SPECTRAL RESPONSE OF VEGETATION COVERED SURFACE SUBJECT TO FLOODING DUE TO VIEWING GEOMETRY

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Abstract

The objective of this research was to study the bidirectional reflectance of a natural surface with different levels of flooding due to different viewing angles, since the multi-angle imaging for orbital sensors requires special attention at the analysis of the Pantanal. Measurements were made at the Laboratory for Radiometry at INPE using a portable spectro-radiometer FieldSpec® 3. The results of the bidirectional reflectance analysis in band (first four bands and the panchromatic bands of sensor CCD sensor aboard the CBERS satellite) of grass samples at different levels of flooding, presented anisotropic behavior with a preferential zenith direction of 30º in azimuth of 0º for vegetated areas, of 45º in azimuth of 45º for wetlands, of 30º in azimuth of 90º for areas in process of flooding and of 45º in azimuth of 90º for inundated areas. This anisotropic behavior was observed in band reflectance of the surface estimated from the MODIS/TERRA (measured in nadir and in several lateral satellite viewing angles) for the first seven bands in the scene involving pasture and flooded pasture in the region of Nhecolândia. There was a strong anisotropy in the region of grasslands and low anisotropy for areas with flooded pastures.

Key words: Bidirectional reflectance. Wetland. Anisotropy.

Resumo

Resposta espectral de superfície vegetada sujeita a inundação em razão da geometria de visada

O objetivo desta pesquisa foi estudar o fator de reflectância bidirecional de uma superfície natural (amostra de grama "Batatais" sem e com diferentes níveis de inundação) em função de diferentes ângulos de visada. As medições foram feitas no Laboratório de Radiometria do INPE utilizando um espectrorradiômetro portátil FieldSpec® 3. Analisando os dados do fator de reflectância bidirecional in-band (bandas 1 a 4 e pancromática do sensor CCD do satélite CBERS), plotados em coordenadas polares, observa-se que a amostra de grama e diferentes níveis de inundação possuem um comportamento anisotrópico. Os resultados indicam que em todos os experimentos foram encontrados comportamentos anisotrópicos, com direção preferencial de 30º zenital no plano azimutal de 0º para superfícies vegetadas, de 45º no plano azimutal de 45º para as áreas úmidas, de 30º no plano azimutal de 90º para as áreas de enchente e de 45º no plano azimutal de 90º para as áreas de cheia.

Palavras-chave: Fator de reflectância bidirecional. Inundação. Anisotropia.

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INTRODUCTION

The spectro-radiometry is a crucial technique to describe the spectral behavior of targets, whose domain is important to extract information from multi- and hyper-spectral environmental satellite imagery, as well as the delineations of geometric configuration for the acquisition of new sensor data. Remote sensing techniques have been used extensively to obtain meteorological and environmental data, as well as to monitor and map environmental phenomena. This information, estimated from satellite images, allow the improvement of several studies and applications, such as the improvement for weather and climate monitoring, for agricultural productivity, for use in soil exploitation, among others.

Remote sensing is based on measurements of spectral radiation reflected or emitted by the surfaces, and these values are recorded by environmental satellites and related to Lambertian surfaces. According to Miesch (2002) most applications in remote sensing consider the natural surfaces as Lambertian surfaces (isotropic), a situation that really does not occur, because the spectral radiance varies depending on the azimuth and zenith angles of illumination and sight (CUI et al., 2009). This anisotropy feature should be considered during the evaluation of data from satellite images, because the natural surfaces usually exhibit anisotropic reflectance patterns (TANRÉ et al., 1983; NOGUEIRA et al., 1996; ROLIN ET AL., 2000).

The laboratory and field spectroradiometry is relevant to provide basic information for the calibration of orbital sensors (HUETE, 1997), as well as to understand the interaction between terrestrial objects and incident solar radiation (MILTON, 2009). The reflectance spectrum considers the directional properties of natural surfaces, therefore their representation is a function of the bidirectional spectral reflectance distribution (TANRÉ et al., 1990), which is an input parameter used in many environmental studies and allows to discern physical-chemical and biological characteristics of surface objects. Besides that, this object property is difficult to measure, and its obtaining is made indirectly through a mathematical approximation denominated directional spectral reflectance factor (DRF). This factor is defined as the ratio between the spectral radiance of the target by the spectral radiance of an ideal Lambertian surface, both obtained under the same conditions of illumination and observation (STEFFEN; MORAES, 1993).

According to Abdon et al. (2007), until the year of 2002, 23.6% of the natural vegetation from the Pantanal Biome was already eliminated, and 85% of this deforestation occurred in the *Cerrado* Biome. Most of the cleared natural vegetation cover (98.14%) was occupied by planted pasture, however in areas of annual flooding a strong tendency for restoration of natural vegetation cover is observed. The identification of areas with removed vegetation and characterization of some types of Pantanal vegetation is not easily interpreted and explored by satellite images. These features occur mainly due to a limited knowledge of the reflectance spectrum of the different Pantanal biomes, which are subject to periodic intra and inter-annual flooding and it is exposed to exogenous factors which influence the acquisition of spectral reflectance.

Presently there is a great availability of multi-angle images from by satellite sensors, such as China-Brazil Earth Resources Satellite (CBERS), *Satellite Pour l'Observation de la Terre* (SPOT), Moderate Resolution Imaging Spectro-radiometer (MODIS), Polarization and Directionality of the Earth's Reflectance (POLDER), Multi-angle Imaging Spectro-Radiometer (MISR), which requires a special attention for the analysis of their products and could provide a better knowledge of the Pantanal anisotropic characteristics, whose hydrologic system is different from other Brazilian regions because it presents four types of flooding regimen: dry, flooding, wetlands (in this work we considered wetlands as the result of final flooding process) and ebb.

In order to study the influence of the flood regimen on a vegetated surface, the objective of this work is to understand the differences of the spectral reflectance (pasture sample) with or without flooding, to characterize the Lambertian variation in a defined wavelength or spectral interval, by measuring the DRF under different observation conditions, and to show that the assumption of anisotropy for the analysis of typical Pantanal surfaces done by satellite images must be considered.

MATERIALS AND METHODS

To simulate the influence of flooding in the Pantanal Biome (Figure 1) an experiment was done in the Laboratory for Radiometry (Larad) of the National Institute for Space Research (INPE) in São José dos Campos, SP, with natural grass to simulate pasture areas.

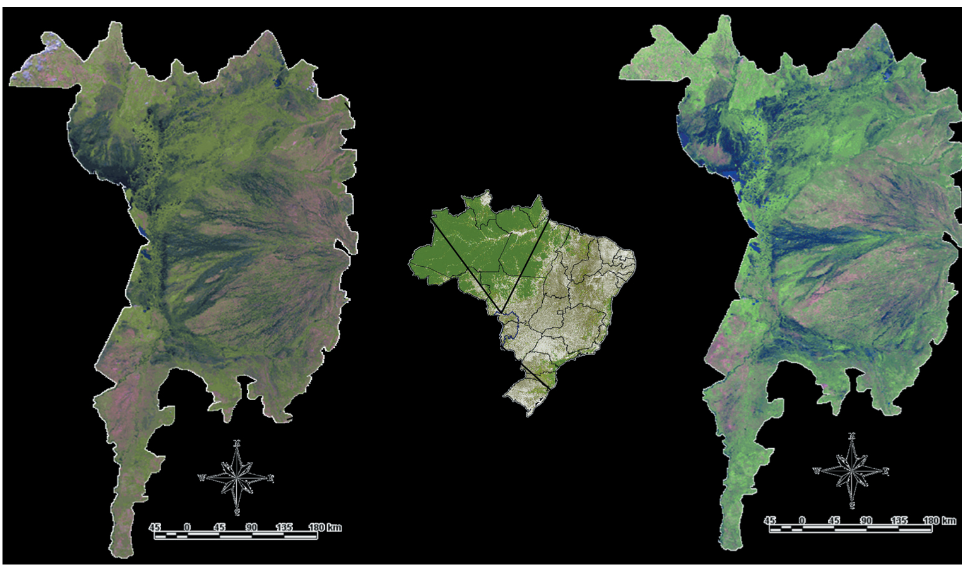

Figure 1 – Variation of the Pantanal Biome wetlands for the rainy season observed by satellite

The Larad consists of a darkened room to avoid interference from other light sources. During the experiment, a constant pattern length was adopted for source-target-sensor, in order to allow the manipulation/operations of spectro-radiometer data. The distance between the grass and the sensor was 0.25m and the distance between the grass and the light source was 1.2m. We used a sample of “*Batatais*” type grass without and with different levels of flooding, featuring the situations of drought, moist, flooding and wetlands. The last two situations were considered to simulate a water layer of 2.5 cm and 5 cm above the surface, respectively, as shown in figure 2.

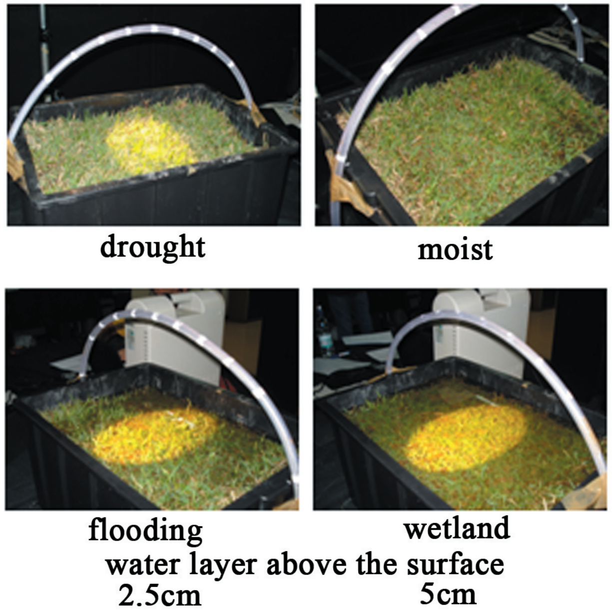

Figure 2 - Laboratory experiment: grass at different stages of flooding

The spectral radiance measurements were made in different zenithal and azimuth angles using a portable spectro-radiometer FieldSpec® 3, developed by Analytical Devices Corporation, with viewing IFOV of 25 degrees. The study consisted in the maintenance of the halogen illumination source (250 Watts) fixed in the zenithal angle of 45º and azimuth angle of 270º (perpendicular to the experiment box). The measures of the grass surface radiance and of an ideal Lambertian surface (Spectralon plate with 100% reflectance) to solid angles characterized by zenithal angles of 45°, 30°, 15°, 0°, -15°, -30° and -45° in planes which involve the azimuth angles of 0 to 180º (PV azimuth plane); 45 to 225º (PI); and 135 to 315º (PIC), while for the azimuth plane of 90 to 270º (PVC) we performed measures in the zenithal angles of 45, 30, 15 and 0 degrees (Figure 3).

For each viewing angle three radiance spectra of the dry and flooded surface radiance were obtained, and each radiance spectrum represents an average of 10 samples. After data collection, the radiometric measures were reduced by processing the average DRF spectrum for each experiment setup and for each dry-to-flooded stage of grass. In-band DRF were obtained for the bands of the CCD sensor, which cover the spectral intervals of panchromatic (PAN: 0.51 to 0.73 μm), blue (CCD1: 0.45 to 0.52 μm), green (CCD2: 0.52 to 0.59 μm), red (CCD3: 0.63 to 0.69 μm) and near infrared band (CCD4: 0.77 to 0.89 μm).

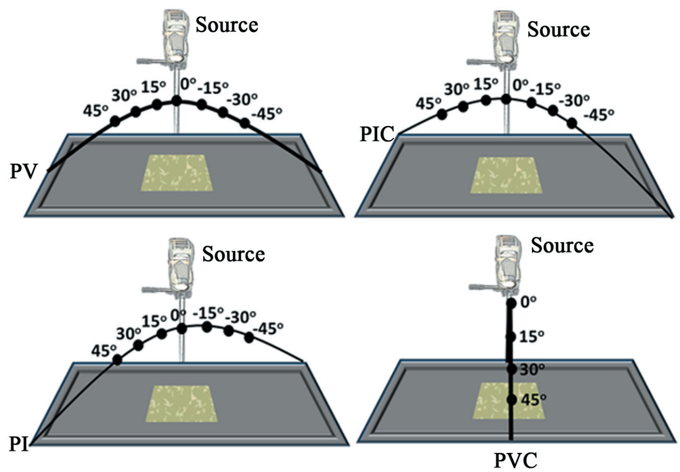

Figure 3 – Geometric configuration of the radiometric acquisition

RESULTS AND DISCUSSION

Figure 4 shows the reflectance spectrum (y axis, dimensionless) of the grass sample for the spectral range of 400 to 2300 nm (x axis) obtained in four experiments executed in the laboratory (dry, flooding, wetlands and ebb) with an observation geometry similar to the acquisition of satellite images with the nadir scan. In the vegetation reflectance spectrum some dominant factors in the spectral behavior can be mentioned: leaf pigments, cell structure, water content, geometry form and structural canopy, stage of growth, among others. In the region of the electromagnetic spectrum for the visible (400 to 700 nm), the main elements that interact with electromagnetic radiation are the leaf pigments found mainly in chloroplasts (chlorophyll, carotenoids, xanthophylls) that act as absorbers of electromagnetic radiation.

In the region of electromagnetic radiation corresponding to the near infrared (NIR) and medium (SWIR), which includes the wavelengths above 700 nm, the absorption and scattering process of electromagnetic radiation are dominated by cellular structure (epidermis, cuticle, spongy mesophyll and air cavities) that cause high values of reflectance. Besides the cellular structure, the water content inside the leaf causes absorption bands in the region of the electromagnetic radiation around 1,400 nm and 1,900nm.

Figure 4 shows that the reflectance spectrum decreases gradually when flooding level increases. This feature is caused by the spectral properties of water, which absorbs the electromagnetic radiation in the region of SWIR. Table 1 shows the values of the reflectance factor integrated in the bands of the CCD/CBERS sensor and the albedo value for the experiment samples. As seen in the graph, the addition of water to the flooding process decreases 48% from the value of reflectance in the panchromatic band (PAN) and in the green band (CCD2), 56% in the band referring to the blue (CCD1) and approximately 53% in the bands of red and near infrared (CCD3 and CCD4, respectively).

Referring to albedo values, which correspond to spectral reflectance integrated along the electromagnetic spectrum analyzed (400 to 2300 nm), there is a reduction of 37% from the normal condition to the humid situation, 69% in the flooding condition and approximately 86% when comparing the initial conditions with the maximum water level analyzed.

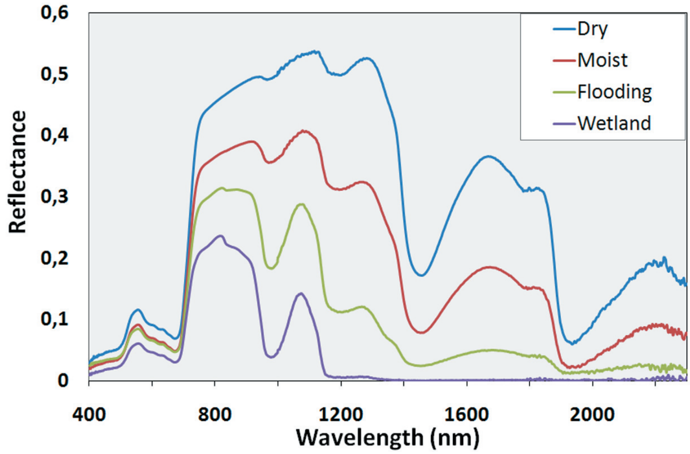

Figure 4 – Reflectance spectrum of the "batatais" grass sample

Table 1 - Reflectance factor values integrated in the bands of CCD/CBERS sensor and the value of albedo for the samples Dry, Wet, flooding and wetland

	Dry	Wet	Flooding	Wetland
PAN	0,11	0,09	0,07	0,06
CCD1	0,05	0,04	0,03	0,02
CCD2	0,10	0,08	0,07	0,05
CCD3	0,08	0,06	0,05	0,04
CCD4	0,47	0,37	0,30	0,22
Albedo	0,29	0,18	0,09	0,04

The characterization of isotropic or anisotropic behavior of different inundation level simulations of the vegetation covered surface was performed by the analysis of bidirectional reflectance in band, equivalent to the bands of CBERS CCD sensor, obtained for the solid angles defined by the field of view (zenith and azimuth angles of the sensor, following the azimuth planes (PI, PIC, PV, PVC).

Figure 5 shows the bidirectional reflectance in band obtained for the solid angles of observation evaluated at the PV azimuth plane. At figure 5 one observes that, for all bands, an increase of the water amount on the surface causes a decrease in the intensity of reflectance and in no of the analyzed cases the surface presented an isotropic behavior. In conditions of dry and wet vegetation covered surface, the preferential anisotropy was observed for the observation zenith angle of 30º. It is affected by the leaf angle distribution (LAD) of grass which promotes the backscatter of irradiance in this direction. For the flooding and wetland situations the preferential anisotropy occurs in the observation zenith angle of -15°, with the exception of CCD4 band, which displays anisotropy of the same intensity in the observation zenith angle of -45º.

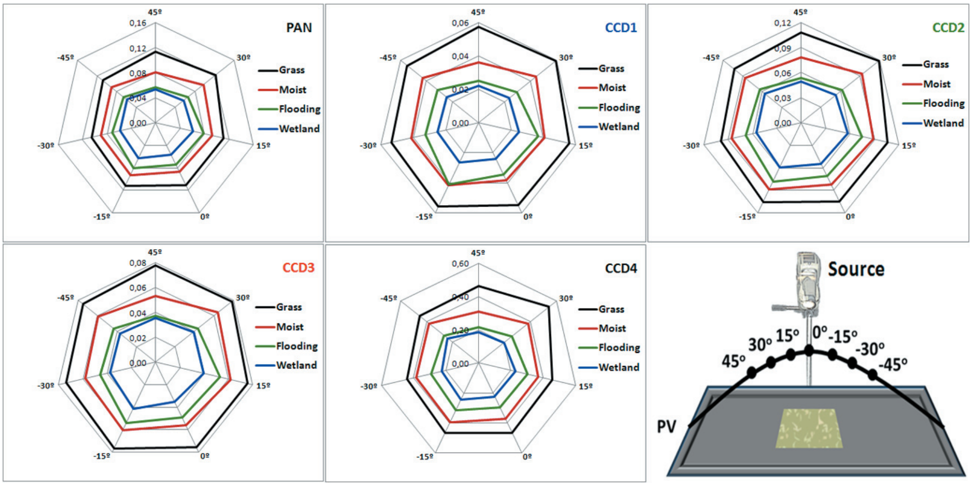

Figure 5 - Bidirectional reflectance curves as a function of the geometric variables - PV azimuth plane

In the evaluation of polar representation from the bidirectional reflectance (in band), as a function of the geometric variables oriented along the PVC azimuth plane (Figure 6), one observes the occurrence of anisotropy directed of 30°, except for the observed situation of wetland, whose maximum reflection values occurs at the 45º observation angle, showing the specular reflection, which is common in water bodies.

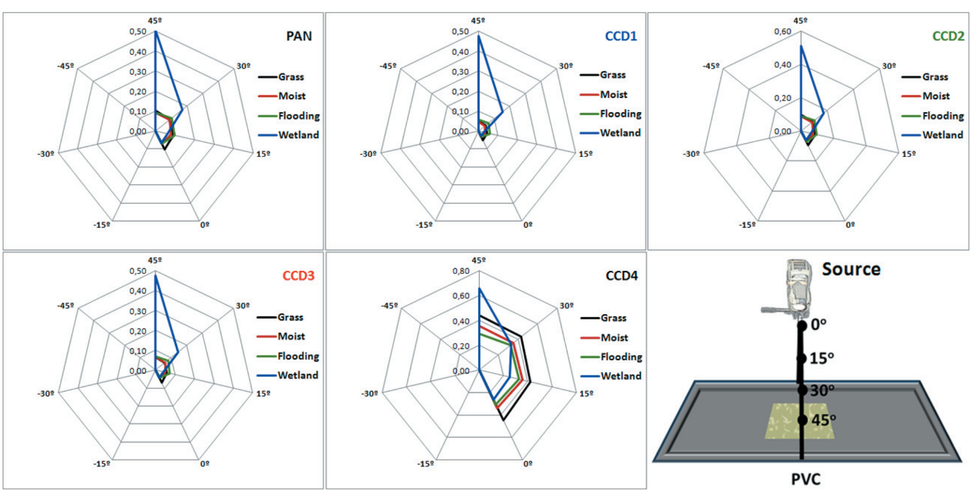

Figure 6 - Bidirectional reflectance curves as a function of the geometric variables - PVC azimuth plane

Figure 7 shows the occurrence of anisotropy in all analyzed cases. Noteworthy are the cases with highest values for the flood situation, where the zenith angle of 45º is preferred. For the case of vegetation the largest anisotropy occurs in zenith angle of 15°, while in wet situation the largest anisotropy is observed at -45° and in cases of wetland the preferential angle is -30°.

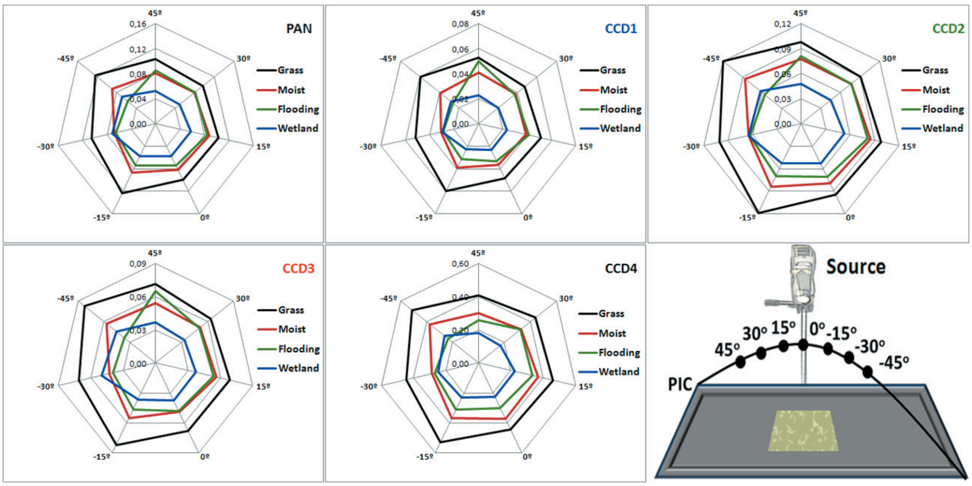

Figure 7 - Bidirectional reflectance curves as a function of the geometric variables - PIC azimuth plane

At Figure 8 a variable intensity and zenith direction was observed in anisotropy values. The case of flooding shows a totally different behavior from other situations. In other cases the preferential anisotropy in the zenith angle is of 45º.

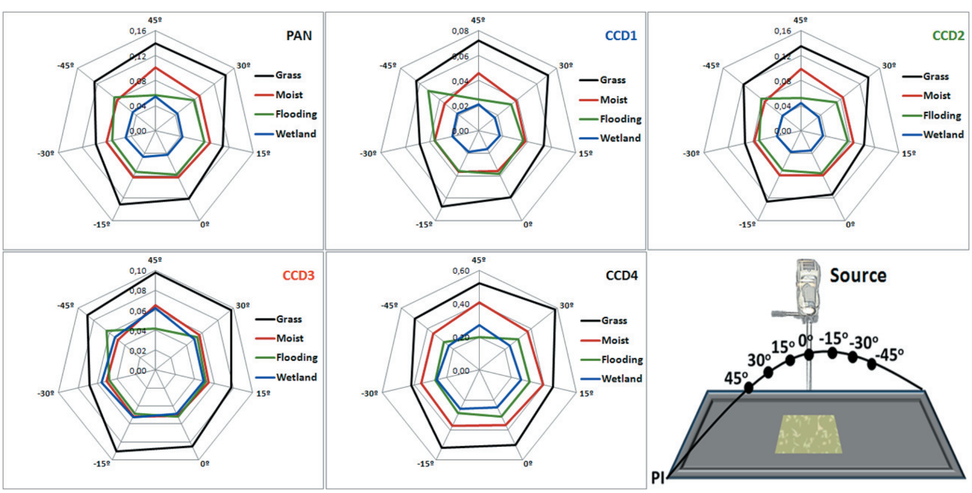

Figure 8 - Bidirectional reflectance curves as a function of the geometric variables - PI azimuth plane

Figure 9 summarizes the anisotropy for the four hydrological situations analyzed (dry, wet, flooding and wetland) and describes the preferred direction of 30° zenith in the azimuth plane of 0º for vegetation covered surfaces, 45 ° in the azimuth plane of 45° for wet areas, 30° in the azimuth plane of 90° for the areas of flooding and 45° in the azimuth plane of 90° for the wetland areas. Although the vast majority of studies that use environmental satellites considers surfaces as Lambertian, in the analysis of polar diagrams, a variable anisotropy behavior was verified both in the direction and intensity of bidirectional reflectance.

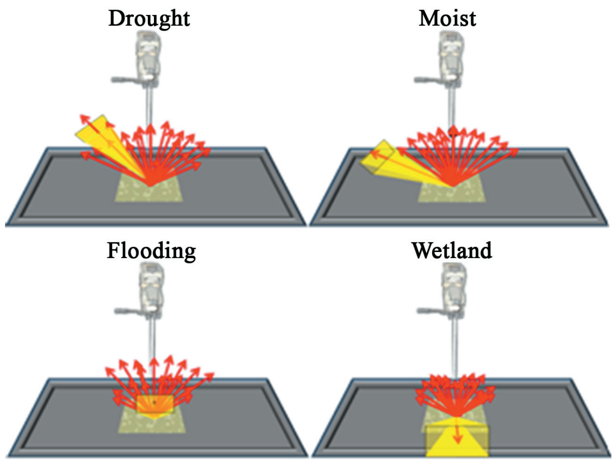

Figure 9 – Preferential outline of anisotropy

The effect of anisotropy at the existing areas in the Pantanal region can be observed in the multi-target images of surface reflectance, derived from the MODIS sensor aboard the Terra satellite (Figure 10). This product was generated from images of the Nhecolandia region (MS) on Nov. 3rd and 8th 2010, which were acquired, respectively, with vertical targeted (nadir) and lateral. In the vertical view (Figure 10a) the observations of the elements that compose the scene were taken near nadir, with a variation of the view angle from 5 to 15 degrees, while in lateral view (Figure 10b) the observation of the scene elements varied from 40 to 50 degrees in relation to the vertical location.

The obtainment of surface reflectance for the different angles of observation was done after eliminating the effects of the atmospheric influence. The surface reflectance images (Figures 10a and 10b) show significant differences in bidirectional reflectance intensities. Since satellite data were taken from close dates, physical, chemical and biological properties of the elements that compose the scenes did not change significantly in order to cause such a modification in the intensity of reflectance, demonstrating that the main contribution for these changes is the effect of anisotropy of different surfaces.

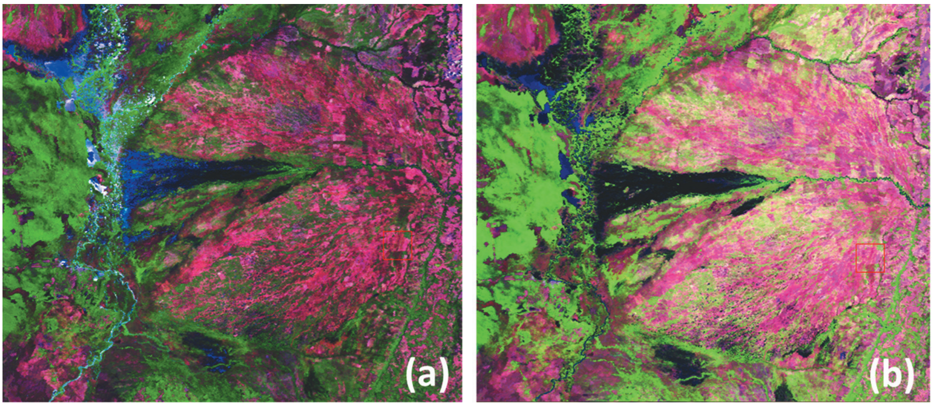

Figure 10 - Reflectance images from MODIS sensor of the Nhecolandia region, MS: (a) nadir target achieved in November 3 of 2010, and (b) lateral views acquired on November 8 of 2010

Figure 11 shows the average spectral reflectance of bands 1 to 7 (reflectance in band) of MODIS for two representative elements of pasture and flooded pasture in the region of the Taquari Fan. Analyzing the reflectance in band for a pasture area, we found that the spectral reflectance detected by the MODIS sensor at different observation angles showed different reflectance, and that the highest levels detected were in lateral view. These differences were not observed in the reflectance in band in the flooded pasture sample, indicating that under these conditions the surface behavior is closer to an isotropic surface for a sun illumination angle corresponding to the time of imaging from MODIS in this region. This behavior is due mainly to the fact that water bodies present low reflectance and this influences on the reduction of the reflectance contribution from submerged vegetation.

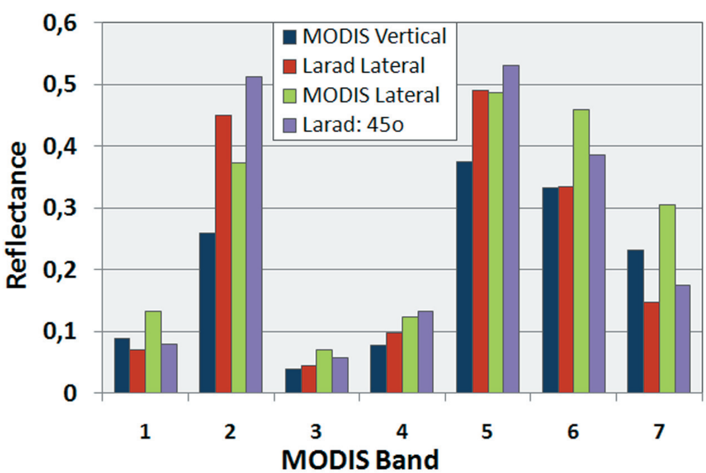

Figure 11 – Reflectance of pasture and flooded pasture in bands of 1 to 7 of MODIS taken in vertical and lateral observation

After the DRF spectrum was obtained in the Larad experiment for vegetation covered areas and flooded vegetation in the same conditions of vertical and lateral views, MODIS reflectance bands can be simulated (Fig. 12 b). Comparing these simulations with the reflectance in band obtained from the Terra satellite images (Fig. 12), it was verified that there was a similarity in the spectral behavior of objects measured in the laboratory and estimated by satellite data. It was observed specifically that vegetation covered areas have a strong anisotropy behavior and in conditions of flooded vegetation, this tendency is minimized due to the sun angle and satellite IFOV. The similarity of this comparison shows the effectiveness of this study on spectro-radiometry of surfaces in the laboratory.

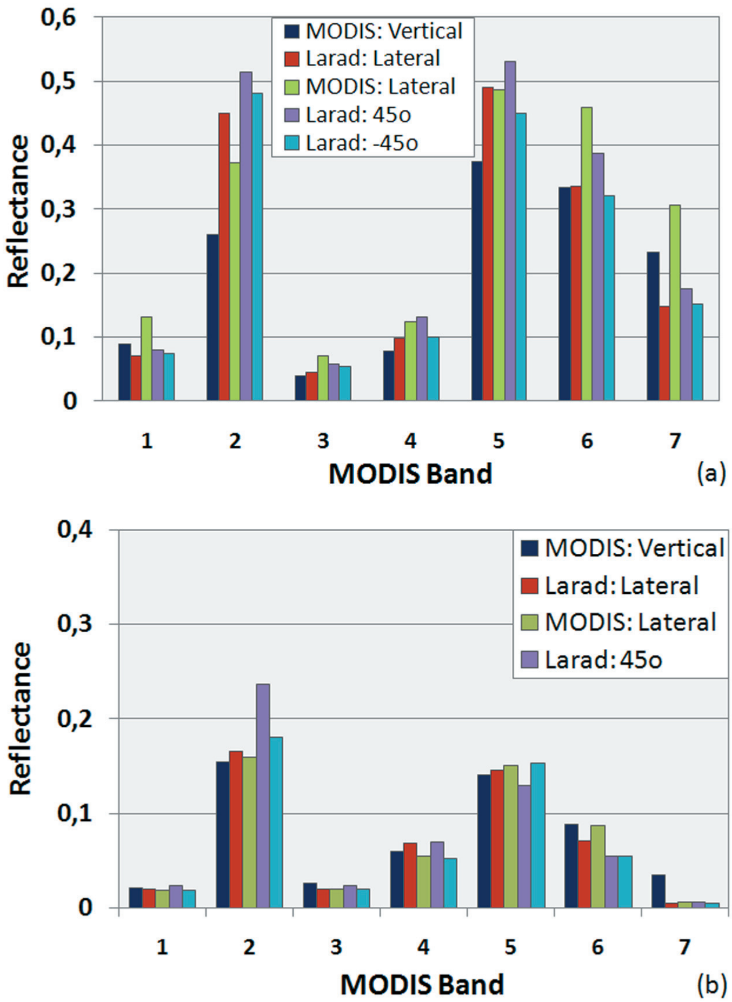

Figure 12 – Reflectance of pasture and flooded pasture in the bands 1 to7 from MODIS obtained from Earth satellite images and estimated through measurements performed in laboratory for vertical and lateral conditions

CONCLUSIONS

Although the laboratory work does not represent faithfully the field reality, it provides reliable results for the analysis of the Lambertian characteristics of natural surfaces. The effect of anisotropy due to backscattering was verified. It occurred in all bands of the CCD/CBERS sensor system and in all hydrological conditions simulated in the vegetation covered surface.

In surfaces predominantly covered with vegetation, a more pronounced backscattering of electromagnetic radiation was observed (zenith angle of observation 30º at the azimuth plane of 0°) due to the spatial constitution of this canopy which promotes the incident preferential scattering. It was verified that while the influence of water body dominates the reflectance spectrum, a specular reflection opposite to the lighting angle was detected.

This study showed that to analyze environmental satellite data of the Pantanal Biome, the anisotropy factor of surfaces must be considered to obtain images with the same angle along the year, as well as for images obtained with multi-angles available from orbital sensors. Therefore, the assumption of a Lambertian behavior from a surface can induce to errors when modeling and analyzing superficial and atmospheric phenomena.

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