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On the Use of the EOS - MODIS Vegetation Indices for Monitoring the Cerrado Region, Brazil: Insights and Perspectives

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Abstract The Moderate Resolution Imaging Spectroradiometer (MODIS), recently launched onboard the Terra platform is expected to fulfill a gap in remote sensing data availability and to decisively contribute to a better understanding and monitoring of the Cerrado vegetative cover. Thus, in this study we evaluated the response of the MODIS vegetation indices to the distinct vegetation types encountered in the Cerrado biome. Both the Normalized Difference Vegetation Index (NDVI) and the new Enhanced Vegetation Index (EVI) showed a good discrimination capability and responded satisfactorily to the marked Cerrado seasonal contrast. Nevertheless, the superiority of the EVI was clearly demonstrated.

Keywords: vegetation indices, MODIS, cerrados.

1 Introduction

The Brazilian Cerrado, the second largest biome in South America, comprises a vertically structured mosaic of grassland, shrubland, and woodland. A major characteristic of the Cerrado is the distinct seasonality in its phenological cycle, which is a direct response to the dominant tropical rainy / dry climate (Eiten, 1993). Approximately 90% of the rainfall is concentrated from October to March. During the dry season, air humidity is very low (below 20% in August and September) and rainfall may be zero in some months.

The Cerrado is also the most severely threatened biome in Brazil as a result of rapid land conversion to cultivated pastures and crops (Dias, 1992). Therefore, the discrimination of land cover types and the identification of land conversions currently taking place is a mandatory issue

and one of the top priorities for the Global Land-Cover and Land-Use Change Strategy within the scope of the NASA Earth Observing System (EOS) program (LCLUC homepage, 2000).

Thus, in this study, we investigated the response of the spectral vegetation indices (VI's) to the Cerrado vegetative cover and its marked seasonal contrast. In particular, we analyzed the VI's developed for the Moderate Resolution Imaging Spectroradiometer (MODIS), recently launched onboard the Terra platform (Justice et al., 1998). These include a continuity Normalized Difference Vegetation Index (NDVI), produced to extend the existent AVHRR-NDVI datasets, and the new Enhanced Vegetation Index (EVI), resistent to atmospheric and canopy background effects (Huete et al., 1999; van Leeuwen et al., 1999).

2 Experimental Design

Study Area – The results presented in this study were obtained at the Brasilia National Park (BNP), which comprises an area of aproximately 30,000 ha and is located in the northern Federal District, Brazil, between 15°35' and 15°45' south latitude and 47°53' and 48°05' west longitude (**Figure 1**). The BNP encompasses the major true savanna formations encountered in the cerrado biome, which depict the transitions from the dominant herbaceous stratum (savanna grassland and shrub savanna) to the more complex, wooded dominated stratum (wooded savanna and the savanna woodland) (Ribeiro & Walter, 1998).

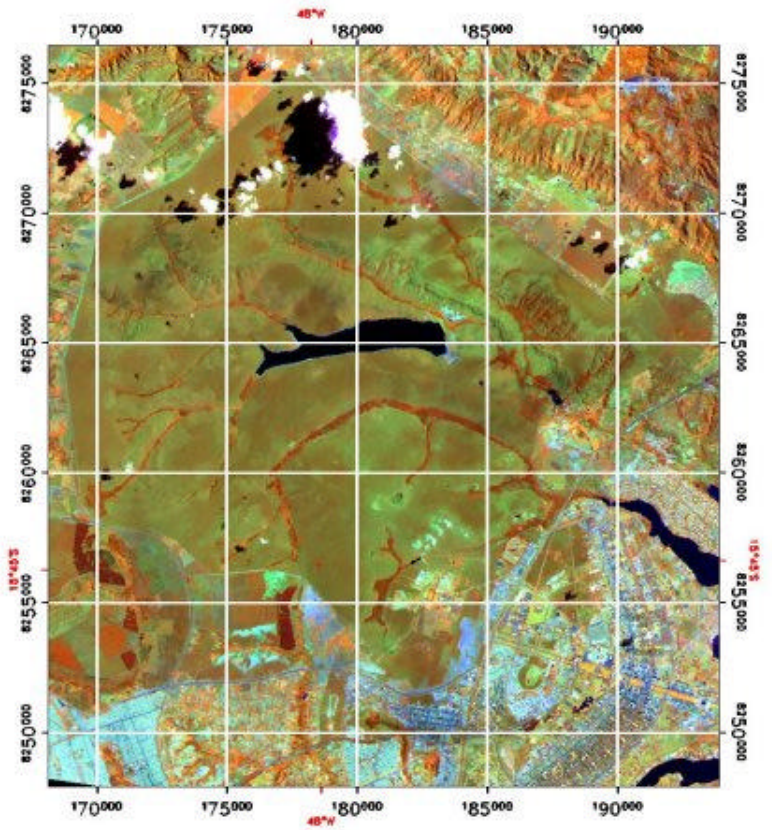

Figure 1 – Brasilia National Park (center) and Brasilia (lower right corner)

Field Data –The major data presented and discussed in this paper was obtained by the Modland Quick Airborne Looks (MQUALS) package, consisting of a calibrated spectroradiometer,

operating within the range from 269.2 to 1068.78 nm, at 1.5678 nm resolution, and a visible digital camera. Both instruments were attached to an ultra-light type aircraft and flown over the site on May 5 (wet season) and July 18 (dry season) to provide top-of-canopy, nadir reflectance values and digital images over the major cerrado formations (cerrado grassland, shrub cerrado, wooded cerrado, cerrado woodland), and over a forest formation (gallery forest) – (**Figure 2**).

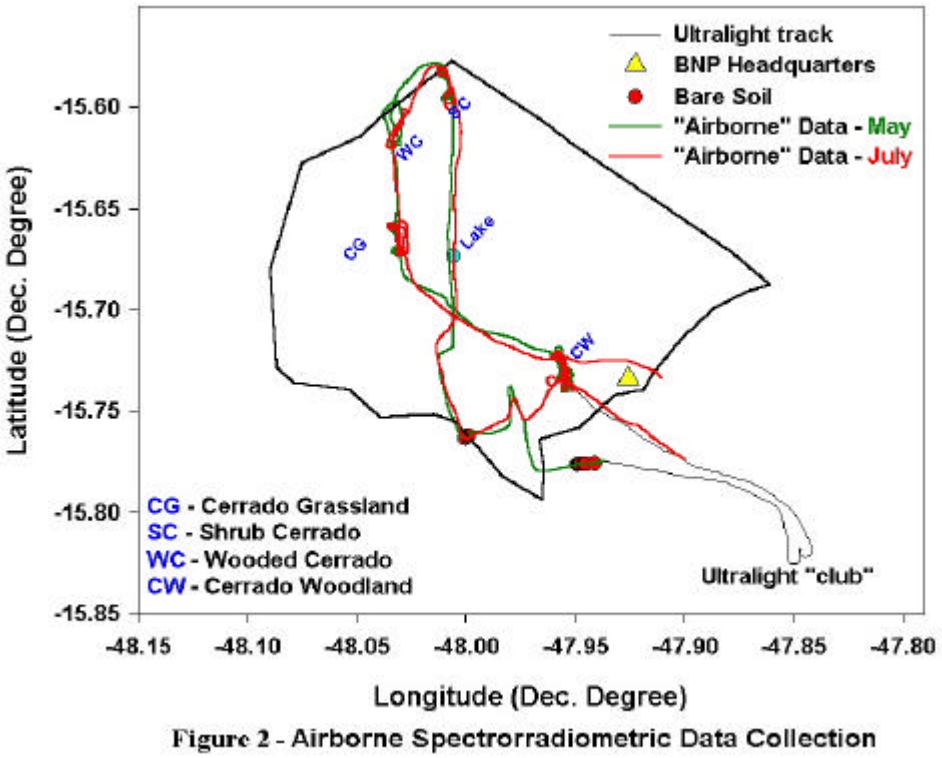

Figure 2 - Airborne Spectrorradiometric Data Collection

Data Processing & Analysis Approach – The atmospheric free, nadir looking spectroradiometric data, processed to surface reflectance values traceable to a NIST[1] reflectance standard, was convoluted to the MODIS bandpasses and converted to the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI), according to the following equations:

$$NDVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}}$$

$$EVI = \frac{(\rho_{NIR} - \rho_{Red})}{(L + \rho_{NIR} + C_1 \rho_{Red} - C_2 \rho_{Blue})} * 2.5$$

Where L is a canopy background calibration factor that normalizes differential Red and NIR extinction through the canopy, and C_1 and C_2 are coefficients accounting for atmospheric aerosol effects. In this study, L, C_1, and C_2 were approximated by 1, 6, and 7.5, respectively.

The seasonal variation in the VI's response was accounted by:

[1] - U.S. National Instrumentation Standards.

$$\%VI_{variation} = \left(\frac{VI_{wet\ season} - VI_{dry\ season}}{VI_{wet\ season}}\right) * 100$$

Thus, a decrease in either NDVI or EVI, as the vegetation dries out (dry season), results in a positive variation. By contrast, a higher dry season value results in a negative variation.

On the other hand, discrimination assessments[2] were based on ANOVA and a Tuckey test, in relation to which, two vegetation classes were considered to be significantly differentiated by either EVI or NDVI whenever the null hypothesis (i.e., the two classes show identical VI response) was associated with a probability value (p) equal or smaller than 0.05 (Davis, 1986).

3 Results

Some of the structural parameters of the Cerrado physiognomies considered in this study are shown in **Table 1**. A major differentiation criterium among these vegetation types is the continuous and systematic increase in the woody layer as one goes from the cerrado grassland up to the gallery forest. These distinct patterns are clearly accompanied by the VI's response (**Figure 3**). For both seasons, the VI's values tend to increase from the cerrado grassland to the gallery forest. As expected, the NDVI values are always higher than the corresponding EVI values.

Table 1 - Brasilia National Park - Major Characteristics

Vegetation Communities	Above-Ground Characteristics	% Cover of woody layers		Average Height of Trees (m)	
		Shrubs	Trees	Shrubs[3]	Trees
Cerrado Grassland	Open grassland	< 1.15	-	< 1.4	-
Shrub Cerrado	Open grassland with sparse shrubs	4.25	0.64	0.8 / ***1.6***	4.73
Wooded Cerrado	Shrubland with sparse trees	24.27	5.43	0.79 / ***1.17***	5.33
Cerrado Woodland	Mixed grassland, shrubland, and trees	20.87	24.53	***1.65*** / 2.5	5.66
Gallery Forest	Evergreen woodland	-	70 - 95	-	20 - 30

2 - For the discrimination analysis, only the wet season VI's were considered.

3 - Numbers in "bold" indicate the predominant average, whenever two distinct heights can be readily identified.

Concerning the impact of the seasonal contrast onto the VI's, the variations in their values tend to decrease as the woody layer increases; thus, the VI's response of the herbaceous dominated physiognomies (e.g., cerrado grassland & shrub cerrado) will show maximum seasonal variation (as high as 40.65%), as opposed to a completely dominated wooded physiognomy (e.g., gallery forest), which shows VI's variations as low as 7.6% (**Figures 4**). Such variation pattern in the VI's response is expected, since the more developed the woody layer is, the higher the capacity of a given physiognomy to buffer the seasonal changes taking place, mainly at the understory level.

Fig. 4

From **Figure 4**, it is also clear that the EVI, comparatively to the NDVI, shows a stronger response to the seasonal changes in the vegetative cover. Although not shown in here, it has been demonstrated by Ferreira et al. (2000) that the more pronounced MODIS EVI response to the seasonal contrast is directly related to this index higher sensitivity to the red and NIR reflectance bands.

With respect to the VI's discrimination capabilities, the MODIS EVI only failed to significantly discriminate between the wooded cerrado and cerrado woodland, while the MODIS NDVI only failed to discriminate between the cerrado grassland and shrub cerrado.

Concerning the VI's dynamic range, another indicative of their performance, the EVI showed a better response. When considering the total radiometric dataset collected over the Brasilia National Park, the dynamic ranges for the MODIS NDVI and for EVI were 1.41 and 1.63, respectively. On the other hand, when taking into account only the 5 vegetation sites yielded dynamic range values of 1.18 and 1.27, respectively.

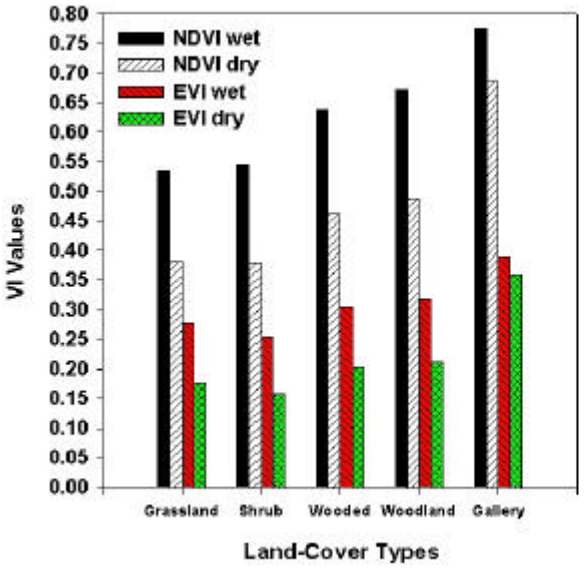

Figure 3 - NDVI & EVI Values (dry & wet seasons)

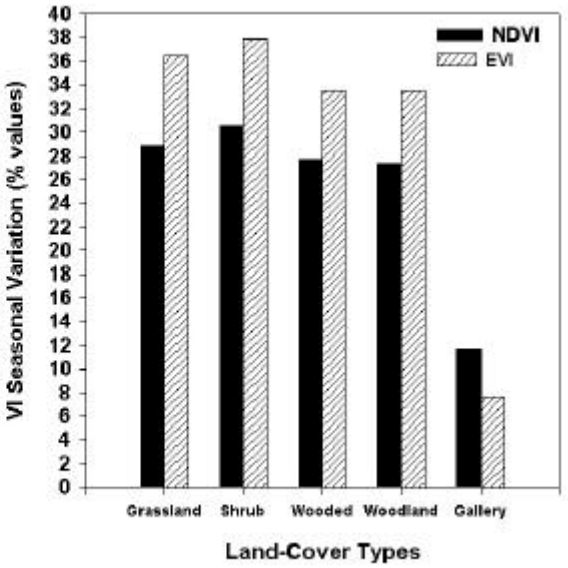

Figure 4 - NDVI & EVI Seasonal Variation

4 Summary and Discussion

It is estimated that approximately 40 % of the cerrado area have been already converted into cultivated pastures, field crops, urban development, and degraded areas. Another 35 % of the total area is occupied by native pastures, which support about 50 million cattle (Mantovani & Pereira, 1998). Unfortunately, this aggressive land occupation and conversion process has not been significantly reduced, since the Cerrado is still a major farming frontier in Brazil.

Nevertheless, very few attempts have been made towards the operational utilization of remote sensing data to effectively monitor this biome. While the high spatial resolution and acquisition costs are the limiting factors regarding the continuous utilization of the TM, and more recently, ETM^+ imagery, the low spatial resolution and low quality of the AVHRR NDVI datasets are the major impediments to their effective utilization. It has been demonstrated that errors of +/- 50% may affect the AVHRR-NDVI product, due to poor sensor calibration, poor pixel location, insufficient cloud screening, and variable acquisition geometry (Goward et al., 1991; Moody & Strahler, 1994).

The MODIS data, marked by substantial sensor improvements, and in particular, the MODIS VI products, in a "ready-to-use" format, at 250m, 500m, and 1km resolution, are expected to fill this gap in data availability, and to decisively contribute to a better understanding of the Cerrado's vegetative cover. The correct application of the MODIS VI's, however, requires a clear understanding of their functionality, behavior, and on how they respond to a specific vegetation type. Thus, in this study we attempted to evaluate the MODIS VI's, based on simulated data, in the context of the Brasilia National Park, which may be assumed to well represent the Cerrado's land-cover mosaic.

While both the NDVI and EVI performed nearly the same with respect to the discrimination of the cerrado vegetation types, it is important to emphasize the superiority shown by the EVI. Its higher dynamic ranges may suggest a greater sensitivity to the vegetative cover variability, and, therefore, a better response to the major land-cover types, as well as to the subtle transitions among them.

One also must consider the conspicuous response of the VI's to the cerrado seasonal contrast, in relation to which, the EVI clearly outperformed the NDVI as well. If the vegetation indices properly and readily respond to such natural changes in the vegetative cover, as it seems to be the case, preventive measures over critical regions, with respect to potential fire hazards, can be established. In fact, Almeida (1997) successfully demonstrated the usefulness of the AVHRR-NDVI datasets for mapping precipitation deficits in the Cerrado region, which would serve as a major input for a warning system for areas under high combustion risk.

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