# CALIBRATING *CERRADO* PHYSIOGNOMIES USING SAR AND OPTICAL IMAGES IN BRAZIL.

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**Commission IV, WG IV/6**

KEY WORDS: JERS-1/SAR, TERRA-MODIS, CERRADO PHYSIOGNOMIES, NDVI

The objective of this study is to evaluate the potential use of L-band SAR images, comparing to optical images, to separate the physiognomic gradient of the *Cerrado* biome. The field data come from a project from the BIOTA/FAPESP Program which visited several remnants between 1999 and 2002. That project studied 206 *Cerrado* polygons within the state of São Paulo – Brazil, in order to discriminate their physiognomies and their conservation stages. This study started in one pilot area located in a Conservation Unit (CU) which presents all *Cerrado* physiognomies. Thus, the vegetation classes within the CU were analyzed using Landsat TM/ETM+ and Terra-MODIS images, and then compared with the JERS-1/SAR images. After the classification of the physiognomies found in the pilot area the same procedure were done for 206 polygons all over the São Paulo state. Thus, the NDVI LANDSAT images were obtained from 1999 to 2002 (combined with field trip) and the NDVI MODIS images were obtained 2000 to 2002. Through those NDVI classes, the backscattering ($\sigma$) of JERS-1 images from 1995 to 1997, were analyzed and showed the predominance of dense type of vegetation in most of the remnants. This images observations corroborated the information found in the field by a botany team, who also found predominantly forest type physiognomies. The results obtained for JERS-1image analyses were: *campo cerrado* around –13 *dB*; *cerrado s.s.* from –12 *dB* to –10 *dB*; *cerradão* from –9 *dB* to –8 *dB*; and rainforest from –8 *dB* to –7 *dB*, are similar to those obtained for *Cerrado* and tropical rainforests according to the literature.

## 1. INTRODUCTION

### 1.1 General Instructions

Originally the *Cerrado* biome occupied 23% of the Brazilian territory (200 million hectare). In 1997, the NGO Conservation International indicated this biome as one of the 18 Hot Spots because more than 70% of it has been surrogated by agriculture, especially soy bean. The State of São Paulo used to have 14% of its area occupied by the biome, whilst today less than 1% remains preserved (SMA-SP, 1999). The **Figure 1** shows the location of the *Cerrado* biome in Brazil and in São Paulo State.

To monitor such a huge area it is absolutely necessary to make use of satellite images even with some uncertainties. Optical images for example, are widely considered as a good mean to describe the green leave structure of the vegetation, although they may saturate in forest physiognomies. Studies with optical images in *Cerrado* physiognomies began in early 80's with excellent results if seasonal conditions were taken into account (Bitencourt *et al.*, 1997, Mesquita Jr., 1998, 2003).

The SAR L-band radiation however, can penetrate more deeply through the canopy of the forest physiognomies and provide more information about the vegetation structure. Several authors have described the good potential of that band to study *Cerrado* physiognomies (Santos et al, 1998; Santos et al, 2000; Sano et al, 2001). It is possible to hypothesise that the combination of SAR image, specially from JERS-1satellite, and optical images together could provide better describe those physiognomies. By merging both data could improve the forest physiognomies discrimination, especially in the *Cerrado* biome, where cerradão is spectrally similar to the seasonal semideciduous forest (SSforest).

**Figure 1 –** South America map overlaid with the *Cerrado* Domain area. The small map on the bottom, shows the Domain in the State of São Paulo (IBGE, 1993).

The objective of this paper is to analyse the potential use of JERS-1 and optical images (Landsat TM/ETM+ and Terra-MODIS NDVI), to discriminate different physiognomies within the *Cerrado* Domain in the State of São Paulo-Brazil. The database comprises the remnants studied in project of the BIOTA Program (http://eco.ib.usp.br/lepac/biota-cerrado) and the JERS-1 2nd Research Investigation Program (NASDA).

## 1.2. Methodology

Remote Sensing data have been frequently used to classify vegetation all over the world. Most of the remote sensing studies of vegetation are done with optical spectral bands. In the recent years, radar images are becoming an useful tool because their characteristics can be essential to efficiently sense some vegetation parameters.

In the particular case of the *Cerrado* biome, its physiognomies may vary from *campo cerrado*, to *cerrado s.s.,* and to *cerradão* (the forest type). Other associated forest types, such as riparian forest and SSForest, can also be found (Mesquita Jr. 1998). Two aspect of the vegetation must be taken into account: green leaves (which can be seasonal) and trucks with branches (which can be permanent). Because of that, the use of optical remote sensing can cause misclassification on the forest physiognomies due to the fact that optical bands detect predominantly the green leaves response. The optical spectral response is directly proportional to the amount of phytomass and the vegetation index, particularly the NDVI (normalised difference vegetation index).

Although the NDVI has been shown useful in change detection, land surface monitoring, and in estimating many biophysical vegetation parameters, there is a history of vegetation index research identifying limitations in the NDVI, which may impact upon its utility in global studies which can be simplified as follow:

- Canopy background contamination: background reflected signal, soils, litter covers, snow, and surface wetness;

- Saturation with chlorophyll signal in densely vegetated canopies; and

- Canopy structural effects associated with leaf angle distributions, clumping and non-photosynthetically-active components (woody, senesced, and dead plant materials).

There are several explanations for the NDVI saturation problem over densely vegetated areas in which NDVI values no longer respond to variations in green biomass. The NDVI has been reported to be an insensitive to quantify LAI (leaf area index) at values exceeding 2 or 3.

The atmosphere degrades the NDVI value by reducing the contrast between the red and NIR reflected signals. The red signal normally increases as a result of scattered, upwelling path radiance contributions from the atmosphere, while the NIR signal tends to decrease as a result of atmospheric attenuation associated with scattering and water vapour absorption. The net result is a drop in the NDVI signal and an underestimation of the amount of vegetation at the surface. The degradation in NDVI signal is dependent on the aerosol content of the atmosphere, with the turbid atmospheres resulting in the lowest NDVI signals (Huete *et al.*, 1997 and 1999).

The MODIS NDVI images are being appointed as an improvements over the current NOAA-AVHRR NDVI. Many new indices have been proposed to further improve upon the ability of the NDVI to estimate biophysical vegetation parameters. However, the robustness and global implementation of these indices have not been tested and one must be cautious that new problems are not created by removing the ‘rationing’ properties of the NDVI.

The NDVI is a ‘normalized’ transformation of the NIR (near infrared) to red reflectance ratio, $\rho$ nir / $\rho$ red, designed to standardise vegetation index values to between –1 and +1;

$$\text{NDVI} = \{(\rho\,\text{nir} / \rho\,\text{red}) - 1\} / \{(\rho\,\text{nir} / \rho\,\text{red}) + 1\}$$

It is functionally equivalent to the NIR to red ratio and is more commonly expressed as:

$$\text{NDVI} = (\rho\,\text{nir} - \rho\,\text{red}) / (\rho\,\text{nir} + \rho\,\text{red})$$

As a ratio, the NDVI has the advantage of minimising certain types of band correlated noise (positively-correlated) and influences attributed to variations in direct/diffuse irradiance, clouds and cloud shadows, sun and view angles, topography, and atmospheric attenuation. Rationing can also reduce, to a certain extent, calibration and instrument-related errors. The NDVI, as a ratio, can be computed from raw digital counts, top-of-the-atmosphere radiances, apparent reflectances (normalised radiances), and partially or total atmospheric corrections. Although the units cancel out, the NDVI values themselves change so one must be consistent in how the NDVI is derived. The extent to which rationing can reduce noise is dependent upon the correlation of noise between red and NIR responses and the degree to which the surface exhibits Lambertian behaviour (Huete *et al.*, 1999).

The NDVI is the only vegetation index currently adapted to global processing and it is used extensively in global, regional, and local monitoring studies. It has also been used on a wide array of sensors and platforms. The MODIS NDVI algorithm will utilise complete, atmospherically corrected, surface reflectance inputs, avoiding atmosphere contaminants such as water vapour. According to Huete and collaborator (Huete *et al.*, 1999) the MODIS NDVI can provide consistent, spatial and temporal comparisons of global vegetation conditions (structure and phenology).

The *cerradão* and the SSForest vegetation differ from one another, in the field, not only in species composition but also in the structure (Batalha et al. 1997 and Batalha et al. 2001). The *cerradão* canopy is 10 to 15 meters high and has a regular surface height geometry, whereas the SSForest canopy is 15 to 25 meters high and its geometry is relatively rough, mainly because of the presence of emergent trees (highest trees in the canopy). These emergent trees can be deciduous or semideciduous, what difficult even more the use of optical remote sensing (Mesquita 1998).

The microwaves radiation in the radar bands is transmitted from antenna and, after that, it receives the reflected signal from the earth surface. The sigma signal ($\sigma$) value is the ratio of the received backscattered energy over the emitted energy. Usually $\sigma$ values are expressed in decibels (dB) units which can be converted into digital numbers (DN) of a intensity image (Roseqvist, 1997; Shimada, 2001).

Generally, the $\sigma$ values are dependent on the geometry of the target on the ground and the wavelength. The JERS-1/SAR signal interacts with earth surface roughness on a magnitude of half of the wavelength $\lambda$ = 23 cm and mostly with objects oriented according to the signal polarization VV vertical emission – vertical reception (such as trunk and branch).

Some parameters are quite important to understand the response of the target on the earth surface. They are: geometry of satellite and antenna (satellite ephemeris and antenna angle) in relation to surface and target (corner reflection and specular reflection). When the satellite is in descendent orbit (North to South), the antenna views the west side, when it is in ascendant orbit (South to North) the antenna views East. With the date acquisition, it is possible to determine the orbit and the antenna angle (http://eus.eoc.nasda.go.jp/euswww). According to Luckman et al. (1999), the satellite orbit is very important to understand the signal reflected by the target in the JERS-1/SAR images.

Another important parameter to be considered in multitemporal acquisition dates is the calibration factor, defined according to the image processing date. The calibration factor for the images processing for each date interval were provided by the JERS-1/SAR constructor.

## 2. MATERIAL & METHODS

To make that study, a pilot area containing all *Cerrado* physiognomies, as well as some spots of associated vegetation such as SSforest, located a conservation unit, named Pé-de-Gigante (47o37'W, 21o37'S), were used to calibrate physiognomies with spectral response in both images: optical and L band/SAR.

That conservation unit has been preserved since 1970 and its vegetation is well studied, not only in the field (Batalha, 1997; Mesquita Jr. 1998; Batalha *et al*. 2001), but also through optical TM-Landsat images (Mesquita Jr. 1998 and 2003). With that information, the contents of each 206 polygons of the BIOTA-Cerrado project were analysed using not only JERS-1/SAR images but also Terra-MODIS images.

The pilot area is a conservation unit created in 1970, with 1,225 hectares. The vegetation comprises all *Cerrado* physiognomies in altitudes raging from 590 to 740 m over the Guarani aquifer in the state of São Paulo – Brazil. Climatically, the region is classified as a tropical season with wet summer and dry winter, which corresponds to the Cwa of Koeppen's Climatic Classification. The mean annual precipitation is 1,475 mm year –1 and the mean monthly temperature is around 23 ºC, with small variations. Wide daily variations on the temperature are observed within a range of 20 ºC. According to Mesquita Jr. (1998), there are in the study area 599,65 ha of *cerrado s.s.*; 404,54 ha of *cerrado s.s*. with thin herbaceous stratum; 49,11 ha of *cerradão*; and 114,14 ha ofc*Campo cerrado*, besides other associated physiognomies.

The total study areas are 206 remnants found within 22 first priority zones (FPZ) as indicated in SMA-SP (1997). Those polygons were overlaid in 23 JERS-1/SAR scenes, in order to analyse their vegetation contents. These polygons are derived originally from the Forest Inventory published by Kronka *et al.* (1993) and visited in the field by a botany team of the BIOTA project.

Primarily, the physiognomies zones map of the pilot area, obtained by Mesquita Jr. (1998) were identified to install 40 plots, comprising the following physiognomies: 10 from Campo Cerrado, 10 from Cerrado s.s., 10 from Cerradão and 10 from SSForest. Those plots were analysed through Landsat NDVI images (1999 to 2002) and MODIS NDVI (2000 to 2002).

Secondly, two SAR images from the JERS-1 satellite were used to calibrate the probable physiognomies zones with the backscattering response, within the pilot area. The SAR image data were supplied by National Space Development Agency of Japan, NASDA.

Samples of matching areas were delimited within the image and average backscattering values were extracted. These values were then correlated with data of total volume of wood ($m^3$/ha), determined during field survey. The microwaves radiation is transmitted from the JERS-1 radar antenna and, after that, it receives the reflected signal from the earth surface. The sigma signal (σ) value, which is the ratio of the received backscattered energy over the emitted energy, are usually expressed in decibels (dB) units but can be converted into digital numbers (DN) of a intensity image. The σ values were obtained using the following equation (Roseqvist, 1997; Shimada, 2001):

$$\sigma = 10 \,.\, \log_{10}\left(\frac{\Sigma\left(DN^{2}\right)}{n}\right) + CF$$

DN = digital number of a pixel of a 16bits image
σ = (sigma) is the ratio of received backscattered energy over emitted energy
n = number of pixels sampled
CF = calibration factor

Another important parameter to be considered in multitemporal acquisition dates is the calibration factor, defined according to the image processing date. The calibration factor for the JER-1/SAR images processing for each date interval are shown in the **Table 1**.

**Table 1** – Calibration factors according to the date interval when the images JERS-1/SAR were processed. Source:

| Processing Date | Calibration Factor (dB) |
|---|---|
| Until February 14, 1993 | -70,00 |
| After February 15, 1993 | -68,50 |
| After November 01, 1996 | -68,20 |
| After April 01, 2000 | -85,34 |

NASDA (EORC - Orderdesk)

Finally, 23 JERS-1/SAR images were transformed in averaged σ values, for each of the 206 fragment found in the 22 FPZ, and then compared with the NDVI values, obtained by Terra-MODIS images. The MODIS NDVI images were processed by EOS-DIS/NASA according to Huete *et al.* (1999).

**Figure 2** shows the JERS-1 images after pre-processing for each FPZ studied. The whole state of São Paulo polygons were taken from 1990 and 1992 (Kronka *et al.*, 1993), the JERS-1 images from 1995 and 1996, and Terra-MODIS NDVI images from November 2000 to June 2002.

All digital processing was performed using the following software: ERDAS Imagine, ARC/VIEW, ERMapper, and ENVI licenced to the University of São Paulo – Brazil.

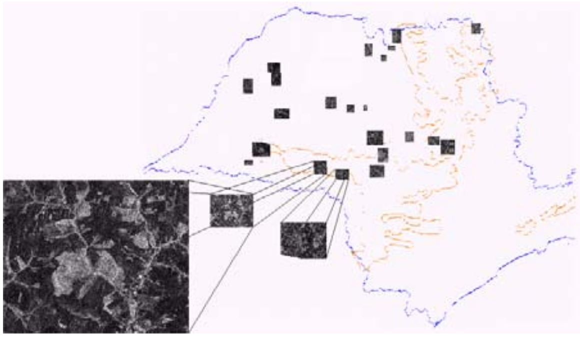

**Figure 2** - JERS-1/SAR Images windows of the 22 priority zones visited during the BIOTA-Cerrado project, with a 12.5 meters spatial resolution.

## 3. RESULTADOS

The JERS-1 σ values from JERS-1/SAR images were extracted using the map of physiognomies, described by Mesquita Jr (1998), and the results are presented in **Figure 3**. The range found was around -6 *dB* to -12 *dB*, covering all *Cerrado* physiognomies found in the pilot area.

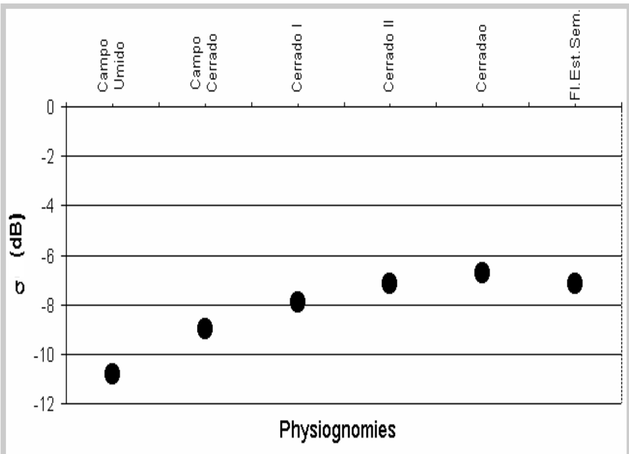


**Figure 3** – Diagram of σ values of the *Cerrado* physiognomies and Seasonal Semideciduous Forest within the Pé-de-Gigante.

Generally speaking, the results obtained in this pilot area are similar to those obtained by Santos et al. (1998 and 2002) and Luckman et al. (1999).

The **Figure 4** shows the relation of the NDVI values (ranging form 0.6 to 0.9) with σ values (ranging from –14 *dB* to –7 *dB*) for all 206 remnants studied. The dispersion of those plots are bigger than expected requiring further analysis that should take into account the topography effects. It is clear that the concentration of remnants with higher NDVI and higher σ values indicates the predominance of dense physiognomies.

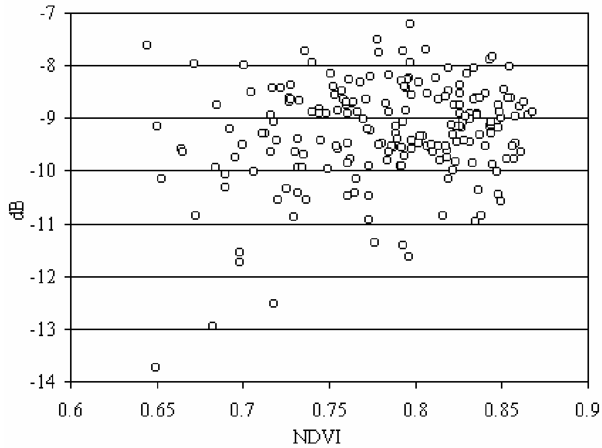


**Figure 4** –Graph of the dispersion of the average values of NDVI (Terra-MODIS) and σ values of each *Cerrado* fragment.

Considering that the MODIS NDVI values are corrected in terms of atmospheric effects and the σ values of the SAR images are properly pre-processed, the points concentration at the right top of the graphic suggest that most of the remnants studied present dense vegetation physiognomies.

Comparing the σ values obtained from all 206 remnants, within the 22 priority zones the results are: zones G, F, S, C, D, Q, Z, U, and R presented higher backcattering dispersion spectrum (from –14 *dB* to –7 *dB*); and the zones B, N, L, A, I, J, M, T, E, H, O, V, K, and P presented lesser dispersion spectrum (-11 *dB* to –7 *dB*).

**Figure 5** shows the location of each FPZ studied and **Figure 6** shows the analyses done of each remnant inside each FPZ. The results from field observation, MODIS NDVI analyses and JERS-1 image analyses showed the predominance of dense type of vegetation within the majority of the remnants.

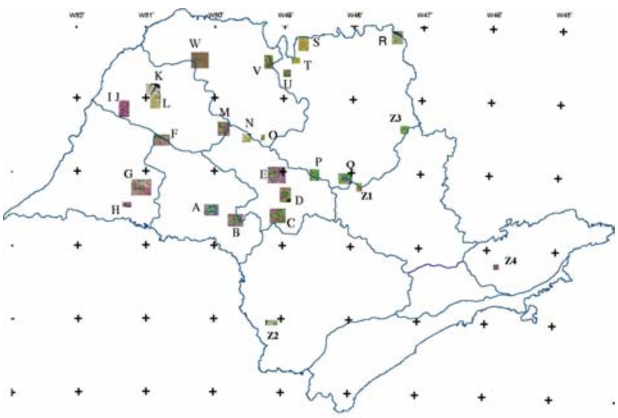

**Figure 5** – The location of the 22 FPZ within the whole state, comprising 206 *Cerrado* remnants located in the 22 priority zones.

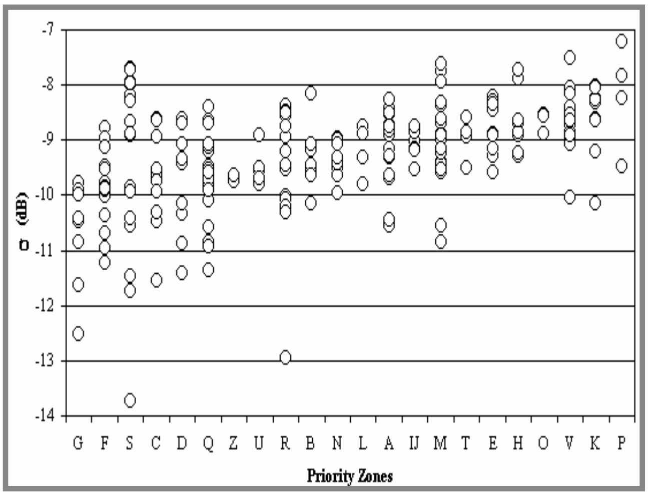


**Figure 6** – Average **σ** values (dB) of 206 remnants within the 22 first priority zones (indicated capital letters).

The highest average σ values of some fragments may indicate the presence of SSForest, because cerradão´s average σ values should range around –9 *dB*.

In order to achieve better results, the digital terrain elevation model for each fragment as well as the ephemeris of the satellite on the acquisition date should be considered. Preliminary study has already been done for Pé-de-Gigante pilot area but further analysis must take place later on, because a two year project is not enough to prepare all necessary data for 206 polygons.

The results obtained in that activity are similar to those obtained for savanna and tropical rainforests by Santos et al. (2002): campo cerrado around –13 *dB*; cerrado s.s. from –12 *dB* to –10 *dB*; cerradão from –9 *dB* to –8 *dB*; and rainforest from –8 *dB* to –7 *dB*.

## 4. CONCLUSIONS

JERS-1/SAR images demonstrated to be good indicators of physiognomies with different aboveground wood biomass, such as *cerrado s.s*., *cerradão*, and seasonal semideciduous forest (SSForest).

MODIS NDVI images showed an excellent performance in indicating all *Cerrado* physiognomies.

Because the pilot area correspond to a well preserved conservation unit it is acceptable the classification of the 206 remnants located in private properties (as Legal Reserve).

The satellite information corroborate the field observation that the *Cerrado* remnants are comprised mostly by the dense physiognomies of the biome.

## 5. ACKNOWLEDGEMENT

To the University of São Paulo and NASDA (the Japanese Space Agency) for the JERS-1 image support. To FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo) in the context of the BIOTA/FAPESP program: “The Biodiversity Virtual Institute Program” (http://www.biota.org.br), for financial support and scholarships.

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