in August. The vegetation fraction changes during the wet season from 44% in January to 37% in April. During the dry season, the values go from to 32% in May to 16% in August. The soil and vegetation fraction and also the NDVI and EVI presented for all the precipitation patterns tested (monthly, 1, 2 and 3 months lag) a significant correlation ($p<0.05$). The strongest relationship founded was with NDVI 1 month lag: $r^2= 0.84$.

B. Relationships between vegetation fractions and vegetation indices

To evaluate the relationship between the vegetation fraction vs. vegetation indices and if its land cover dependence, we carried out a linear regression. The Open Tropical Forest presented a significant correlation between the vegetation fraction and the EVI (r^2=0.84), but not with the NDVI. The results of the linear regression for the Cerrado grassland were r^2=0.93 and r^2=0.98 for the vegetation fraction vs. NDVI and EVI respectively ($p<0.05$). The vegetation fraction is high related with the EVI as it is more associated with structural changes on the canopy rather than with chlorophyll, as the NDVI.

VI. Conclusions

This study has shown that the fraction images derived from the MODIS data can be a source of information to understand vegetation phenology behavior and alteration on the canopy structure. Each landscape analyzed in this study has some unique combination of components that best explain its phenology: the Open Tropical forest is related with the vegetation fraction and shade fraction and the Cerrado grassland's soil and vegetation fraction can explain the phenological behavior of this physiognomy. The shade fraction image presented a significant negative relationship with the EVI, what can explain the increase on the EVI values for the Open Tropical forest during the falling period for deciduous trees. This type of methodology is important to understand the seasonal behavior of the vegetation and the fraction images as the shade and soil complement the data, providing additional information about the land cover and vegetation structure.

Acknowledgment

This research was supported by FAPESP grant (Proc. 2003/01727-0). L. Anderson would like to thank the Brazilian Minister of Science and Technology for the PCI studentship and PARAMA project for research training.

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