DISCRIMINATION AND BIOPHYSICAL CHARACTERIZATION OF BRAZILIAN CERRADO PHYSIOGNOMIES WITH EO-1 HYPERSPECTRAL HYPERION

Tomoaki Miura, [1] Alfredo R. Huete,[2] Laerte G. Ferreira,[3] and Edson E. Sano[4]

1. Introduction

The savanna, typically found in the sub-tropics and seasonal tropics, are the dominant vegetation biome type in the southern hemisphere, covering approximately 45% of the South America. In Brazil, the savanna, locally known as "cerrado," is the most intensely stressed biome with both natural environmental pressures (e.g., the strong seasonality in weather, extreme soil nutrient impoverishment, and widespread fire occurrences) and rapid/aggressive land conversions (Skole et al., 1994; Ratter et al., 1997). Better characterization and discrimination of cerrado physiognomies are needed in order to improve understanding of cerrado dynamics and its impact on carbon storage, nutrient dynamics, and the prospect for sustainable land use in the Brazilian cerrado biome.

Satellite remote sensing have been known to be a useful tool for land cover and land use mapping (Rougharden et al., 1991; Hansen et al., 2000). However, attempts to discriminate and classify Brazilian cerrado using multi-spectral sensors (e.g., Landsat TM) and/or moderate resolution sensors (e.g., NOAA AVHRR NDVI) have often resulted in a limited success due partly to small contrasts depicted in their multi-band, spectral reflectance or vegetation index values among cerrado classes (Seyler et al., 2002; França and Setzer, 1998).

In this study, we aimed to improve discrimination as well as biophysical characterization of the Brazilian cerrado physiognomies with hyperspectral remote sensing. We used Hyperion, the first satellite-based hyperspectral imager, onboard the Earth Observing-1 (EO-1) platform.

2. Materials and Methods

Our study sites were located in the Brasilia National Park (BNP) in the northern Federal District, Brazil (S 15° 40', W 48° 02') (Figure 1). This preserved area contains several of the major "core" cerrado vegetation associations (physiognomies), including cerrado grassland (camp limpo), shrub cerrado (campo sujo), wooded cerrado (cerrado ralo), cerrado woodland (cerrado tipico), and gallery forest (mata de galeria) in the order of increasing arboreous cover (Ribeiro and Walter, 1998).

The first four major cerrado physiognomies described above were structurally characterized using ground transect surveys. At each site (physiognomy), landscape were vertically stratified into an arboreous (shrubs/trees) overstory layer and herbaceous understory layer dominated by grasses, in addition to a background soil/litter layer. Component cover fractions of each layer were then measured using a pin-point technique along a randomly-chosen 100-m transect. The landscape components considered in the measurements were: photosynthetic vegetation (PV), woody materials, and crown covers for the overstory; PV and standing litter for the understory; and soil and surface litter for the background surface layer.

[1] University of Arizona, Tucson, Arizona 85721, USA
  (Currently at University of Hawaii at Manoa, Honolulu, Hawaii 96822, USA: tomoakim@hawaii.edu)
[2] University of Arizona, Tucson, Arizona 85721, USA
[3] Universidade Federal de Goiás, Goiânia – GO, Brazil
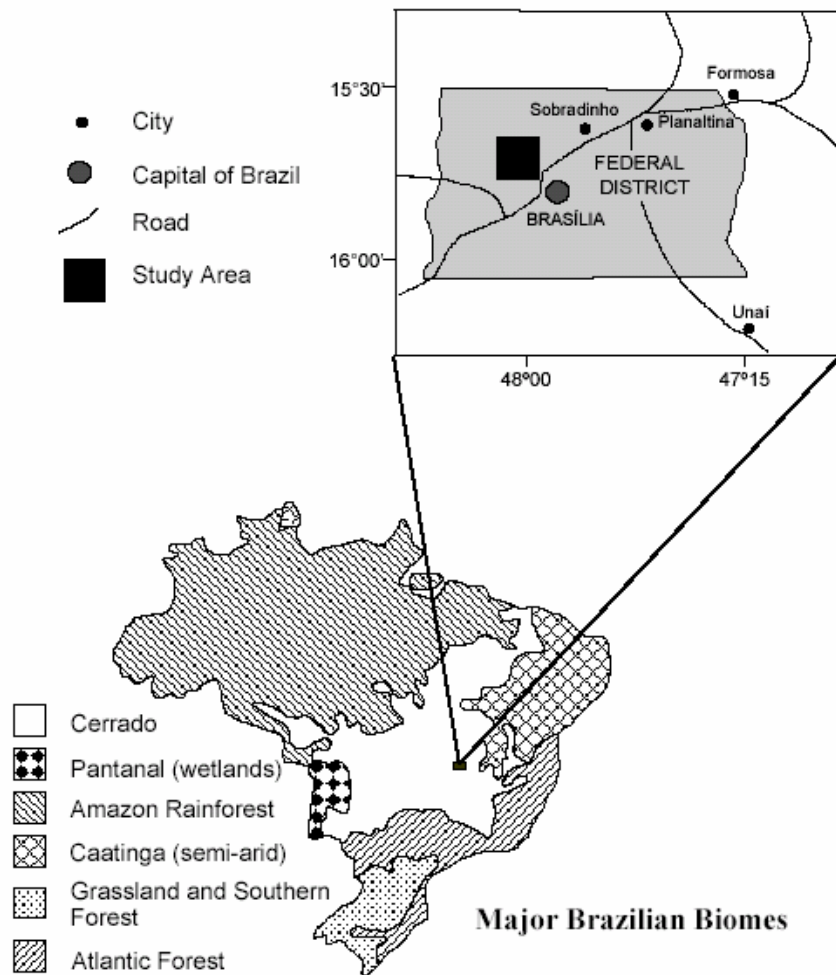[4] EMBRAPA Cerrados, Planaltina – DF, Brazil

Figure 1. Location of the study area (Brasilia National Park).

Hyperspectral Hyperion data were acquired over the field sites on July 20, 2001 during the field measurement campaign. Hyperion collected full range spectral data (400-2400 nm) in 10-nm intervals (full-width at half maximum = 10 nm) at a 30-m ground spatial resolution. The data were preprocessed and radiometrically-calibrated into a Level 1A product at the TRW Hyperion data processing facility. The data were further processed to correct for several known artifacts in the Level 1A products and then converted to ground reflectances using a MODTRAN4-based atmospheric radiative transfer code (ACORN4, http://www.imspec.com/). The atmospherically-corrected Hyperion data were compared to airborne spectrometer (Analytical Spectral Devices, Inc., Boulder, Colorado) data collected at a large dry pasture field in the north of BNP near the Hyperion overpass time, but on the next day. An aircraft was flown "below the atmosphere" at 150 m AGL. The airborne data were calibrated to ground reflectances by taking a ratio to the readings made over a calibrated Spectralon white reference panel before and after the flight. The Hyperion and airborne spectrometer data were statistically similar, indicating good accounting of atmospheric constituents in the Hyperion correction.

Three optical measures of surface biophysical conditions which took a full advantage of hyperspectral remote sensing were employed and applied to the atmospherically-corrected Hyperion data. First, the 1st-order derivative-based green vegetation index with a baseline correction (1st_DGVI) which measures the amplitude of the red-edge feature and thus the amount of PV was computed as (Elvidge and Chen, 1995; Chen et al., 1998):

$$1st\_DGVI = \sum_{i=1}^{n} \left| \rho'(\lambda_i) - \rho'_l(\lambda_1) \right| \Delta\lambda_i \,, \qquad\qquad [1]$$

where $\rho'(\lambda_i)$ is the 1st-order derivative reflectance (approximated by the reflectance difference) at the wavelength, λ_i, $\rho_l'(\lambda_1)$ is the local baseline value at the cut-on wavelength, λ_1. The cut-on and cut-off wavelengths were empirically determined to be ~640 nm and ~800 nm, respectively. Elvidge (1988) proposed the ligno-cellulose vegetation (absorption) index to map spatial variability of NPV using 1987 AVIRIS data, which was also applied and computed as the reflectance difference between 2200 nm and 2330 nm. Finally, we applied the shortwave infrared (SWIR) spectral unmixing to capture spatial variability of PV, NPV, and soils simultaneously in the Hyperion scene (Asner and Lobell, 2000). Details of these methods were provided in the corresponding references.

Pixels over the field sites were extracted from the atmospherically-corrected Hyperion image. GPS coordinates of the sites and low-altitude aerial photos were used to locate the sites in the image. In addition, another set of pixels were extracted over gallery forest, cultivated pasture, and lake water (Santa Maria Lake at the center of BNP) for comparisons.

3. Results

3-1. Field Measurements

Measured landscape component cover fractions of the four cerrado physiognomies as well as the field site locations are summarized in Table 1. The herbaceous layers were dominated by senescent tissues, while the shrub/tree layer were still green at the time of this field campaign. As used for the basis on many cerrado classification schemes (e.g., Ribeiro and Walter, 1998), the crown cover fractions increased from the cerrado grassland to cerrado woodland sites with a discrete increase between the shrub cerrado and wooded cerrado sites. There was a general increase (decrease) in the PV (NPV) cover fractions with an increase in the crown covers, except for the wooded cerrado site. Two of the four sites, the wooded cerrado and shrub cerrado sites, were dominated by the species that grow quickly after burnings and that remained green, which resulted in a larger green cover in the wooded cerrado site than the cerrado woodland site. Nearly no soils were exposed at any of the sites.

Table 1. Landscape component cover fractions of the cerrado physiognomies measured in the field sites

Site Name (Physiognomy)	Site Location (Lat./Lon.)	Crown (%)	Green (PV) (%)	NPV (%)	Soil (%)
Cerrado Grassland	N15°39'55"/ W48°01'52"	1	18	82	< 1
Shrub Cerrado	N15°35'20"/ W48°00'25"	3	23	76	< 1
Wooded Cerrado	N15°36'26"/ W48°01'47"	10	34	63	3
Cerrado Woodland	N15°43'58"/ W48°00'11"	13	30	69	< 1

3-2. Hyperion Reflectance Data

The Hyperion hyperspectral signatures clearly depicted the differences between pasture, gallery forest, and the other four cerrado physiognomies (Figure 2). Spectral signatures in the visible and near-infrared (NIR) regions for the cerrado physiognomies showed small differences, but with the red-NIR reflectance contrast corresponding well with green cover fractions (Figure 2, Table 1). The reflectance values at the shortwave-infrared (SWIR) region (1400 – 2500 nm) and the ligno-cellulose absorptions at 2090 nm and around 2330 nm wavelengths showed larger differences among the cerrado physiognomies (Figure 2). The cerrado physiognomies with less crown cover (and, thus, more NPV cover) showed higher SWIR reflectances and deeper ligno-cellulouse absorpotions (Table 1).
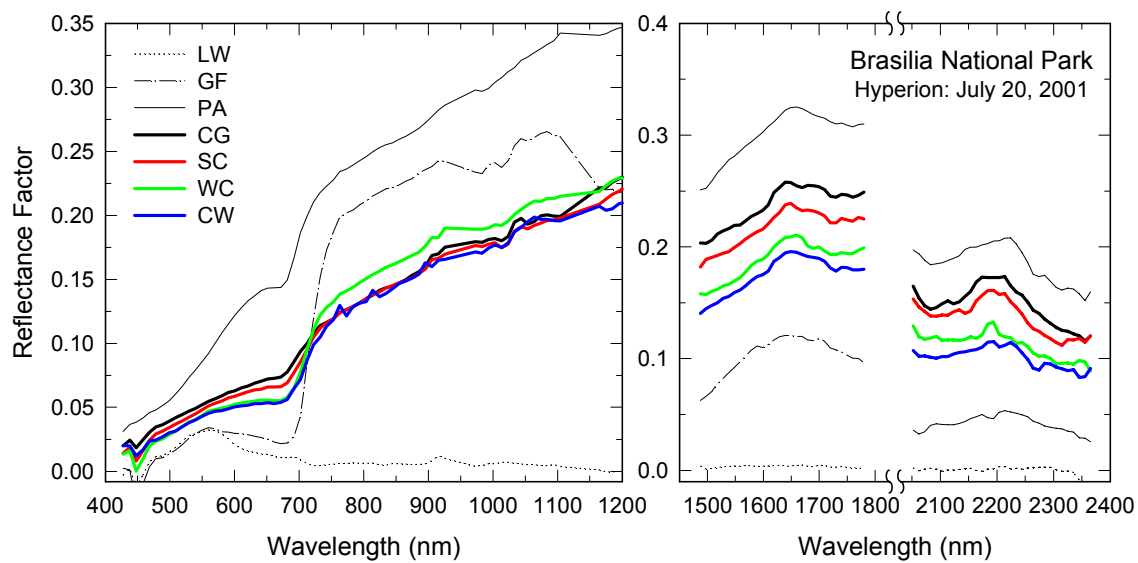
Figure 2. Mean Hyperion reflectance spectra for the four cerrado physiognomies: cerrado grassland (CG), shrub cerrado (SC), wooded cerrado (WC), and cerrado woodland (CW). Mean Hyperion spectra for lake water (LW), gallery forest (GF), and cultivated pasture field (PA) were also plotted for comparisons.

3-3. Correlative Analysis with Biophysical Data

In order to more quantitatively analyze these spectral signatures, we focused on two spectral regions that corresponded well to relative differences in physiognomies, namely, (1) the red-NIR transitional region (650-800 nm) and (2) the SWIR2 spectral region (2000-2400 nm), and performed a correlative comparison of the three optical measures described above with cover fractions.

In Figure 3, the 1st-DGVI values were plotted against the green cover fractions. The 1st-DGVI and green (PV) cover fractions correlated very well.

Similarly, the ligno-cellulose absorption index for 2330 nm was correlated well with the NPV cover fractions (Figure 4). The ligno-cellulose absorption index, however, had large standard deviations (Figure 4) due most likely to the low signal-to-noise ratios of the Hyperion sensor in this wavelength region (< 30:1).

Finally, the SWIR unmixing results from the Hyperion image were compared to an existing vegetation map for BNP. The regional fractional estimates were consistent with the vegetation map (Figure 5). The largest values of green vegetation fractions corresponded well to the occurrences of gallery forest along stream lines. Similarly, relatively large values of green vegetation fractions corresponded spatially well with wooded cerrado and cerrado woodland, while cerrado grassland and shrub cerrado areas were consistent with large NPV fractions.
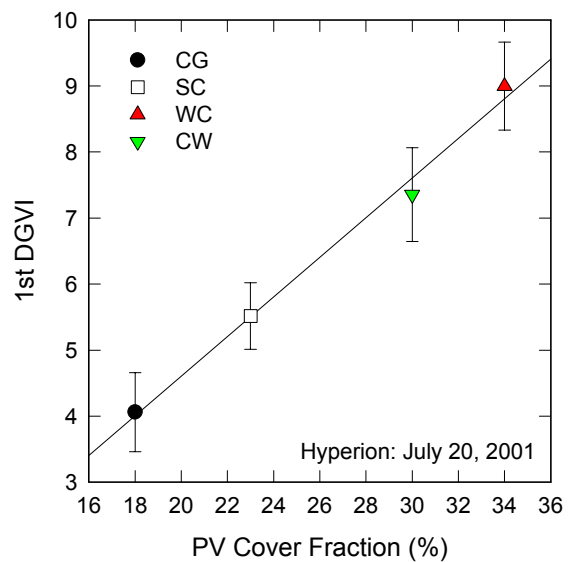

Figure 3. 1st-DGVI plotted against field estimates of PV cover fractions for cerrado physiognomies.

4. Conclusions and Discussions

In this study, we evaluated the utility of hyperspectral remote sensing in biophysical characterization and discrimination of cerrado physiognomies by taking an advantage of a newly available satellite-based imaging spectrometer, EO-1 Hyperion. The atmospherically-corrected hyperspectral reflectance of Hyperion clearly depicted such diagnostic absorption features of vegetation as the red edge, red-NIR transition, and ligno-cellulose absorptions. Likewise, these spectral features were found to be corresponding well with biophysical characteristics (i.e., landscape component cover fractions) of cerrado physiognomies. As the cerrado physiognomic classes are based on differences in the proportion of a grass understory and tree/shrub overstory layer, the cover component fractional estimates of green vegetation, NPV, and soil with the SWIR spectral unmixing resulted in not only biophysically characterizing, but also discriminating cerrado physiognomies. These preliminary analyses showed a great potential of hyperspectral remote sensing in biophysical characterization as well as discrimination of the land covers in the Brazilian cerrado.
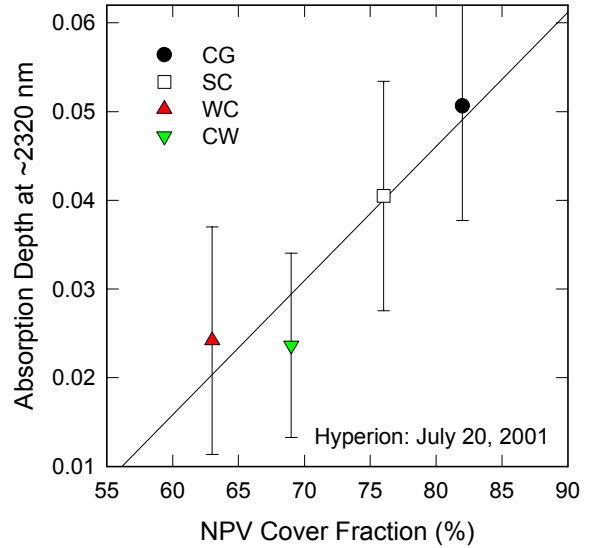

Figure 4. Ligno-cellulose absorption index plotted against field estimates of NPV cover fractions for cerrado physiognomies.
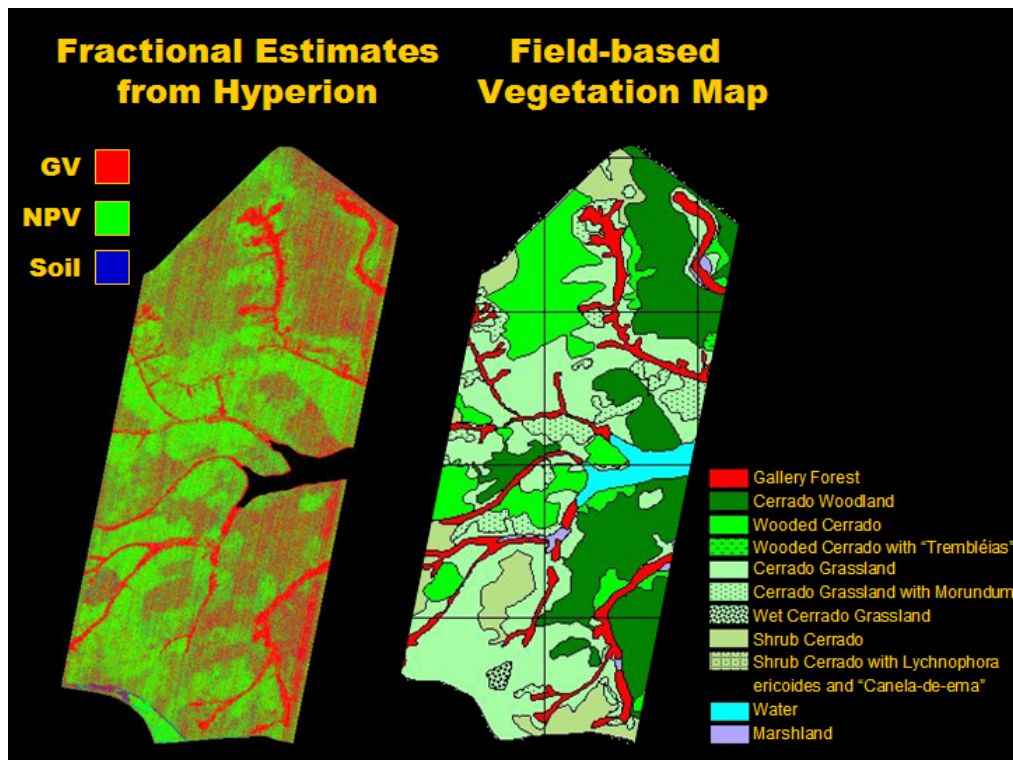

Figure 5. Color composite of green vegetation (red), total litter (green), and bare soil (blue) fractions in comparison to a field-based vegetation map (M. Ferreira, Universidade de Brasilia, personal communication).

References

Asner, G. P. and Lobell, D. B. "A biogeophysical approach for automated SWIR unmixing of soils and vegetation." *Remote Sensing of Environment*, v. 74, p. 99-112, 2000.

Chen, Z., Elvidge, C. D., and Groeneveld, D. P. "Monitoring seasonal dynamics of arid land vegetation using AVIRIS data." *Remote Sensing of Environment*, v. 65, p. 255-266, 1998.

Elvidge, C. D. "Examination of the spectral features of vegetation in 1987 AVIRIS data." *Proceedings of the First AVIRIS Performance Evaluation Workshop*, Jet Propulsion Laboratory Publication 88-38, Pasadena, CA, USA, p. 97-101, 1988.

Elvidge, C. D. and Chen, Z. "Comparison of broad-band and narrow-band red and near-infrared vegetation indices." *Remote Sensing of Environment*, v. 54, p. 38-48, 1995.

França, H. and Setzer, A. W. "AVHRR temporal analysis of a savanna site in Brazil." Int. J. Remote Sensing, v. 19, no. 16, p. 3127-3140, 1998.

Hansen, M. C., DeFries, R. S., Townshend, J. R. G., and Sohlberg, R. "Global land cover classification at 1 km spatial resolution using a classification tree approach." *Int. J. Remote Sensing*, v. 21, no. 6&7, p. 1331-1364, 2000.

Ratter, J. A., Riberio, J. F., and Bridgewater, S. "The Brazilian cerrado vegetation and threats to its biodiversity." *Annals of Botany*, v. 80, p. 223-230, 1997.

Ribeiro, J. F. and Walter, T. M. B. "The major physiognomy in the Brazilian Cerrado region." Cerrado: Ambiente e Flora (ed. by Sano, S. M. and Almeida, S. P.), EMBRAPA-CPAC, Planaltina, DF, chap. 3, p. 169-188, 1998.

Rougharden, J., Running, S. W., and Matson, P. A. "What does remote sensing do for ecology?" *Ecology*, v. 72, p. 1918-1922, 1991.

Seyler, F., Chaplot, V., Muller, F., Cerri, C. E. P., Bernoux, M., Ballester, V., Feller, C., and Cerri, C. C. C. "Pasture mapping by classification of Landsat TM images: Analysis of the spectral behaviour of the pasture class in a real medium-scale environment: the case of the Piracicaba Catchment (12 400 km^2, Brazil)." Int. J. Remote Sensing, v. 23, no. 23, p. 4985-5004, 2002.

Skole, D. L., Chomentowiski, W. H., Salas, W. A., and Nobre, C. A. "Physical and human dimensions of deforestation in Amazonia." *Bioscience*, v. 44, p. 314-322, 1994.