ANALYSIS OF THE VEGETATION PHENOLOGY FROM THE ALTO PARAGUAI BASIN THROUGHT THE REPRESENTATION OF HARMONIC CYCLES OF EVI/MODIS TIME-SERIES

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Abstract

The Alto Paraguai Basin (BAP) is of strategic importance for Brazil, due to its ecological diversity of landscape, especially because it includes the Pantanal floodplain. The harmonic analysis can be used in remote sensing time-series data to study the cyclic behavior of vegetation indices. The visual representation of harmonic terms can help image interpretation through the combination of colors in the HLS (Hue, Lightness, Saturation) space which provides a soft visual transition effect between the cycles. The objective of this study was to analyze the vegetation phenology of the BAP using the harmonic analysis applied to an EVI (Enhanced Vegetation Index) time-series data from MODIS (Moderate Resolution Imaging Spectroradiometer) during 10 hydrologic years from October 2001 to September 2011, considering the HLS representation of the harmonic terms. The results show that the vegetation phenology of BAP presents spatial patterns coherent with the vegetation development and consistent with the variability of the seasonal inundations in Pantanal, which determines the hydrologic conditions of the region, directly affecting the moment of maximum EVI. The HLS representation of harmonic terms indicates that it is an effective tool for the visual interpretation of vegetation cycles.

Key words: Remote sensing. Image processing. Harmonic analysis. HANTS. HLS transform.

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Resumo

Análise da fenologia da vegetação da bacia do Alto Paraguai por meio da representação de ciclos harmônicos de séries temporais de EVI/MODIS

A Bacia do Alto Paraguai (BAP) é de importância estratégica para o Brasil devido à diversidade ecológica da paisagem, principalmente por incluir a planície inundável do Pantanal. A análise harmônica pode ser empregada em séries temporais de dados de sensoriamento remoto orbital para estudar o comportamento cíclico dos índices de vegetação. A representação visual dos termos harmônicos pode auxiliar na interpretação da imagem por meio da combinação de cores no espaço HLS (matiz, luminosidade, saturação), que proporciona um efeito visual de transição suave entre os ciclos. O objetivo deste trabalho foi analisar a fenologia da vegetação da BAP utilizando a análise harmônica aplicada à série temporal de dados EVI (*Enhanced Vegetation Index*) do sensor MODIS (*Moderate Resolution Imaging Spectroradiometer*) para 10 anos hidrológicos, do período de outubro de 2001 a setembro de 2011, por meio da representação HLS dos termos harmônicos. Os resultados mostraram que a fenologia da vegetação da BAP apresentou padrões espaciais coerentes com o desenvolvimento da vegetação, consistente com a variabilidade do ciclo sazonal das inundações do Pantanal que determina as condições hidrológicas da região, afetando diretamente o momento de máximo EVI. A representação HLS dos termos harmônicos mostrou ser uma ferramenta eficaz para a interpretação visual dos ciclos da vegetação.

Palavras-chave: Sensoriamento remoto. Processamento de imagens. Análise harmônica. HANTS. Transformação HLS.

INTRODUCTION

The Alto Paraguai Basin (BAP) is of great importance for Brazil, in a strategic context, due to its ecological diversity, especially because it includes the Pantanal biome, considered one of the largest floodplains in the world, which hosts a large concentration of wildlife. The cycles of flood and drought, caused by seasonality of water, control life and human activities in the region, which are strongly influenced by hydrologic conditions. Pantanal is a well-conserved ecosystem where cattle raising and eco-tourism are the main income activities. The plateau has suffered several changes due to human occupation, substituting natural vegetation by agricultural plantations.

Considering that satellite images provide a synoptic and frequent view of the Earth surface, they have become an important source of information for global vegetation studies of large areas such as BAP. In this context, the MODIS (Moderate Resolution Imaging Spectrometer) sensor, onboard space platforms from the international program EOS (Earth Observing System) conducted by NASA (National Aeronautics and Space Administration), has been an alternative of data generation for the temporal vegetation analysis of Pantanal (MORAES et al., 2009; ANTUNES et al., 2011).

The satellite Terra is one of the orbital platforms from EOS, which transports MODIS. It was launched in December 1999, and crosses the Equator at 10:30 h, local time, in descending orbit (SOARES et al., 2007). MODIS data, with moderate resolution, high repeatability and good radiometric quality, are available free of charge as processed products with high cartographic precision with atmospheric correction, and with a great application potential for monitoring the temporal dynamics of vegetation. (ZHANG et al., 2003).

The vegetation indices obtained from MODIS data enhance the spectral response of plants and eases the influence from the soil. When observed from temporal series, these data can be used to distinguish the vegetation phenology and to record changes in land use/land cover (WARDLOW et al., 2007).

The harmonic analysis has been used for the study of vegetation indices time-series to analyze phenologic changes, to find evidences of changes in the development of vegetation and to show patterns of temporal dynamics (JIA et al., 2011). Within this research line, several studies have been made using EVI (Enhanced Vegetation Index) time-series and harmonic analysis, to evaluate the temporal dynamics of the Taquari River basin in Pantanal, based on vegetation changes (PARDI LACRUZ; SOUZA JÚNIOR, 2007) to extract seasonality parameters of the image time-series and to discriminate areas with annual cultures in the plateau of the Alto Paraguai Basin (VICTORIA et al., 2009), to map and quantify forest areas converted to agriculture and pasture, allowing a more detailed view of the deforestation, to manage the impacts on the landscape of the Bolivian Pantanal (REDO; MILLINGTON, 2011) as well as to discriminate annual cultures in the agricultural frontier region of Mato Grosso, to obtain estimates of planted area, from crop masks using the harmonic terms (ARENAS-TOLEDO; EPIPHANIO, 2011).

The technique of harmonic analysis can be used in time-series of orbital remote sensing data which normally have a periodicity, aiming to study the cyclic behavior of vegetation indices considering the representation of the harmonic terms in the color space HLS (Hue, Lightness, Saturation), which eases the visual image interpretation by the best perception of the human eye.

In this context, the objective of this study was to analyze the phenologic vegetation changes from the BAP, using a harmonic analysis applied to the EVI/MODIS time-series data for 10 hydrologic years, in the period from October 2001 to September 2011 by a HLS representation of the harmonic terms.

MATERIAL AND METHODS

BAP is a crossing-border basin with an extension of around 600,000 km^2, divided between Brazil (60% of its territory), Bolivia and Paraguay (each one with 20% of its territory) (BRASIL, 2011). This study was done in the Brazilian portion of the BAP, inserted in the States of Mato Grosso and Mato Grosso do Sul, as illustrated in figure 1.

The MODIS time-series images from satellite Terra were obtained from the Brazilian MODIS Products Database, which is a repository from Embrapa Agricultural Informatics (a research unit of the Brazilian Agricultural Research Corporation), developed to store and release to users ready products by States, in the geographic projection and GeoTIFF format (ESQUERDO et al., 2010).

The image processing of this database is done automatically by routines implemented in IDL (Interactive Data Language) of ENVI (EXELIS, 2012), with the execution of programs from computer package MRT (MODIS Re-projection Tools) (LP DAAC, 2012). The disclosure of products on the Internet is done in the GeoNetwork environment, which is a Web catalogue to manage geo-referenced data (OSGEO, 2012).

Presently a complete time-series of product MOD13Q1 is available from collection 5, with 250 m spatial resolution, which consists of pixel compositions of high radiometric quality, best observation geometry, least cloud cover and aerosols, selected from daily images during the period of 16 days (LATORRE et al., 2007), upgraded and distributed from LP DAAC (Land Processes Distributed Active Archive Center) from EOS/NASA, for the 26 Brazilian States.

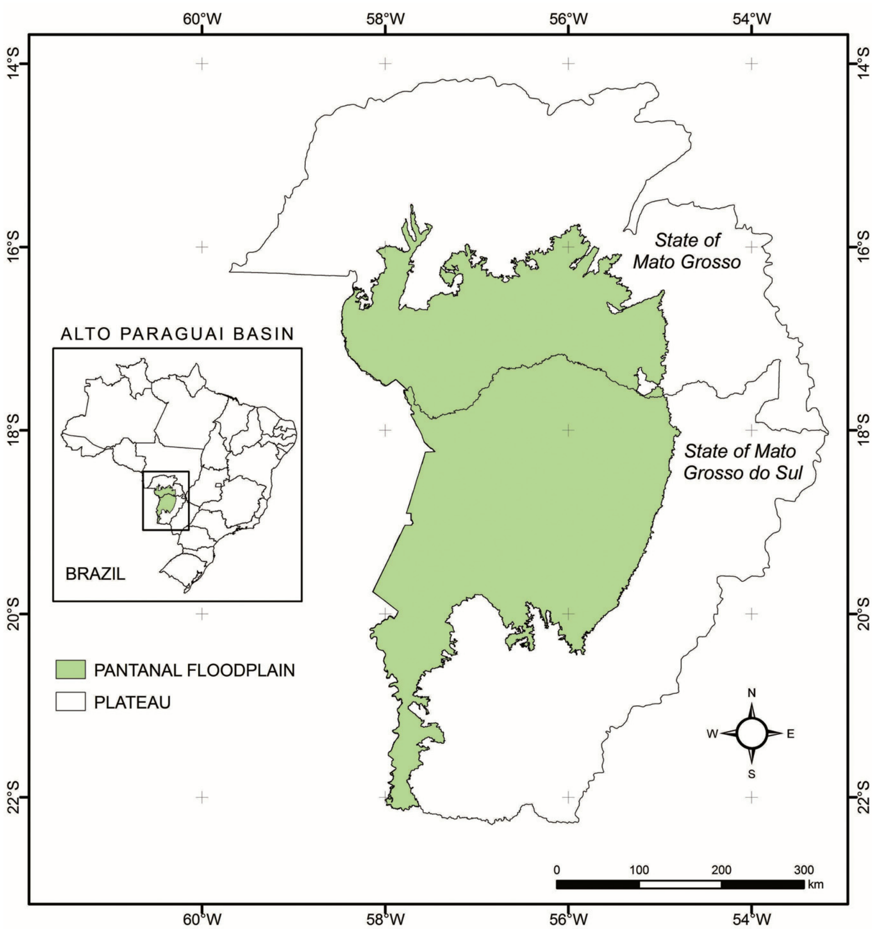

Figure 1 - Alto Paraguai Basin (BAP), Brazilian portion formed by regions of plateau and Pantanal floodplain

The vegetation index used in this study was EVI, aiming to best represent the dynamics of vegetation along an image time-series. EVI was developed by HUETE et al., (1994) to optimize the spectral response of vegetation and to improve the sensitivity in regions with higher phytomass, allowing the vegetation monitoring by the deduction of the substratum effects from the vegetation canopy and atmospheric influences, calculated by Equation (1):

$$EVI = G \times \left[\frac{(\rho_{NIR} - \rho_{RED})}{(\rho_{NIR} + C_1 \times \rho_{RED} - C_2 \times \rho_{BLU} + L)} \right] \quad (1)$$

where,

ρ_{BLU} = reflectance factor in the blue band (459 to 479 nm);

ρ_{RED} = reflectance factor in the red band (620 to 670 nm);

ρ_{NIR} = reflectance factor in the near infrared band (841 to 876 nm);

G = 2.59: gain factor;

L = 1: adjustment factor of the substratum from the canopy;

C_1 = 6.0 e C_2 = 7.5: aerosol resistance coefficients which use the blue band to attenuate the resistance of aerosols in the red band.

In order to analyze the EVI time-series, a Fourier Transform was used, whose purpose is to decompose a complex function formed by the summation of sinusoidal and co-sinusoidal waves, where each wave is defined by a unique value of amplitude and phase, according to illustration in figure 2.

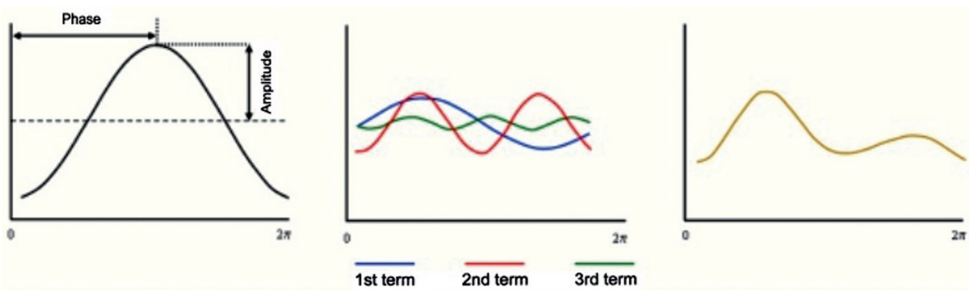

Figure 2 - Representation of harmonic terms generated by the Fourier Transform

Source: PARDI LACRUZ (2006), adapted from JAKUBAUSKAS et al. (2001).

The amplitude corresponds to half the value, where the function is maximized and the phase is the displacement between the origin and the peak of the wave in the interval from 0 to 2p. Each harmonic term represents the number of cycles completed by a wave in a certain time interval, and it is responsible for a percentage of the total variance of the original temporal data series. So the first harmonic has a period T similar to the total period under study, the second harmonic corresponds to half the period of the first harmonic T/2, the third harmonic to T/3, and so on (PARDI LACRUZ, 2006).

According to JAKUBAUSKAS et al. (2001), a time-series data from N samples can be represented by a Discrete Fourier Transform, according to Equation (2):

$$f(x)_t = \bar{c} + \sum_{j=1}^{N/2} c_j \cos\left(\frac{2\pi\, t}{N} - \varphi_j\right) \quad (2)$$

where,

$\bar{c}$ = average of values from the time-series;

c_j = amplitude of the do j^{th} harmonic;

φ_j = phase angle of the j^{th} harmonic.

The amplitude is calculated by the Equation (3):

$$c_j = \sqrt{a_j^2 + b_j^2} \quad (3)$$

where, a_j and b_j are the cosine components and the sine of the amplitude vector c_j which are obtained by Equations (4) and (5) respectively:

$$a_j = \frac{2}{N} + \sum_{t=1}^{N} y_t \cos\left(\frac{2\pi\, t}{N}\right), \text{ for } t \geq 0. \tag{4}$$

$$b_j = \frac{2}{N} + \sum_{t=1}^{N} y_t \operatorname{sen}\left(\frac{2\pi\, t}{N}\right), \text{ for } t \geq 1. \tag{5}$$

The phase angle is calculated by Equation (6):

$$\varphi_j = \begin{cases} \arctan \dfrac{b_j}{a_j}, & \text{if } a_j > 0. \\ \arctan \dfrac{b_j}{a_j} \pm \pi, & \text{if } a_j < 0. \\ \dfrac{\pi}{2}, & \text{if } a_j = 0. \end{cases} \tag{6}$$

The images obtained from the application of the Fourier Transform are generated in a base by pixel for each composition of the temporal series. In practice it means to decompose the annual variation of EVI in harmonics which represent the average and the annual, semiannual, quarter, etc. oscillations, aiming to identify targets of the Earth surface. The zero harmonic image (additive term) corresponds to the EVI average, which represents the total vigor for each type of vegetation cover during the period under study. The amplitude images indicate the maximum variation of EVI for the entire period. The phase indicates the time along the temporal series when the highest amplitude value occurs. The interval of the values from phase images is 0° to 360° and can be associated with the months of the year.

The behavior of these parameters in phenology studies is an indicative of the type of change occurring along time. Seasonal changes only in amplitude can indicate variations of the land use type or of the vegetation conditions. The phase changes alone could indicate time variations of maximum vegetative vigor. The amplitude and phase changes can indicate significant transformations on the Earth surface, related to the alteration of soil management or substitution of vegetation.

The processing of EVI time-series was done using the software package HANTS (Harmonic Analysis of NDVI Time-Series), originally developed by ROERINK et al. (2000) and implemented in IDL language by DE WIT & SU (2005). The basic concept of the algorithm is that the vegetation development presents a strong seasonal effect which can be simulated by sinusoidal functions of low frequency, with different phases and amplitudes. Clouds cause changes in the temporal series and can be considered as high frequency noise. The HANTS algorithm analyzes the original time-series, it identifies areas of low frequencies related to vegetation and, with the Fourier Transform, eliminates disparate values from the time-series which represent the high frequencies.

The efficient visual representation of amplitude and phase images of the harmonic terms can help in the interpretation of phenologic changes in the vegetation by color combination. The phase, however, is quantified in a circular scale, which makes the interpretation of images in the RGB color space difficult. In this space, an abrupt change among the dark color with minimum intensity and the brilliant color with maximum intensity takes place. On the other hand, in the HLS color space, the component hue is inherently circular, giving a visual effect of smooth transition from blue to magenta and to red. The other harmonic parameters are linear and can be well represented by the components lightness or saturation (HALL-BEYER, 2007).

Based on that, in order to analyze the condition of vegetation growth, especially the phase information, the HLS transform was applied to the harmonic terms obtained with the HANTS algorithm, according to a procedure developed by FOLEY & VAN DAM (1984), implemented in the ENVI software package. The color space is formed by a double hexacone, as presented in figure 3.

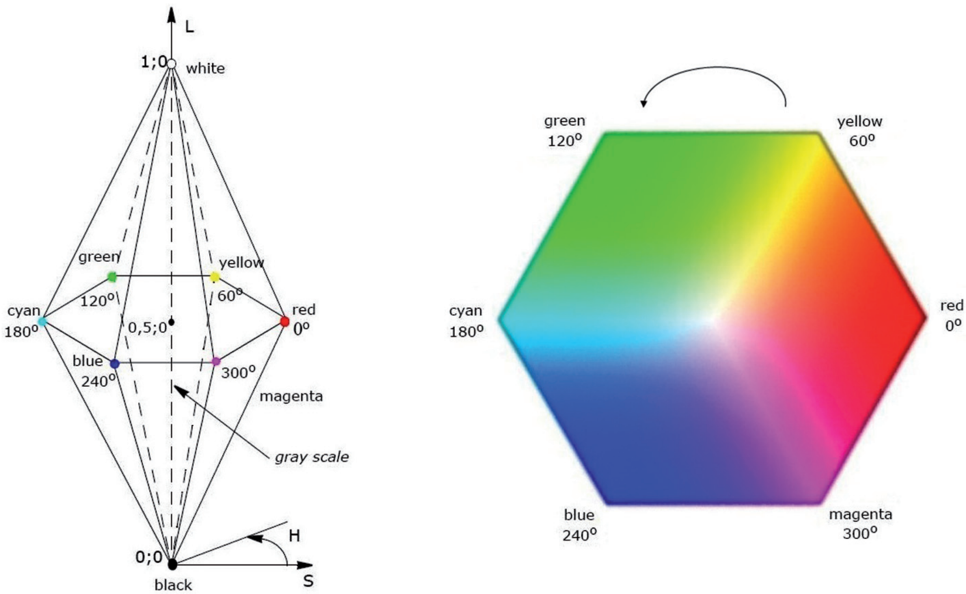

Figure 3 - Color space HLS

The primary colors are situated in the perimeter of the common base and the white and black colors in the vertex of each one of the cones. The gray tones are localized on the common axis of both cones. Hue (H) is the angle around the vertical axis of the hexacone coursing counterclockwise, with the red at 0°, yellow at 60°, green at 120°, cyan at 80°, blue at 240° and magenta at 300°.

Saturation (S) is measured in radial form from the vertical axis, 0 and the white colors with the gray tones vary till 1, which are the pure colors. Lightness (L) can vary between 0 for black till 1 for white and the pure colors present a lightness of 0.5.

RESULTS AND DISCUSSION

The processing of MODIS images consisted in cutting the geographic borders of BAP obtained from the mosaic of Mato Grosso and Mato Grosso do Sul States. Afterwards, EVI 16-day time-series compositions were obtained from the last 10 years. For this purpose, the natural hydrologic cycle of the BAP, which starts in October and closes by September of the following year, (Oct. 2001 to Sept. 2011) with 23 compositions for each year, totaling 230 images, was considered.

The EVI time-series was initially processed by HANTS separately for each hydrologic year, from Oct. 2001 to Sept. 2011. The data are in the original scale factor, for the valid interval ranging from -2,000 to 10,000. The adjustment tolerance between the difference of values from the Fourier Transform and the original values of EVI, was defined as 1,000.

The harmonic terms generated were the amplitude and phase for the frequencies 0, 1, 2 and 3 which correspond to the EVI average of each time-series and to the cycles of 1 year, 6 months and 4 months respectively. Generally these 3 harmonics are sufficient to explain most variance of time-series from images.

The HLS transform was used to illustrate the vegetation development in each hydrologic year. For each pixel the phase of the annual cycle was attributed to the component hue, the amplitude to the component lightness and the average of the annual cycle of EVI to the component saturation. Figure 4 shows the representation of HLS of the BAP landscape for the 10 hydrologic years, in the period from Oct. 2001 to Sept. 2011.

To help understand the HLS representations, the color legend shown in figure 4 establishes a correspondence with the occurrence of the vegetative peak in the different hydrologic years, which gives an overview of the phenologic changes from vegetation within BAP. In this type of HLS representation, a high colorless intensity, from clear gray to white, refers to an EVI almost constantly high during the year, such as in agricultural regions. A dark intensity indicates a constantly low EVI, such as in permanently flooded regions. Those areas with clearer coloration present a strong effect of the yearly cycle. As the hue indicates the maximum time of EVI, the color order red - orange - yellow - olive - green - turquoise - cyan - celestial - blue - purple - magenta - rose, corresponds to the temporization of the phase in the months of October - November - December - January - February - March - April - Mai - June - July - August - September, respectively.

Analyzing the temporal representations of HLS in BAP during the hydrologic years 2001/2002 to 2010/2011 of figure 4, it can be observed that the Pantanal region has vegetative peaks in different moments each year, occurring between rose and red in the months of September and October, which is related to the end of the flood period.

The tributaries to the Paraguay River which drains the Pantanal floodplain are directly influenced by the rainfall. After the first rains, the output of the rivers increases and the overflow to the floodplain starts, and inundations occur in the East-West and North-South directions. Generally the flood period in Pantanal lasts from March to September and the drought period extends from October to February.

The Paraguay River is the main collecting drain of water from the BAP. The hydrological station of the Paraguay River is installed in the 6th Naval District of the Brazilian Navy, located in the municipality of Ladário, Mato Grosso do Sul State. It is the oldest and most complete data record of floods in Pantanal, disposing daily registrations since 1900, disclosed by the Service of Nautical Signaling from the West. Along this measuring scale, most water volume of BAP passes, approximately 81% of the average flow output from the Brazilian territory. So it is the main reference to characterize the hydrologic regime of BAP, indicating a period of drought or flood in Pantanal (GALDINO; CLARKE, 1995).

Figure 5 shows the flood data referring to the hydrologic years 2001/2002 to 2010/2011, collected in the flood gauge of the fluviometric station (66825000) of height measurement of Paraguay River in Ladário.

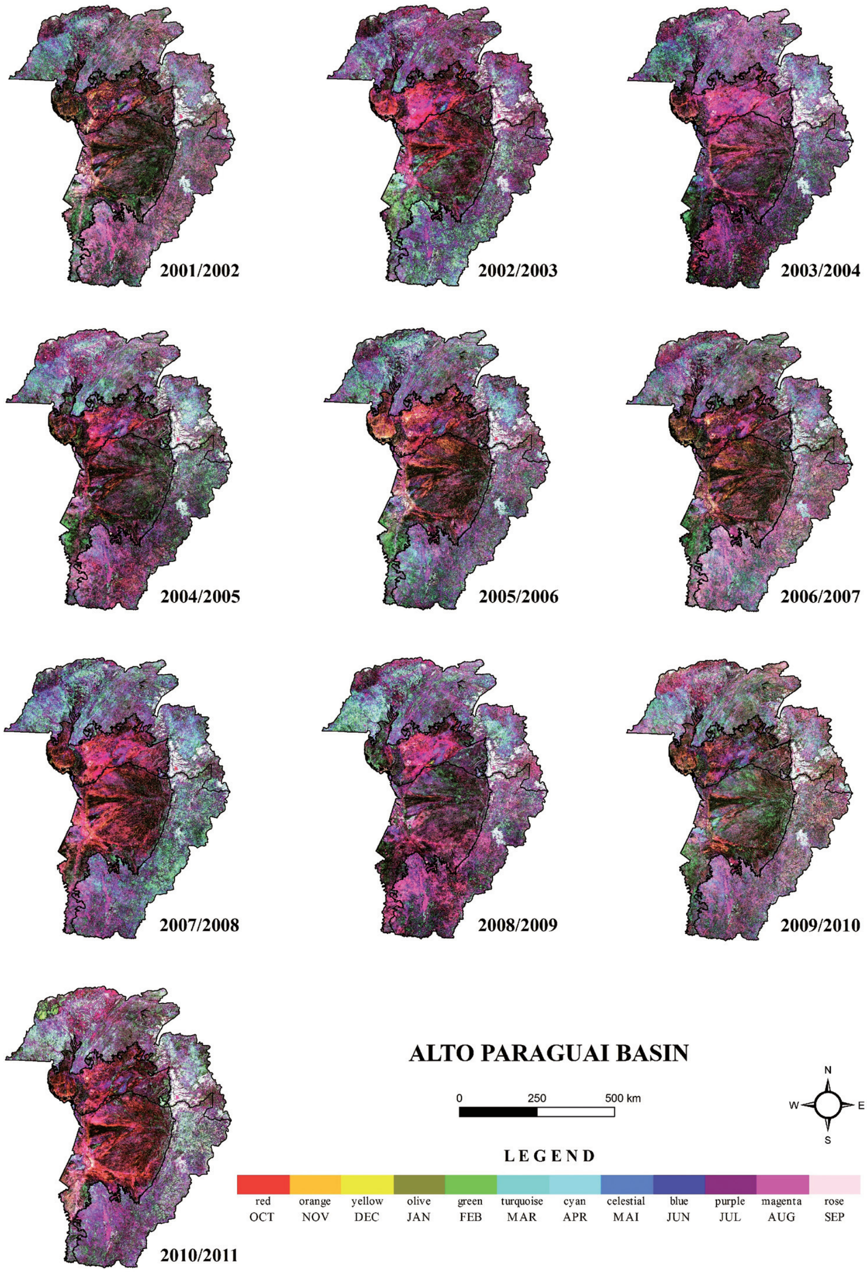

Figure 4 - HLS representation of BAP landscape for the 10 hydrologic years of the period from October 2001 to September 2011

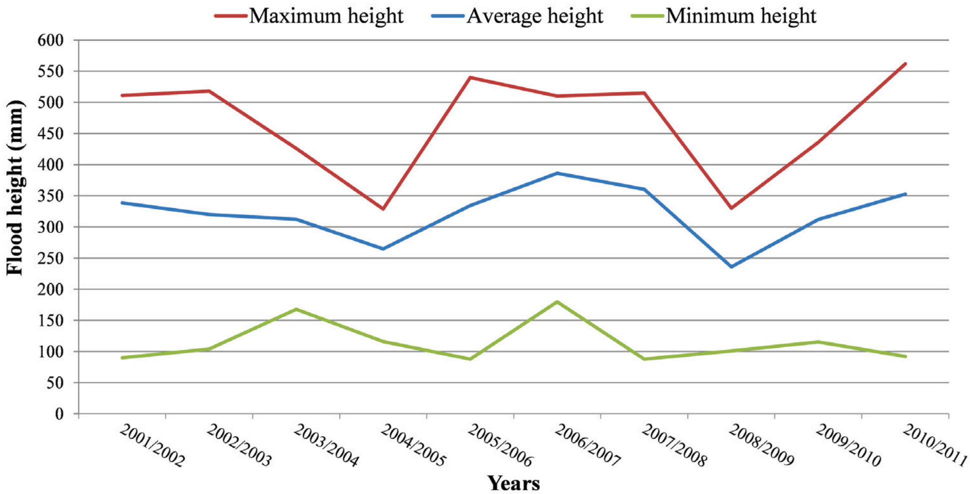

Figure 5 - Flood height of the Paraguay River in Ladário for the 10 hydrologic years of the period from October 2001 to September 2011

Source: MARINHA DO BRASIL (2012),

Based on the classification by GALDINO et al. (2002), when the maximum height of the Paraguai River in Ladário is equal or surpasses the flood alert level , which is 4.00 m, it is considered as an inundation in Pantanal, otherwise it is considered as a drought. When the peak of the flood is situated between 4.00 and 4.99 m, it is considered a small inundation, between 5.00 and 5.99 m it is a normal inundation and above 6.00 m it is considered a very large inundation.

Analyzing the graph from figure 5, we can perceive that during the hydrologic years 2005/2006 and 2010/2011 strong inundations occurred, favoring the maintenance of vegetation vigor for a longer time. Due to that, in the HLS representations of Pantanal from these years in figure 4, the red tones predominate, which are related to the occurrence of the maximum EVI in October, after the flood period.

On the other hand, during the hydrologic years 2004/2005 and 2008/2009 there was a strong drought, with a sensitive reduction of soil moisture and consequently of the vegetation vigor. Due to that, at the HLS representations referred for these years in figure 4, the green tones predominate, especially at the fan of Taquari River in Pantanal, indicating that the maximum EVI was postponed to February, after a long drought.

The other years considered had a hydrologic period within normality, which means that the vegetation is in intermediate conditions in comparison with the years of inundation and drought and consistent with the variability of the seasonal cycle from the region. The development of vegetation in Pantanal is correlated to the inundation level which determines the hydrologic conditions of the region, directly affecting the moment of maximum EVI.

The EVI temporal series were processed again by HANTS, now with all 10 hydrologic years together, from October 2001 to September 2011, with the same parameterization as adopted earlier.

Thereby the HLS transform synthesizes the vegetation development in the 10 year period. For each pixel, the phase of the total cycle was attributed to the hue, the amplitude of the total cycle to the lightness and the average of the total cycle from EVI to the saturation.

Figure 6 shows the representation of HLS of the BAP landscape for the entire period of October 2001 to September 2011, with the color legend corresponding with the occurrence of the vegetative peak in the complete time-series.

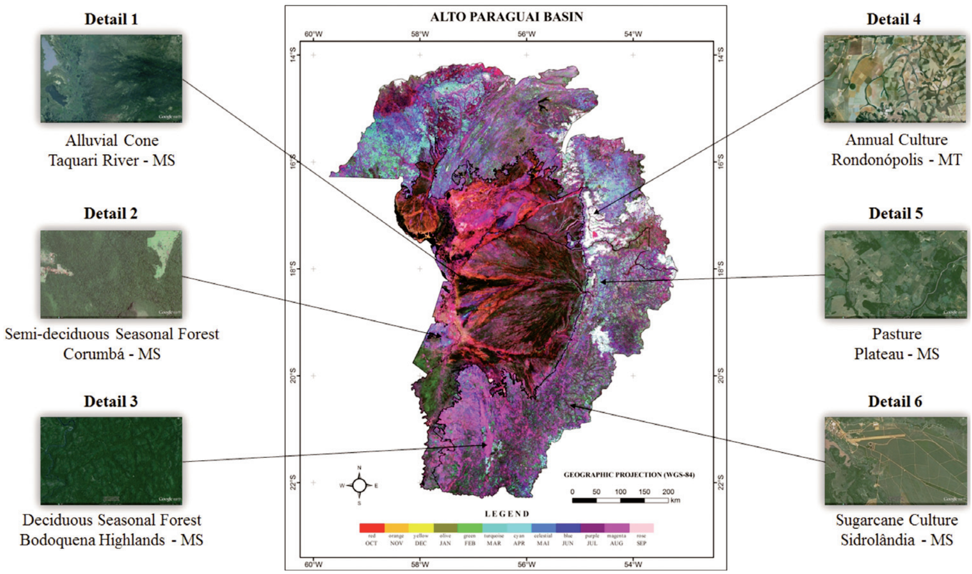

Figure 6 - HLS representation of BAP landscape for the period from October 2001 to September 2011

Source of image details: DigitalGlobe/Google Earth.

The HLS representation of the 10 hydrologic years from figure 6 offers a synoptic view from the lush landscape of the BAP in the period from October 2001 to September 2011, allowing an overall analysis of the general spatial variability of the growth conditions of the vegetation for some types of land use/land cover types.

The dark intensity, close to black, indicates a constantly low EVI during the entire time-series referring to the permanently flooded regions, such as in the alluvial cone of the Taquari River, in Detail 1 of figure 6.

The semi-deciduous seasonal forests, which lost from 20% to 50% of their leaves during the drought time, appear darker in magenta tones, presenting the vegetative peak in August, such as in the area close to the municipality of Corumbá, in Detail 2 of figure 6.

The deciduous seasonal forests which lost over 50% of their leaves during the dry season, are more brilliant in magenta tones, with vegetative peak also in August, such as at Bodoquena Highlands, in Detail 3 of figure 6.

The brilliant intensity close to white refers to a constantly high EVI during the entire time-series, which is manifested in all harmonics, such as in the agricultural region of Rondonópolis, in Detail 4 of figure 6, where there is a strong predominance of annual cultures such as soybean, maize, cotton and sunflower, with several vegetative peaks during the year.

Pastures are clearer varying around cyan tones, indicating the reduction of seasonality, with the vegetative peak occurring in the months of March and April, depending on the susceptibility to the flood regime, such as in the area which is not prone to localized inundation on the plateau of BAP in Mato Grosso do Sul State, seen in the Detail 5 of figure 6.

Sugarcane culture can also be observed in green to turquoise tones, with vegetative peak from February to March, such as in the expansion area localized in the municipality of Sidrolândia, seen in the Detail 6 of figure 6.

CONCLUSIONS AND SUGGESTIONS

The results of this paper show the potential of the harmonic analysis in the study of the cyclic behavior of vegetation indices, whose understanding is important to demonstrate alterations of vegetation growth and to show patterns of temporal dynamics.

The HLS representation of the harmonic terms of EVI/MODIS time-series indicated that the vegetation phenology of BAP has coherent spatial patterns with the vegetation development of the 10 analyzed years, which is consistent with the variability of the seasonal cycle from the Pantanal inundations that directly affect the moment of maximum EVI.

The HLS transform used in this study is based fundamentally on the harmonic terms zero and first, which represent, respectively, the average and the amplitude of the annual EVI cycle. In future studies it is suggested using also the second harmonic term, which represents the semiannual oscillation of the EVI time-series, to propitiate a more detailed analysis of the spatial variability of growth conditions of the BAP vegetation.

REFERENCES

ANTUNES, J. F. G.; ESQUERDO, J. C. D. M. ; LAMPARELLI, R. A. C. Monitoring the temporal dynamics of four vegetation cover types from the Pantanal using the wavelet transform applied to a time-series of EVI/MODIS data. **Geografia**, Rio Claro, v. 36, n. especial, p. 173-185, 2011.

ARENAS-TOLEDO, J. M.; EPIPHANIO, J. C. N. Harmonic amplitude-terms mask to highlight agriculture in the savanna domain below the Brazilian Amazonian frontier. **International Journal of Remote Sensing**, v. 32, n. 18, p. 5021-5034, 2011.

BRASIL. AGÊNCIA NACIONAL DE ÁGUAS (ANA). **Boletim de Monitoramento da Bacia do Alto Paraguai**, Superintendência Múltiplos e Eventos Críticos: Brasília, v. 6, n. 1, p. 1-21, 2011.

DE WIT, A. J. W.; SU, B. Deriving phenological indicators from SPOT-VGT data using the HANTS algorithm. In: INTERNATIONAL SPOT-VEGETATION USERS CONFERENCE, 2nd., **Proceedings...** Belgium: Antwerp, p. 195-201, 2005.

ESQUERDO, J. C. D. M.; ANTUNES, J. F. G.; ANDRADE, J. C. DE. **Desenvolvimento do banco de produtos MODIS na Base Estadual Brasileira.** (Comunicado Técnico, 100) - Campinas: Embrapa Informática Agropecuária, 7 p., 2010.

EXELIS VISUAL INFORMATION SOLUTIONS (EXELIS). **ENVI/IDL.** Disponível em <http://www.exelisvis.com/>. Acesso em: 27 abr. 2012.

FOLEY, J. D.; VAN DAM, A. **Fundamentals of Interactive Computer graphics.** Addison-Wesley Publishing Company, 664 p., 1984.

GALDINO, S.; CLARKE, R. T. **Levantamento e estatística dos níveis hidrométricos do rio Paraguai em Ladário, MS - Pantanal. Período 1900-1994.** (Documentos, 14) - Corumbá: Embrapa Pantanal, 72 p, 1995.

GALDINO, S.; VIEIRA, L. M.; OLIVEIRA, H. de; CARDOSO, E. L. **Impactos da Agropecuária nos Planaltos sobre o Regime Hidrológico do Pantanal.** (Circular Técnica, 37) - Corumbá: Embrapa Pantanal, 6 p, 2002.

HALL-BEYER, M. IHS Co-representation of circular and non-circular variables using harmonic analysis parameters. **Canadian Journal of Remote Sensing**, v. 33, n. 5, p. 416-421, 2007.

HUETE, A.; JUSTICE, C.; LIU, H. Development of vegetation and soil indices for MODIS-EOS. **Remote Sensing of Environment**, v. 49, n. 3, p. 224-234, 1994.

JAKUBAUSKAS, M. E.; LEGATES, D. R.; KASTENS, J. H. Harmonic analysis of time-series AVHRR NDVI data. **Photogrammetric Engineering and Remote Sensing**, v. 67, n. 4, p. 461-470, 2001.

JIA, L.; SHANG, H; HU, G.; MENENTI, M. Phenological response of vegetation to upstream river flow in the Heihe Rive basin by time series analysis of MODIS data. **Hydrology Earth System Sciences**, v. 15, n. 3, p. 1047-1064, 2011.

JUNK, W. J.; CUNHA, C. N.; WANTZEN, K. M.; PETERMANN, P.; STRUSSMANN, C.; MARQUES, M. I.; ADIS, J. Biodiversity and its conservation in the Pantanal of Mato Grosso, Brazil. **Aquatic Sciences**, v. 68, n. 3, p. 278-309, 2006.

LAND PROCESSES DISTRIBUTED ACTIVE ARCHIVE CENTER (LP DAAC). **MODIS Reprojection Tool.** Disponível em <https://lpdaac.usgs.gov/tools/modis_reprojection_tool>. Acesso em: 27 abr. 2012.

LATORRE, M. L.; SHIMABUKURO, Y. E.; ANDERSON, L. O. Sensor MODIS: Produtos para Ecossistemas Terrestres - MODLAND. In: SHIMABUKURO. Y. E.; RUDORFF, B. F. T.; CEBALLOS, J. C. (Coord.). **O Sensor Modis e suas aplicações ambientais no Brasil**. São José dos Campos: Editora Parêntese, SP, Brasil, 2007.

MARINHA DO BRASIL. **Serviço de Sinalização Náutica do Oeste.** Disponível em <https://www.mar.mil.br/ssn-6>. Acesso em: 27 abr. 2012.

MORAES, E. C.; PEREIRA, G.; ARAI, G. Uso dos produtos EVI do sensor MODIS para a estimativa de áreas de alta variabilidade intra e interanual no bioma Pantanal. **Geografia**, Rio Claro, v. 34, n. especial, p. 757-767, 2009.

OPEN SOURCE GEOSPATIAL FOUNDATION (OSGEO). **GeoNetwork opensource.** Disponível em: <http://geonetwork-opensource.org/>. Acesso em: 27 abr. 2012.

PARDI LACRUZ, M. S. **Análise de séries temporais de dados MODIS como uma nova técnica para a caracterização de paisagem e análise de lacunas de conservação.** 129 p. Tese (Doutorado em Sensoriamento Remoto) - Instituto Nacional de Pesquisas Espaciais, São José dos Campos, 2006.

PARDI LACRUZ, M. S.; SOUSA JÚNIOR, M. de A. Uso de séries temporais EVI/MODIS e análise harmônica para o estudo da bacia do rio Taquari. **Revista Brasileira de Cartografia (RBC)**, v. 59, n. 1, p. 9-15, 2007.

REDO, D. J., MILLINGTON, A. C. A hybrid approach to mapping land-use modification and land-cover transition from MODIS time-series data: A case study from the Bolivian seasonal tropics. **Remote Sensing of Environment**, v. 115, n. 2, p. 353-372, 2011.

ROERINK, G. J.; MENENTI, M.; VERHOEF, W. Reconstructing cloudfree NDVI composites using Fourier analysis of time series. **International Journal of Remote Sensing**, v. 21, n. 9, p.1911-1917, 2000.

SOARES, J. V.; BATISTA, G. T; SHIMABUKURO, Y. E. **Sensor MODIS:** Histórico e Descrição. In: O Sensor Modis e suas aplicações ambientais no Brasil - Shimabukuro. Y. E.; Rudorff, B. F. T.; Ceballos, J. C. (Coords). São José dos Campos: Editora Parêntese, SP, Brasil, 2007.

VICTORIA, D. de C.; ANDRADE, R. G.; PAZ, A. R. da. Série temporal de imagens EVI/MODIS para discriminação de formações vegetais no Pantanal. **Geografia**, Rio Claro, v. 34, n. especial, p. 721-729, 2009.

WARDLOW, B. D.; EGBERT, S. L.; KASTENS, J. H. Analysis of time-series MODIS 250m vegetation index data for crop classification in the U.S. Central Great Plains. **Remote Sensing of Environment**, v. 108, n. 3, p. 290-310, 2007.

ZHANG, X.; FRIEDL, M. A.; SCHAAF, C. B.; STRAHLER, A. H.; HODGES, J. C. F.; GAO, F.; REED, B. C; HUETE, A. Monitoring vegetation phenology using MODIS. **Remote Sensing of Environment**, v. 84, n. 3, p. 471-475, 2003.