Structural-functional model to remote sensing of vegetation physiognomies seasonal variation based on life form

Humberto N. de Mesquita Jr.*[1], Timothy J. Malthus[2], Marisa D. Bitencourt[3], Peter A. Furley[4]

1 & 3 - LEPaC - Lab. Ecol. da Paisagem e Conservação, Departamento de Ecologia - IB/USP
2 & 4 – School of GeoSciences, University of Edinburgh
*tel. +55-11-30917603, email. beto@ib.usp.br

There are in the literature, many attempts to classify vegetation-using indices derived from orbital sensors. The relationship between remotely sensed data and the vegetation structure has been the object of study both for experts in environmental remote sensing and plant ecology. One difficulty to establish these relationships is due to the vegetation dynamics. In cases where the vegetation undergoes seasonal variation in its green biomass, as occurs in the Brazilian *Cerrado*, misclassification may take place. To minimize such effects, a semi-empirical model of NDVI seasonal *Cerrado* variation was developed. The objective of this study is to improve understanding of the seasonal variation of *Cerrado* vegetation indices derived from orbital sensors, using a model that couples reflectance with the proportional contribution of its life forms seasonally. The *Cerrado* tract used as a case study is located in São Paulo State (21°37'30" S, 47°37'30" W) and ranges from grassland to forest sub-types. Two approaches were conducted to model the Canopy: one was a simplified seasonally structure canopy and another a not temporal relatively complex canopy structural 3D model. The procedure followed an aggregation method, using the PROSPECT model to generate transmittance and reflectance of green leaves and the SAIL model to generate canopy reflectance. The results obtained were compared with 9 Landsat-TM images. The NDVI obtained from those Landsat-TM images show a high coincidence with the curves generated by the model, throughout the range of plant physiognomies. During the growing season, the grassland showed values smaller than those predicted by the model but the remaining subtypes had an encouraging level of coincidence with the model. On second approach, the SPRINT model was used to model a gradient of physiognomies sampled in the field over a 39 permanent plots (Leaf Area Index and phytossociological parameters). This method of analysis of seasonal variation by modeling NDVI derived from empirical models and meteorological data, and the relationship between spatial explicit structure of the vegetation and orbital remote sensing provide a measurable condition to quantify the relative seasonal variation of the *Cerrado* physiognomies by orbital sensor.

Introduction

According to Coutinho (1978), the term ***cerrado sensu lato*** (*s.l.*) covers the range of savanna physiognomies, from grassland to arboreal types of vegetation. Depending on the stage that the *Cerrado* has reached in the continual process of ecological readjustment to achieve 'equilibrium' with its surrounding environment, it will have greater or lesser proportions of herbaceous and arboreal components. Such a concept of ecological equilibrium varies according to soil type and water supply (Sarmiento & Monasterio, 1984) as well as being primarily determined by climate. Traditionally, the *Cerrado* can be subdivided into five principal physiognomic structures: *campo limpo, campo sujo, campo cerrado, cerrado s.s. and cerradão*, representing the range from grassland to full cover forest.

The complexity of the *Cerrado* physiognomies and their seasonal variations are responsible for many misclassifications, not only in the field but also when remotely sensed satellite data are used to classify them. The principal reason for such misclassification is that leaves are lost during the dry period and new leaves emerge during the rainy period (Sarmiento & Monasterio, 1984), both of which strongly affect the spectral responses registered by remote sensors in the visible and infrared bands. Several attempts have been made to identify these physiognomies correctly using satellite images, especially using vegetation indices. However, when the vegetation undergoes seasonal variation of its green biomass, it greatly increases the chances of misclassification. Clearly, timing of the satellite imagery is critical to the classification eventually achieved.

There have been several attempts to represent the complex interaction between light and vegetation. For example, Goel (1988) reviewed many ways of modeling the Bi-directional Reflectance Distribution Function (BRDF) and highlighted the two main approaches to conceptualizing the models: firstly, empirical models, based on curve-fitting from data collection and/or based on indices associated with biophysical environment, and secondly, physical models,

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which are predictive models of the relationship between leaves, canopy structure, and biophysical characteristics with electromagnetic radiation, emitted or reflected. A widely used empirical model is based on the NDVI, used for mapping and event detection. Physical models can be divided into turbidity, geometric, hybrid, discrete, radioactive transfer models, and computed intensive simulation models.

Turbidity models assume the vegetation canopy to be a continuous and homogeneous layer, horizontally uniform, with flat and thin layers on the terrain. The vegetation elements of the canopy are randomly distributed, and its structure are set by the leaf area index (LAI) and the leaf angle distribution (LAD).

The SAIL model (Verhoef, 1984) is a well-known turbidity model. This model was successfully applied to homogeneous canopies with few irregular elements, such as mature agricultural crops. Another type of physical model is the electromagnetic radioactive transfer model of green leaves (based on reflection, transmission and absorption properties). The PROSPECT model defines the radiation scattering in the leaves by refraction index, and a parameter of the mesophyll tissue structure. Pigment concentration and water content (set by experimental data) define the absorption properties.

Goel & Thompson (2000) presented the SPRINT model to calculate the vegetated and non vegetated elements of scene reflectance. This model can be categorized as a fast computational simulation model. It was presented as a universal model because it can emulate the turbid, geometric and hybrid models as well as computational simulation models.

The objective of the present study is to improve understanding of seasonal variation of vegetation indices derived from orbital sensors, for *Cerrado* vegetation, using a model that couples reflectance with the proportional contribution of its life forms.

Study site location

The study site is a conservation unit named Pé-de-Gigante in Sao Paolo State, Brazil, created in 1970, with a preserved area of approximately 1225ha. The vegetation is composed of a gradient of all *Cerrado* physiognomies (varying from grass to forest), with one small occurrence of semi-deciduous seasonal forest and, along the stream, riparian forest in degraded state. The conservation unit is located in Santa Rita do Passa Quatro municipality (47°37'W, 21°37'S), in São Paulo State. The relief is moderately flat with altitudes ranging from 590m to 740m containing the headwaters of the Paulicéia river. The geological substrate is formed of alluvial deposits from the erosion of sandstone formations, resulting in soils of low fertility. The land is completely covered by *Cerrado,* varying from predominantly herbaceous to predominantly arboreal forms, with smaller tracts of seasonal semi-deciduous forest, riparian forest, and vegetation of steep slopes (pioneer plants mixed with *Cerrado* species).

Methods

The life forms of herbaceous and arboreal components were used as parameters to feed the model of seasonal spectral response. A semi-empirical model was made by aggregation, using modules to generate: a) the vegetation physiognomies and seasonal variation, b) climatic variation, and c) canopy reflectance. Three components, evergreen and deciduous trees, and grassland, defined a canopy model of the green leaf seasonal variation. The model was built in the visual modeling program *Simeli 2.1.* (School of GeoSciences, University of Edinburgh). The output of the model was LAI and chlorophyll content, during the seasonal year. The curve of annual variation for each life form was based on the research by Sarmiento & Monasterio (1983; 1984). The input parameters [[do you need to list these parameters?]] of the model were at this stage hypothetical. However, the range of variation was abstracted from the literature, as determined in previous studies of *Cerrado* areas or with *Cerrado* species (Miranda et al., 1997, Paulilo et al., 1994).

A semi-empirical model of NDVI was made by aggregation, using the PROSPECT model to generate transmittance and reflectance of green leaves and the SAIL model to generate canopy reflectance.

The PROSPECT model input data was arbitrarily defined, but which are nevertheless realistic values. The LAI range of variation was varied from maximum to zero for deciduous tree and grassland, or partially reduced in the evergreen canopies (never less than 50% reduction). The maximum values of LAI were 4 for the tree layer, and 0.5 for the grass layer. The maximum chlorophyll concentration was 700µg/cm^2 for the tree layer, and 500µg/cm^2 for the grass layer. Other parameters were kept constant: these included 2 layers of cells, 0.025 for water content, and 0.01109 for dry matter.

The canopy model simulated 10 different physiognomic categories, defined by their proportions of trees (deciduous and evergreen) and grassland, varying from 0% tree cover and 100% grassland to 100% tree cover and 0% grassland. The intermediate physiognomies were set at equal intervals generating a gradient between the two extremes.

The output of the PROSPECT model was a 5nm spectral resolution dataset, for each month of the simulated seasonal year. The SAIL model, used in this work, had an input transmittance and reflectance at the same spectral bands of TM Landsat sensor. The PROSPECT output spectral curves were filtered for Thematic Mapper sensor bands of 3, 4 and 5. Reflectance, transmittance, and LAI were used in the SAIL model to calculate canopy reflectance for a nadir view to estimate the NDVI seasonal variation in the different physiognomies.

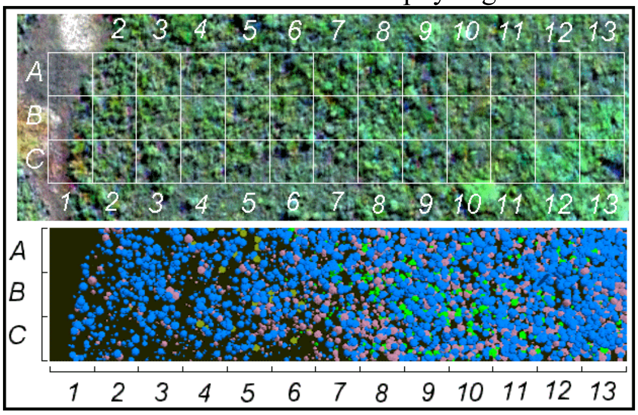

Figure 1 - Top: physiognomic gradient with 39 permanent plots sampled in the field (*Ikonos* 1x1m, multispectral + panchromatic) and; bottom: the 3D diagram of 8 types of tree individuals generated by the SPRINT model.

3D scene building in the SPRINT model was done by the individual declaration of X and Y special position, height, crown diameter and height for each tree [[were these parameters measured in the field??]]. Each tree was classified based on the crown shape and size, density, and leaf angle distribution . All 4,534 tree individuals with diameter higher than 10cm were classified in 8 types with similar characteristics of the model parameters (**fig. 1**).

Results

A model for one calendar year was built with the results produced from each section of the model. The curves obtained for all 10 types of physiognomy were compared with mean NDVI values extracted from wetland grassland, campo *cerrado, cerrado s.s., cerrado s.s.* (with inconspicuous grass layer), *cerradão* and seasonal semi-deciduous forest in 9 Landsat TM images obtained for the study site (**fig.2**).

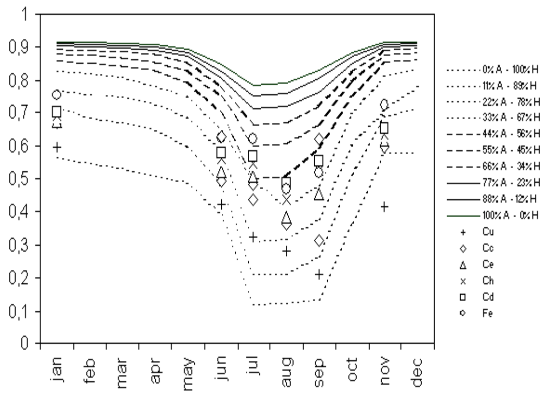

Figure 2 - Monthly variation of NDVI. Lines are model-derived data and dots derived from satellite images (**Cu** = wetland grass, **Cc** = Campo Cerrado, **Ce** = Cerrado s.s., **Ch** = Cerrado (with inconspicuous grass layer), **Cd** = Cerradão, **Fe** = Seasonal Semidecidous Forest).

The sensor-derived NDVI data shows a high coincidence with the curves generated by the model, for all the life forms of the *Cerrado* vegetation. During the growing season the grassland physiognomy shows values smaller than those predicted by the model [[any idea why – imprecise parameterisation?]]. The simulated forest physiognomies gave NDVI values larger than the maximum values obtained from the satellite images.

The graphical results obtained from the SPRINT model are shown on **figure 3**, to all the plots 59 view angles, spatially distributed to all ranges on zenith and azimuth.

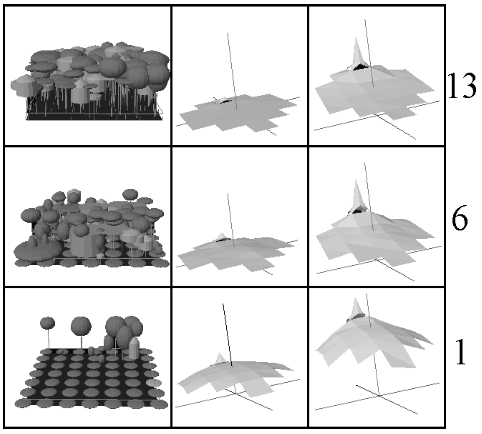

Figure 3 - Vegetation three-dimensional representation of the 3 plots of the 39 sampled (left) and the anisotropy for red (middle) and infrared (right).

In order to quantify the anisotropy over the physiognomic gradient the variance of NDVI of all angles was calculated for each plot (**fig. 4**). The estimated results indicate a higher anisotropy on the plots in the middle of the gradient, which represent the intermediate physiognomies. The cerrado s.s. is the physiognomy with the roughest canopy because of two layers consisting of herbaceous and arboreal components.

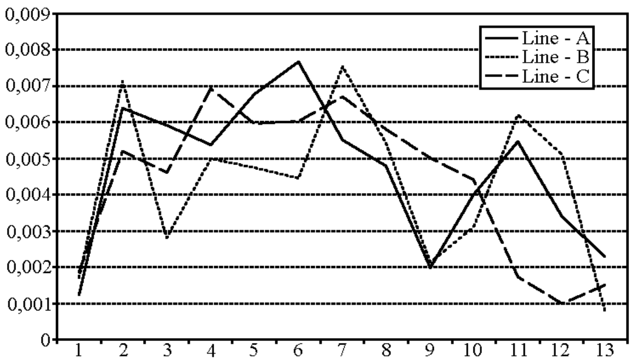

Figure 4 - NDVI variance of 39 plots, of three lines (A, B and C) over the physiognomic gradient obtained to 59 view angles to each plot.

Discussion

The method of analysis derived from empirical models and meteorological data, showed an encouraging level of results and has considerable potential for improving the understanding of NDVI variation of *Cerrado* vegetation. This should ultimately lead to improved classifications of *Cerrado* and other forms of savanna vegetation types using remotely sensed data and hence an improvement in monitoring both climatically-related and disturbance related changes in such systems. However, the ability to assess seasonal changes in reflectance for some *Cerrado* types will ultimately limit the degree to which the method can improve the monitoring methods. Further research will concentrate on a sensitivity analysis of the model.

The anisotropy effects of the physiognomies is similar to the findings of others . Muller (1993) compared Landsat and SPOT images and found lower values to red and higher to infrared [[in what types??]]. The LAI obtained from the SPRINT generated scene were lower than the LAI measured in the field which may suggest that the contribution from the herbaceous layer was under-estimated in the model.

The hypothetical parameters used were useful in building the model, However, to fully test the results requires additional field data. Other parameters can be kept constant, and successfully parameterized, including dry matter (with a knowledge of the tree species), and soil properties (estimated by empirical model or satellite sample).

Acknowledgements

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