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A Comparative Analysis on the Use of Optical and SAR Data for Monitoring the Brazilian Cerrado

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Abstract - The wet season synthetic aperture radar (SAR) data and Landsat/Thematic Mapper (TM) vegetation indices from the Brasilia National Park were obtained in order to analyze their potential for Cerrado land cover monitoring. The comparison between the normalized SAR backscattering coefficients and the Normalized Difference Vegetation Index (NDVI) as well as the new Enhanced Vegetation Index (EVI) showed a good discrimination capability of grassland, mixed grassland/shrubland/woodland and woodland covers of the Brazilian Cerrado.

Keywords : vegetation indices, radar, tropical savanna.

1. Introduction

The Brazilian Cerrado covers more than 208 million hectares in the central part of the country and occurs mostly in Oxisols (Eiten, 1993). Physiognomically, the Cerrado is constituted by grasslands, shrublands and woodlands. Variations in their proportion were the basis to define different Cerrado types. The Cerrado is also the most severely threatened biome in Brazil. The flat topography, low land prices, and the construction of Brasilia have contributed greatly to convert natural vegetation into cultivated pastures and grains (soybean, corn and bean, among others).

It is already well-known that the optical data are related to the top few millimeters of the canopy, while the synthetic aperture radar (SAR) data have more penetration capability, providing “volumetric”information. Therefore, a combined analysis of SAR and optical data may improve the mapping and monitoring the Cerrado vegetation types and conditions. The primary goal of this study was to investigate the response of both optical and SAR data to the Cerrado's vegetative cover.

2. Experimental Design

Study Area – The test site corresponded to the Brasilia National Park (BNP), a 30,000 hectares, preserved area 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).

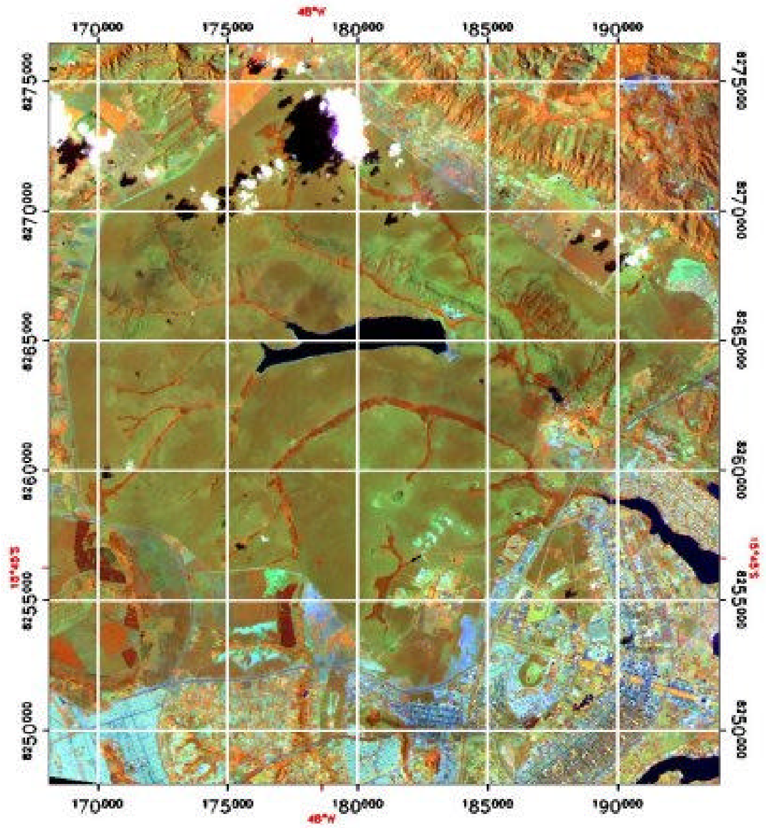

Figure 1 – Brasilia National Park, located in the northern end of the Brasilia city, Federal District.

Remote Sensing Data – The SAR data was acquired by the Japanese Earth Resources Satellite (JERS-1) on February 1st, 1996. The JERS-1 SAR system operates at a wavelength of 23.5 cm (L-band), HH polarization, and incidence angle of 35°. The swath width is about 75 km, and the nominal spatial resolution is 18 meters. The image was georeferenced to the Universal Transerve of Mercator (UTM) coordinate system. The Landsat/TM image was acquired on March 24, 1996 from the National Space Research Institute (Inpe), in Sao Jose dos Campos, SP. The path/row corresponded to 221/71.

Data Processing & Analysis – In this study, we considered the six dominant vegetation comunities encountered in the Park (Macedo, 1992): savanna grassland; shrub savanna; savanna grassland or shrub savanna with "termiters"; wooded savana; savanna woodland; and gallery forest. The descriptions of each class are shown in **Table 1**.

The georeferenced SAR and TM images were overlaid by the vector format, vegetation map of BNP to facilitate the extraction of representative backscatter coefficients ($\sigma°$) and reflectance (ρ) values in each Cerrado unit. **Table 2** shows the number of selected windows in each vegetation unit. In order to keep the size of the window approximately constant for both systems, each sampling area corresponded to 25 pixels for SAR (nominal spatial resolution of 18 meters) and 9 pixels for TM (nominal spatial resolution of 30 meters), i.e., an approximated area of 8.1 km^2 in the terrain. Tab. 02

Table 1 – Characteristics of the major savanna types in the Brasilia National Park.

Savanna Class	**Above-Ground Characteristics**	**Arboreous Cover (%)**	**Average Height of Trees (m)**	**Brazilian Nomenclature**
Savanna grassland	open grassland	< 1	-	Campo Limpo
shrub savanna	open grassland with sparse shrubs	< 5	2	Campo Sujo
Savanna grassland or shrub savanna with "termiters"	open grassland with or without sparse shrubs; presence of "termiters"	< 5	2	Campo com Murundus
Wooded savanna	shrubland with sparse trees	5-20	2-3	Cerrado Ralo
Savanna woodland	mixed grassland, shrubland and trees	20-50	3-6	Cerrado Típico
Gallery forest	evergreen woodland mainly along streams	40-70 (dry season); 50-90 (wet season)	20-30	Mata de Galeria

Source: adapted from Ribeiro & Walter (1998).

Table 2 – Number of windows selected in each Cerrado class in order to extract representative backscatter coefficients and reflectance values from JERS-1 SAR and Landsat/TM images, respectively.

Cerrado Unit	Number of Windows
Savanna grassland	54
shrub savanna	42
Savanna grassland or shrub savanna with "termiters"	32
Wooded savanna	65
Savanna woodland	74
Gallery forest	30

The backcatter coefficients values were obtained through the following equation:

$$\sigma^o = 10\log[\overline{DN}^2 + STD^2] - 68.5$$

where *DN* is the average digital number and *STD* is the corresponding standard deviation.

In relation to the optical data, for each selected site, the extracted data was first normalized to "top of atmosphere" apparent reflectances and then corrected for Rayleigh scattering and ozone absorption using the 6S radiative transfer code simulations. The equations describing such procedures are listed below:

$$L_{s(\lambda)} = n_1 + m_1 \times DN_{\lambda}$$

$$\rho_{app} = \frac{L_{s\lambda} \times \pi}{E_{0,\lambda}} \Rightarrow \frac{L_{s\lambda} \times \pi \times d^2}{E_{0,\lambda} \times \cos(\theta_z)}$$

$$\rho^* = \frac{\frac{\rho_{app}}{t_{o3}} - \rho_{a,r}}{T_r}$$

where: $L_{s\ (\lambda)}$ (W/m^2/µm) is the radiance at the sensor; $DN_{(\lambda)}$ is the digital number for one TM band; *n*, *m* are the TM calibration coefficients; ρ_{app} is the "top of atmosphere" apparent reflectance; $E_{0\,\lambda}$, is the solar exo-atmospheric irradiance related to each TM spectral interval; θz is the solar zenith angle; *d* is the Earth to sun distance (astronomical units); ρ^* is the Raleigh/Ozone corrected reflectance; T_{o3} is the ozone transmittance (absorption); $\rho_{a,r}$ is the Raleigh atmospheric reflectance; T_r is the total atmospheric Rayleigh transmittance.

The corrected reflectance data was then spectrally enhanced through the NDVI and EVI algorithms, as follow:

$$NDVI = \frac{r^*_{NIR} - r^*_{\mathrm{Re}\,d}}{r^*_{NIR} + r^*_{\mathrm{Re}\,d}}$$

$$EVI = \frac{r^*_{NIR} - r^*_{\mathrm{Re}\,d}}{(r^*_{NIR} + 3.3 * r^*_{\mathrm{Re}\,d} - 4.5 * r^*_{Blue} + 0.6)}$$

Where r^*_{NIR}, r^*_{Red}, and r^*_{Blue} are the Rayleigh/Ozone corrected reflectances in the NIR, Red and Blue bands, respectively.

The data analysis of this study was focused on the SAR-VI's relationships. In other words, we wanted to know how the SAR , NDVI and EVI vary with respect to each other in the Cerrado biome. Since the VI's and SAR backscatter show significant scale differences, normalized values was utilized in the scatter crossplot encompassing SAR-VI data:

$$Normalized_{SAR\,T\arg et\,1} = \frac{SAR_{T\arg et\,1} - (Average)\,SAR_{Total\,Data}}{S\tan dard\ Deviation_{Total\,Data}}$$

$$Normalized_{VI\quad T\arg et\,1} = \frac{VI_{T\arg et\,1} - (Average)\,VI_{Total\,Data}}{S\tan dard\ Deviation_{Total\,Data}}$$

where average values and the corresponding standard deviations refer to the six selected vegetation classes.

The expectation was that such analyzes would help us to understand the response of each data set (SAR and optical) to the green vegetation cover and what were the background effects (especially on the SAR data).

3. Discussion and Conclusions

Figure 2 and 3 shows the scatterplots between normalized SAR and normalized NDVI and EVI, respectively. First of all, these figures indicates the possibility of identification of at least three groups of Cerrado classes: a) savanna grassland, shrub savanna and savanna grassland or shrub savanna with “termiters”; c) wooded savanna and savanna woodland; and d) Gallery forest. In other words, optical and microwave remote sensing data can easily separate the grasslands, mixed grassland/shrubland/woodlands and woodlands of tropical savannas.

We can also notice from both scatterplots that most of the points related to the savanna grasslands, shrub savanna and gallery forests are located above the 1:1 line. This is indicating that low vegetation cover of grasslands respond weakly in the SAR backscattering process.

Although the microwave backscattering is particularly sensitive to water in matter (Lewis et al., 1998), we can assume, based on precipitation data (there was no soil moisture or plant water content measurements during the SAR overpass), that dielectric constant over grasslands and shrublands of the Park were relatively low. Precipitation records from Santa Maria raingage in the Park showed only 7.0 mm of rainfall between January 13 to 31, 1996 (19 days time period before the JERS-1 overpass). Regarding the gallery forest, although it presents the highest backscatter values in the SAR data, comparatively, this unit present higher response in both NDVI and EVI. The understanding of such behavior needs to be find out yet.

On the other hand, savanna grassland or shrub savanna with "termiters" and savanna woodland are located below the 1:1 line, indicanting stronger response in the SAR data. As pointed out by Sano et al. (1999), the relatively high $\sigma°$ for the sites with "termiters" can be explained by the presence of these small elevations randomly distributed in either savanna grasslands or shrub savannas. A number of studies reported that as the soil roughness increases, $\sigma°$ also tends to increase (Dobson & Ulaby, 1981; Rao et al., 1993) so that the presence of these small irregularities in the terrain probably increased the the amount of backscattered microwave energy over this type of Cerrado class. For the savanna woodland, which is an intermediate vegetation type, that is, neither a high density nor a low density biomass Cerrado class, the relatively higher values of SAR data in comparison to the normalized VIs can be explained by the contribution of significant vegetation structure in the SAR "volumetric"backscattering process.

As a concluding remarks, the authors would like to highlight that the results and discussions presented in this study, although promising, are still preliminary. We are currently processing and analyzing airborne spectroradiometric data from both wet and dry season, as well as dry season SAR and TM data in order to obtain a conclusive analysis about the effective contribution of both optical and microwave sensors to monitor Cerrado land cover types. Another approach we intend to analyze is the use of vegetation isoline equations in Red-NIR reflectance space (Yoshioka et al., 2000). This approach my allow us to better understand the role of green vegetation and canopy background in the Cerrado's SAR data.

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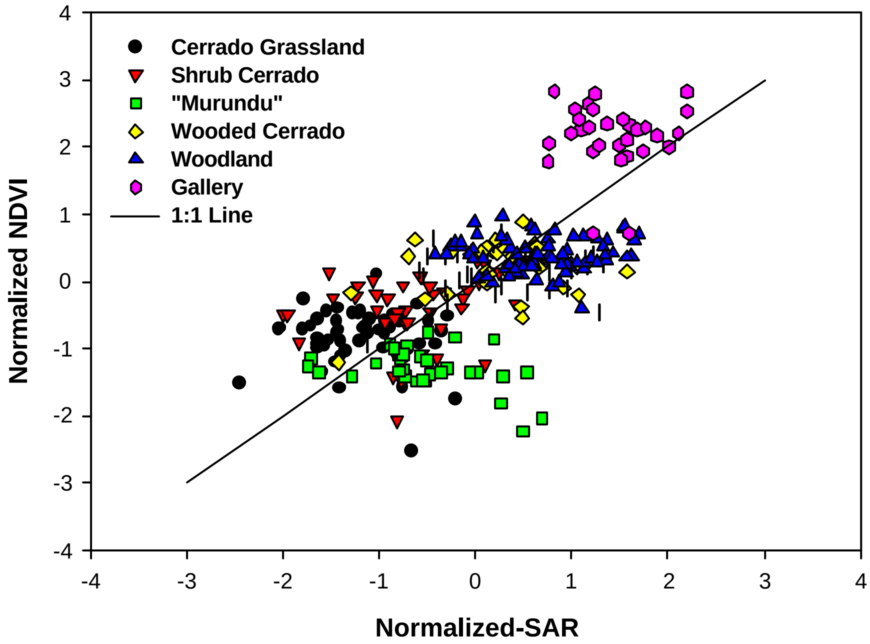

Figure 2 – Relation between normalized SAR and normalized NDVI over the Brasilia National Park.

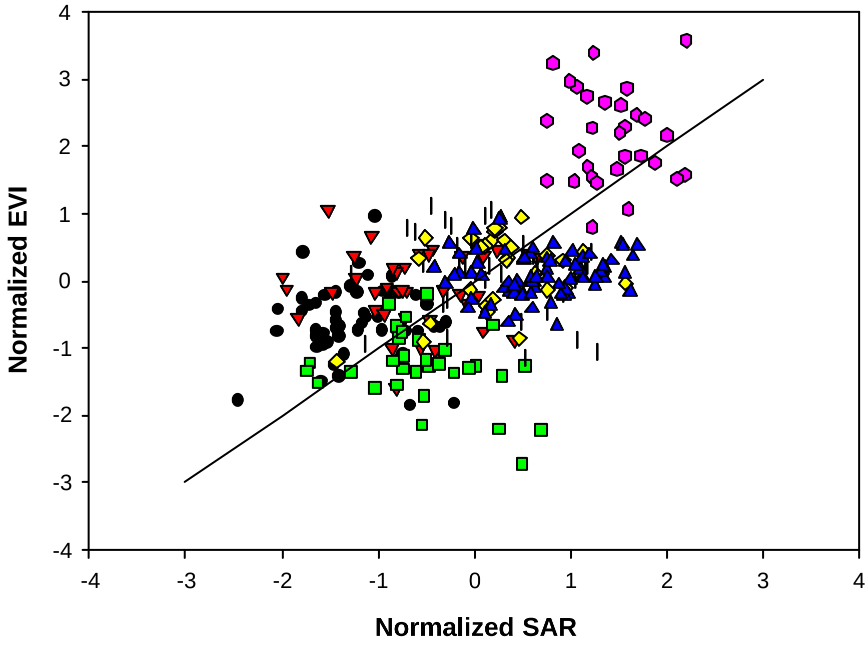

Figure 3 – Relation between normalized SAR and normalized EVI over the Brasilia National Park.