SPATIOTEMPORAL VARIABILITY OF EVAPOTRANSPIRATION IN PANTANAL, BRAZIL, USING SATELLITE IMAGES

Janice Freitas LEIVAS[1]
Antônio Heriberto de Castro TEIXEIRA[1]
Ricardo Guimarães ANDRADE[1]
Daniel de Castro VICTORIA[1]
Fabio Enrique TORRESAN[1]

Abstract

Despite the importance of evapotranspiration (ET) for the Pantanal, there are few studies about it. In this study we aim to estimate evapotranspiration in Pantanal by applying a spectral-agrometeorological model SAFER (Simple Algorithm for Retrieving Evapotranspiration) using satellite images and data from meteorological stations to analyze spatiotemporal variability of ET biome´s. We used 46 images taken by MODIS (Moderate Resolution Imaging Spectroradiometer) satellite, with a 250 m spatial resolution and a 16-day resolution time, covering rainy (October 2011 to March 2012) and dry (April to September 2012) periods. The SAFER model was effective to estimate ET large scale for rainy and dry season and was sensitive to variations observed in the land use class as well as the relation with the air temperature, solar radiation and rainfall. The highest values of ET were observed in the rainy season, due to the higher availability of water because of rainfall and higher incidence of solar radiation, and the smaller ET values were observed in the dry season.

Keywords: Remote sensing. MODIS. Evapotranspiration. Pantanal. Solar radiation.

Resumo

Variabilidade espaço-temporal da evapotranspiração no Pantanal, Brasil, utilizando imagens de satélite

Apesar da importância da evapotranspiração (ET) para o Pantanal, existem poucos estudos sobre o tema. Este estudo tem o objetivo de estimar a evapotranspiração no Pantanal aplicando o modelo agrometeorológico-espectral SAFER (Simple Algorithm For Evapotranspiration Retrieving) e utilizando imagens de satélite e dados de estações meteorológicas para analisar a variabilidade espaçotemporal dessa variável no bioma. Foram utilizadas 46 imagens do satélite MODIS (Moderate Resolution Imaging Spectroradiometer), com resolução espacial de 250 m e temporal de 16 dias, referentes aos períodos chuvoso (outubro de 2011 a março de 2012) e seco (abril a setembro de 2012). Os dados meteorológicos foram agrupados em 16 dias para coincidir com a resolução temporal das imagens. O modelo SAFER foi eficaz para estimar a ET em larga escala, tanto para o período chuvoso quanto para o seco, e foi sensível às variações observadas entre as classes de uso e cobertura das terras, assim como à relação com a temperatura do ar, radiação solar global e precipitação. Os maiores valores de ET foram observados na estação chuvosa, em decorrência da maior disponibilidade de água em razão da precipitação e da maior incidência de radiação solar, e os menores valores de ET foram observados na estação seca.

Palavras-chave: Sensoriamento remoto. MODIS. Evapotranspiração. Pantanal. Radiação solar.

---

[1] Embrapa Satellite Monitoring Researcher –CNPM. Av. Soldado Passarinho, 303 - 13070-115 - Campinas - SP, Brasil. E-mails: {janice.leivas, heriberto.teixeira, ricardo.andrade, daniel.victoria, fabio.torresan}@embrapa.br

INTRODUCTION

Since the 1970s, the Pantanal biome has been changing, especially in relation to evapotranspiration (ET), with its decrease due to the removal of natural vegetation (Grizio-orita and Souza Filho, 2014). Evapotranspiration is one of the most important variables in the hydrological cycle, making the link among energy, water availability and climate. The change of land use and its cover generates impacts on biosphere/ atmosphere interaction, affecting essential climatic variables, such as ET. Evapotranspiration is controlled by atmospheric evaporative demand and the terrestrial surface, which physiologically and aerodynamically regulates evapotranspiration through features such as stomata activity and canopy rugosity (MATSUMOTO et al., 2008). In agriculture, quantitative information of evapotranspiration is of great importance for the severity assessment, distribution and frequency of drought periods, as well as for the elaboration of projects and management of irrigation and drainage systems (HENRY; DANTAS, 2007).

The Pantanal biome is the largest tropical humid area of the planet, in which seasonal flooding occurs by Paraguay River and its tributaries (ABDON, 2004). This biome is characterized by a cycle of dry and flood periods (flood pulse), with an annual flood cycle which covers about 30% of its territory (ANDRADE et al., 2012). In general, the flood regime influences the main biotic and abiotic processes, and specific landscape units (ADAMI et al., 2008). In the dry period, for instance, several areas seasonally flooded are used for beef cattle grazing and reproduction (ABDON et al., 2007).

The high evaporative demand of dry and flood periods during most of the year (about four months) makes the Pantanal a highly dynamic environment in relation to water vapor transfer to the atmosphere. The Pantanal has fundamental importance in rainfall recycling through evapotranspiration, being essential for the understanding of the broad effects of land use change and forest conversion on Cerrado (savanna) areas, and probably on the Amazon region (LATHUILLIÈRE et al., 2012).

Despite the ET importance, there are few studies on the subject in the Pantanal. Due to extension, water regime and great spatiotemporal variability, satellite images are very important for the biome monitoring. Andrade et al. (2010) emphasize that remote sensing techniques have been efficiently applied because they allow estimating ET of large areas without having to quantify other hydrological processes. Models like SEBAL (Surface Energy Balance Algorithm for Land), proposed by Bastiaanssen et al. (1998a, 1998b); METRIC (Mapping Evapotranspiration at High Resolution with Internalized Calibration), proposed by Allen et al. (2007a, 2007b), and SAFER (Simple Algorithm for Evapotranspiration Retrieving), proposed by Teixeira (2013) have been implemented for spatiotemporal assessments of surface biophysical parameters.

In this study, ET estimates were conducted based on satellite images and meteorological data, through the application of the spectral-agrometeorological model SAFER. This algorithm has the advantage of not needing a thermal band and the possibility of application with data from different types of stations (agrometeorological, conventional and automatic), an important feature for the historical trends evaluation of the elements of the energy balance and productivity of large-scale water over the years, given that automatic sensors are relatively recent advances in instrumental technology (TEIXEIRA et al., 2013b).

The aim of this study is to estimate the evapotranspiration in the Pantanal biome by applying SAFER algorithm and using MODIS images and data from weather stations, with the purpose to analyze the spatiotemporal variability of that variable in the Pantanal.

MATERIAL AND METHODS

The study area is the Pantanal biome (Figure 1), which encompasses Mato Grosso and Mato Grosso do Sul states. The Pantanal has an area of 150,355 km^2 (ABDON et al., 2007) and suffers the biogeographical influence of nearby biomes, such as the Cerrado (East), the Amazon (North), and the Chaco (Southwest). The climate of the region is classified, according to Köppen, as Aw, hot sub-humid tropical climate, with rainy season in summer and drought in winter, with an average annual rainfall of 1200 mm. The rainy season extends from October to March, and the dry period is between April and September, which has the lowest precipitation between July and August (ZAVATTINI, 2009). The soil can also be considered a criterion of delimitation for the Pantanal, as well as the land relief, flood regime and vegetation (VILA DA SILVA, 1998).

In this study we analyzed the influence of seasonality on the ET estimate flood during the rainy season (October 2011 to March 2012) and the dry period (April to September 2012). Daily data of air temperature, solar radiation and precipitation obtained during the period from the Julian Day (JD) 273/2011 to 257/2012, provided by the Meteorological database for training and research (Banco de Dados Meteorológicos para Ensino e Pesquisa - BDMEP) of the National Institute of Meteorology (INMET, Brazil). The data collected during 16 days were grouped together to coincide with the MODIS sensor temporal resolution. The Penmann-Monteith method was applied for estimating evapotranspiration through data from surface weather stations. In addition, MODIS/Earth sensor images were used (October 2011 to September 2012).

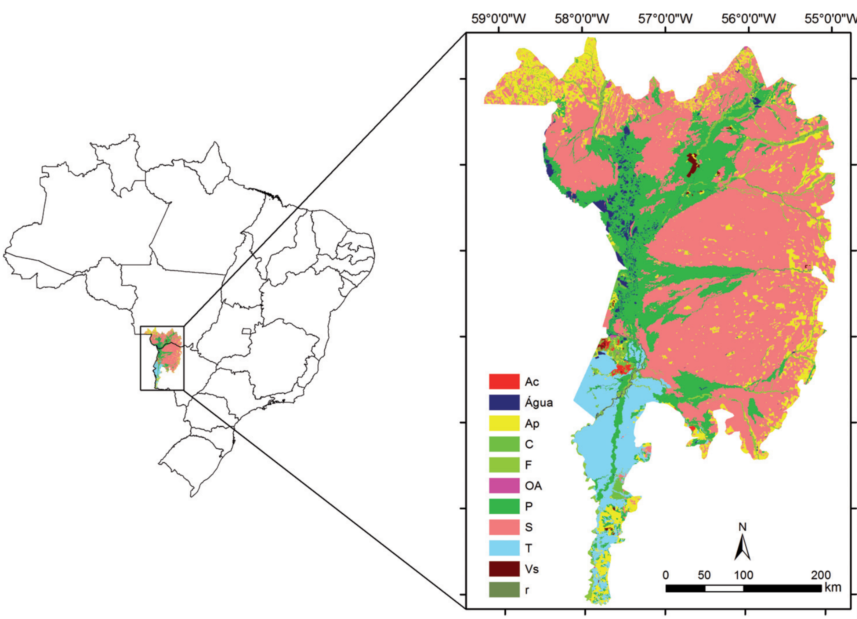

Figure 1 - Location of the Pantanal biome with classes of land use and cover (Probio), 1: 250,000 scale. Agriculture (Ac), water (Água), planted pasture (Ap), seasonal decidual forest (C), semi-decidual seasonal forest (F), anthropogenic areas (OA), pioneer formations (P), Savanna/Cerrado (S), steppic savanna/Chaco (T), secondary vegetation (Vs) and vegetation refuges (r). Source: Adapted from Andrade et al., 2012

For the evaluation of surface ET estimation, according to the classes of land use and cover of the Pantanal Biome, the Project for the Conservation and Sustainable Use of Brazilian Biological Diversity (Probio) was used, according to a survey and a mapping of the remnant vegetation of the Pantanal Biome (in 2002) on the 1: 250,000 scale (EMBRAPA, 2004).

For the ET estimation, 46 MODIS images were obtained (which are available on the website: http://edcimswww.cr.usgs.gov/pub/imswelcome/). The images refer to tiles H12V10 and H12V11 of the years 2011/2012 along with data from weather stations provided by INMET. In SAFER, the surface albedo (α_0) was estimated from the MODIS bands 1 and 2 with 250 m spatial resolution:

$$\alpha_o = a + b\alpha_1 + c\alpha_2$$

where α_1 and α_2 are reflectance at spectral bands of the MODIS sensor bands 1 and 2, and a, b and c are regression coefficients which feature, respectively, 0.08, 0.41 and 0.14 (Teixeira et al., 2014). The surface temperature (ST) was estimated by the residue in the daily radiation balance (TEIXEIRA et al., 2014b):

$$T_S = \frac{R_G - \alpha_0 R_G + \varepsilon_A \sigma {T_a}^4 - R_n}{\varepsilon_S \sigma}$$

where R_G and T_a are, respectively, the daily values of global solar radiation and air average temperature measures on agrometeorological stations; R_N is the balance of daily radiation; ε_S and ε_A are respectively the emissivity of the surface and atmosphere; and σ is the Stefan-Boltzmann constant (5.67 x 10^{-8} W m^{-2} K^{-4}).

ε_S and ε_A were calculated as follows (Teixeira, 2010; Teixeira et al., 2014):

$$\varepsilon_S = a_S \, 1n \, NDVI + b_S$$

$$\varepsilon_A = a_A \, (-1n \, \tau)^{b_A}$$

where τ is the atmospheric transmissivity calculated as the R_G ratio of radiation incident at the top of the atmosphere; NDVI is the Normalized Difference Vegetation Index; and a_S, b_S, a_A and b_A are regression coefficients: 0.06, 1.00, 0.94 and 0.10, according to Tahir (2010) and Teixeira et al. (2014a).

The R_n was obtained by the daily values of the number of shortwave radiation through the Slob's equation (Teixeira et al., 2013, 2014a):

$$R_n = (1 - \alpha_0)R_G - a_L \, \tau$$

where the regression coefficient a_L was spatially distributed according to its relationship with air temperature (Teixeira et al., 2013; 2014a):

$$a_L = a_T T_a - b_T$$

in which the values adopted (6.99 and 29.93) for a_T and b_T regression coefficients were Teixeira's. (2014a).

The ET was obtained with the spectral agro-meteorological model-SAFER and it was transformed into latent heat flux (λE) (TEIXEIRA et al., 2013, 2014a,b):

$$\frac{ET}{ET_0} = \left\{ \exp\left[a_S + b_S \left(\frac{T_0}{\alpha_0 NDVI} \right) \right] \right\} \frac{ET0_{ano}}{5}$$

where the original coefficients a_s and b_s (1.9 and -0.008) were used, but with a correction factor $ET0_{year}/5$, in which $ET0_{year}$ is the annual reference ET int 2012 of the meteorological stations in the Pantanal and 5 is the ET0 annual value of the region where the model was developed.

For the results analysis of the model used to obtain ET, the Probio project classes of land use and cover were used (Embrapa, 2004). Due to the high number of classes in the caption, they were grouped according to Victoria et al. (2009). To subsidize the results, meteorological stations data from Corumbá (19° 00′ S latitude; 57° 64′ W longitude) and Aquidauana (20° 48′ S latitude; 55° 78′ W longitude), in Mato Grosso do Sul state (MS), were analyzed. The data were grouped according to averages (air temperature, solar radiation) and sum (pluvial precipitation) for 16 days, in order to coincide with the date of acquisition of images throughout the study period. With the weather stations data, evapotranspiration was estimate by the Penman-Monteith method proposed in FAO-56 Bulletin (ALLEN et al., 1998).

RESULTS AND DISCUSSION

Analyzing the estimated ET spatial distribution, through spectral-agrometeorological model SAFER estimated in the Pantanal, one notes that according to the classes of land use and cover, different values of evapotranspiration were obtained in the rainy season, between October and March (JD 273/97 of 2011/2012), and in the dry season, between April and September (JD 113 to 257/2012), according to Figures 2 and 3, respectively. The statistics were drawn taking into consideration sample agriculture classes (Ac), water (Ag), planted pasture (Ap), seasonal decidual forest (C), seasonal semi-decidual forest (F), anthropogenic areas (OA), pioneer formations (P), Savanna/Cerrado (S), steppic savanna/Chaco (T), secondary vegetation (Vs) and vegetation refuges (r).

In the rainy season (Figure 2), the daily average for the class “seasonal decidual forest” was 2.72 ± 0.48 mm d^{-1}. In agriculture areas, the ET was 1.84 ± 0.83 mm d^{-1}; in areas occupied by man, 0.92 ± 0.65 mm d^{-1}; on the Savanna/Cerrado it was 1.47 ± 0.59 mm d^{-1} and steppic savanna/Chaco, 1.38 ± 0.53 mm d^{-1}. In the dry season (Figure 3), the class “seasonal decidual forest” presented 2.09 ± 0.31 mm d^{-1}; in agriculture areas, 1.98 ± 0.51 mm d^{-1}. In the anthropized area, ET was 0.85 ± 0.53 mm d^{-1}; in the Savanna/Cerrado, 1.26 ± 0.31 mm d^{-1}; and in the Chaco, 1.47 ± 0.33 mm d^{-1}.

For “water”, the results obtained in the rainy season were around 1.92 mm.day^{-1}, being the value below the one reported in literature. This discrepancy may be due to the fact that the shape data used was from 2002 (Probio project), and the images and meteorological data are from 2011/2012. Another factor that may have influenced the low values of ET can be related to the negative NDVI in water bodies, although there is little water in the Pantanal and in the submerged vegetation, which means that the NDVI values may not have been considered negative, but close to zero, due to the influence of the vegetation reflectance.

The results obtained with the application of the SAFER model confirm Oliveira and Pereira's results (2012). The authors analyzed the historical series of the MODIS evapotranspiration (MOD16A2), 1 km resolution, and observed large seasonal amplitude of ET. The minimum value of ET was 35.30 $mm.month^{-1}$, occurring in the dry period, and the maximum value of 188.40 $mm.month^{-1}$ was found in 2003 (due to high precipitation in the same year and in 2002, which possibly resulted in a greater availability of water on the soil, further development of vegetation, resulting in greater evapotranspiration). Andrade et al. (2009) in a study on the Pantanal, using SEBAL model and MODIS image (7/21/2008), with a 250 m resolution, obtained biophysical parameters for the biome, finding average daily evapotranspiration of 2.6 mm d^{-1}. In a study conducted by Andrade et al. (2012), using the algorithm SEBAL, values of average daily ET of 2.4 mm day^{-1} were obtained on the steppic Savanna/chaco. In areas related to Savanna (Cerrado), livestock (planted pasture) and anthropized areas, the daily ET ranged from 1.3 to 1.9 mm day^{-1}.

In general, at a seasonal scale, the lowest ET were observed in the dry period (compared to the rainy season), which indicates that the main active component on ET is solar radiation. Lathuillière et al. (2012) stressed the importance of the Pantanal biome in rainfall recycling through evapotranspiration, being essential for the understanding of the effects of land use change and forest conversion in Cerrado and probably in the Amazon region.

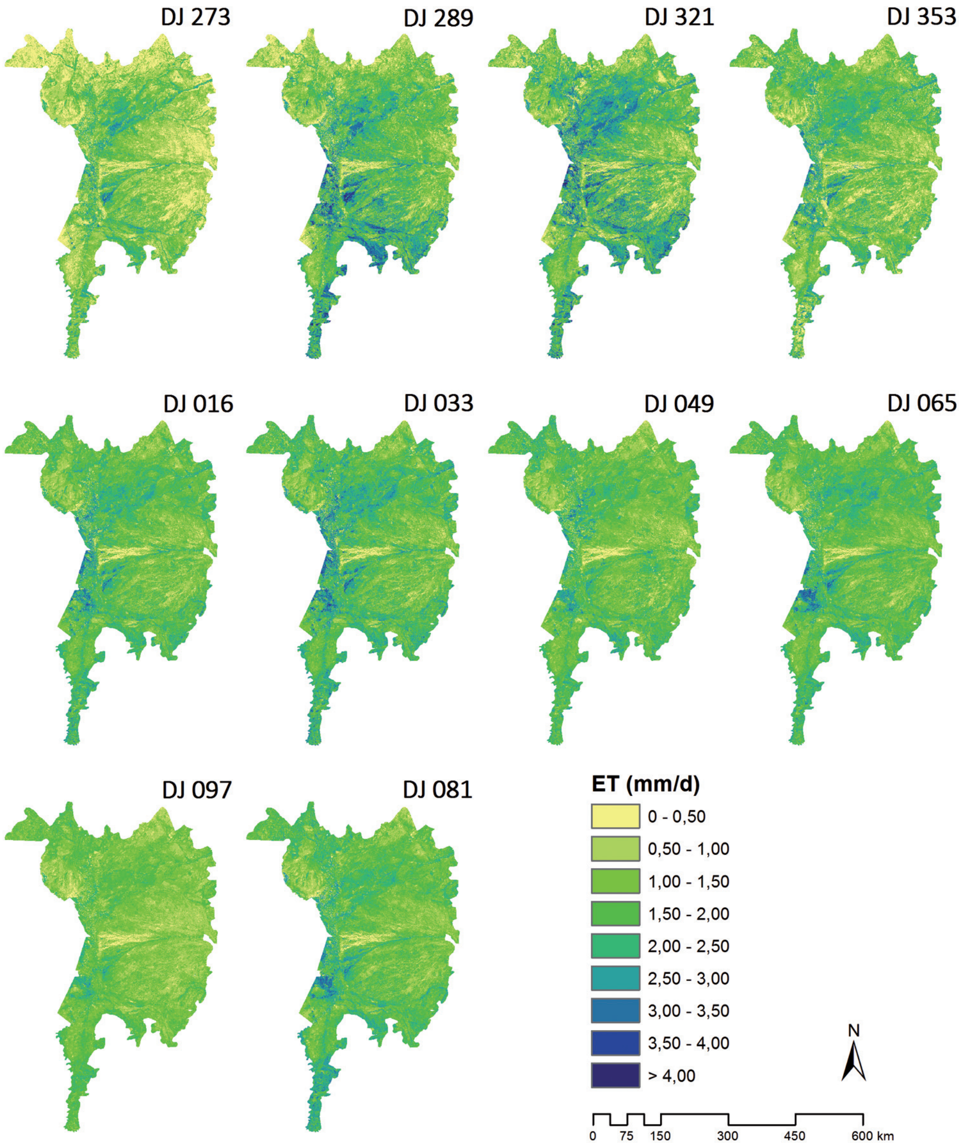

Figure 2 - Spatial distribution of ET estimates (mm d^{-1}) for the Pantanal biome, related to the rainy season, the period between October 2011 (JD 273/2011) to March 2012 (81/2012)

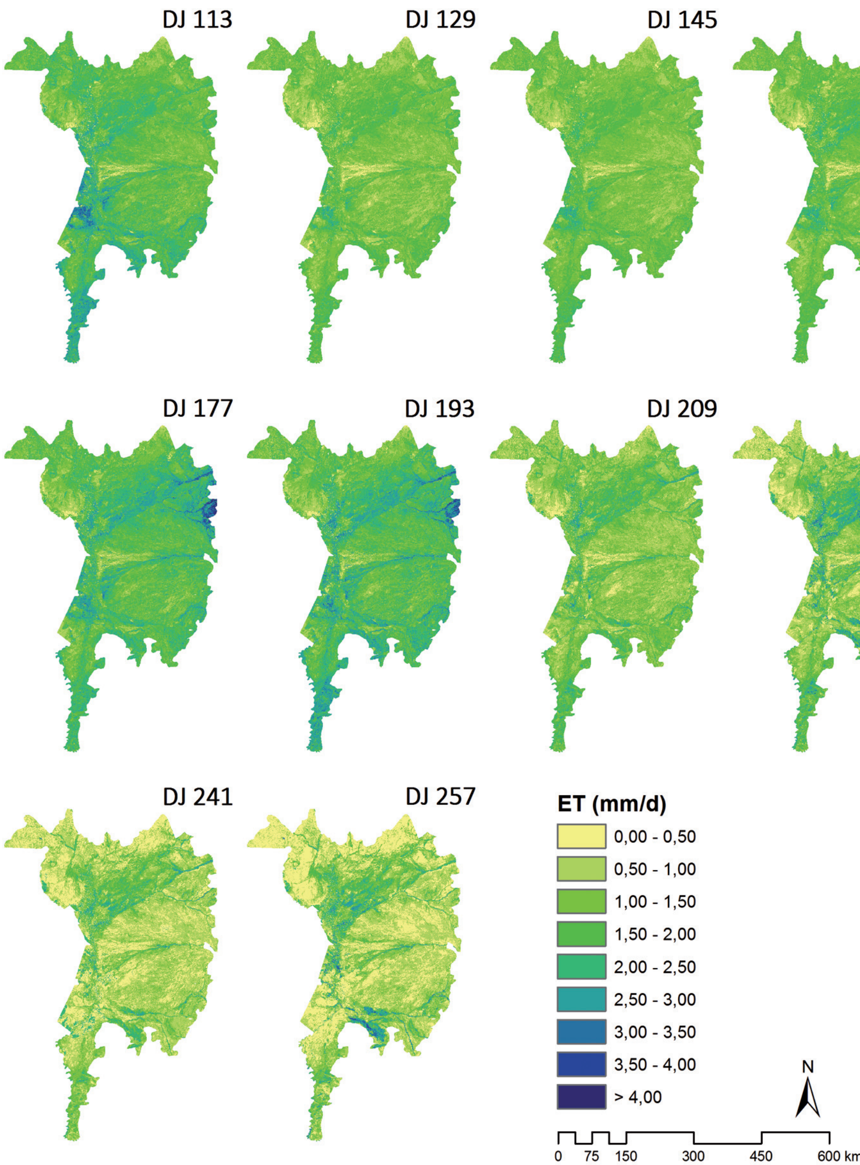

Figure 3 - Maps of ET estimates (mm d^{-1}) for the Pantanal biome related to the dry season, the period between the JD 113 to 257/2012

Meteorological variables such as air temperature, global solar radiation, relative humidity, insolation, pluvial precipitation, and wind speed, among others, influence evapotranspiration. To support the results obtained with SAFER model, with the use of satellite images, meteorological data from two different localities as Corumbá (western part of the biome) and Aquidauana (East) were analyzed, as well as the ET estimate by the Pennan-Monteith model (FAO-56) (Figure 4). The following variability of meteorological variables in Corumbá and Aquidauana/MS was observed, at 16-days scale: air temperature (a), global solar radiation (Rg), and precipitation (c) in the rainy season (JD 289/2011 to 92/2012) and in the dry period (JD 93 to 288/2012). In the dry season, it is observed that the maximum air temperature values occurred in the period between the JD 213 to 272, referring to the months of August and September 2012, whose 16-day average reached 30°C (Figure 4a).

In Figure 4b, the seasonality of global solar radiation is observed, evidencing the effect of radiation decrease in the dry period with an average of 16 days, around 15 $MJ.m^{-2}$ and 20 $MJ.m^{-2}$ in the rainy season, leading to a evapotranspiration decrease, as one can see on the maps of ET estimate (Figures 2 and 3). This occurs because the more away from the line of Ecuador, the higher the latitude, and thus greater the incidence of solar radiation in the summer (coinciding with the rainy season in the Pantanal) and lower in the winter (dry), corroborating with Varejão-Silva (2006) results.

It was observed that in the dry season, in mid-May (JD 144), the Rg is approximately 10 $MJ.m^{-2}$. This fact may be related to fires and wildfires, which contribute to the increase of suspended particles in the air in the dry season. The highest values of solar radiation were observed in December, corroborating with the results obtained by Fraga (2009) who, starting with monthly data from the Pantanal, observed that ET decreased from April to September (dry season), same period in which the radiation balance declined. These results corroborate with Oliveira et al. (2006) studies, who observed seasonal variation of the latent heat of evaporation according to the behavior of radiation balance and local pluvial precipitation on South Pantanal of Mato Grosso, with a higher amount of energy available in the wettest months.

In the rainy season, high rainfall rates were observed in Corumbá and Aquidauana-MS. In the dry period (from April to September 2012), intense precipitation was observed in Aquidauana, between JD 176 and 191. During this period, the global solar radiation presented low values, as well as air temperature, influencing the average evapotranspiration decrease calculated for the 16 days included in the period (Figure 4d). In the dry season, an extreme event occurred, with precipitation around 140 mm in 16 days, in Aquidauana/MS. Between August and September 2012 (JD 213 to 272), rainfall rates near zero were observed in Corumbá and Aquidauana/MS, what permitted one to observe the monthly rain precipitation variability (Figure 4c). These results corroborate with Zavattini (2009), who found the lowest rainfall rates in Aquidauana in July and August. According to Hasenack et al. (2003), the total annual average precipitation in the Pantanal presented West-East and East-Southeast gradients.

ET average variation (Figure 4d) for the 16 days (range adopted to coincide with the MODIS images dates) was similar to the radiation balance behavior (Figure 4b). In the period from July (JD 182) and September 2012 (JD 273), rains were scarce, influencing ET behavior, with average values around 2 mm in Aquidauana/MS. In the 2011/2012 rainy season, from JD 288, due to high solar radiation common in the summer months, ET average values reached around 4 mm. From April 2012 (JD 96) on, ET decreased until the end of the dry season (September 2012 – JD 272).

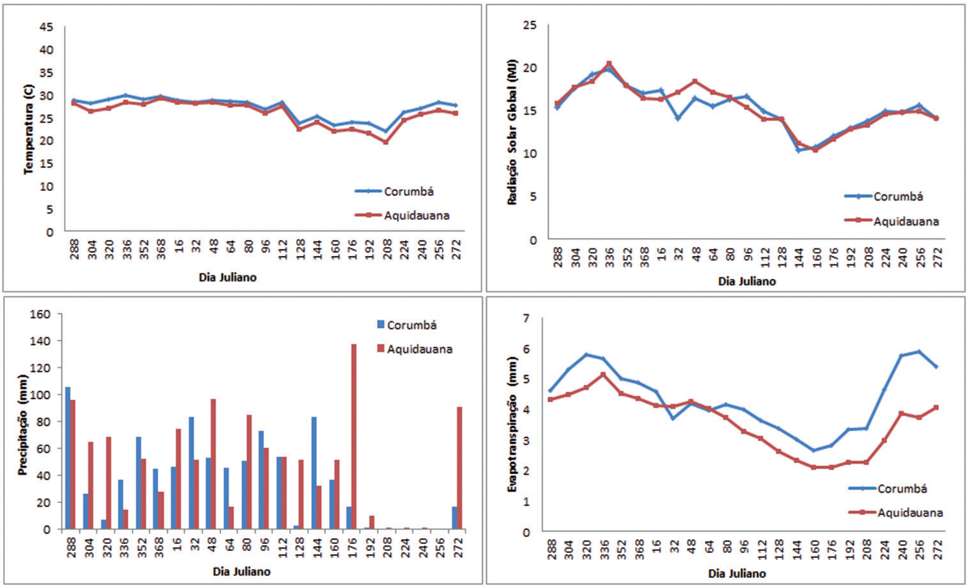

Figure 4 - Seasonal variation of weather variables (temperature (°C) and average global solar radiation (MJ.m^{-2}) of 16 days, and rainfall accumulation of 16 days (mm) of Corumbá and Aquidauana/MS, from the 2011 rainy season (JD 288 to 96) at the end of the 2012 dry period (JD 92 to 277)

Goulart et al. (2015) analyzed evapotranspiration in the Pantanal using Morlet Wavelet method. They found the highest values of evapotranspiration during the wet season, and higher energy intensity at high frequency range probably due to the increased availability of water, caused by precipitation and flood, and global radiation, what corroborates with the results obtained in this study.

From the results obtained one can infer that ET variability/sub estimates are related to the intense dynamics of the Pantanal biome, causing changes between each flood and dry periods. Since the shape refers to the 2002 land use classes, and the input data of the model are from 2011 and 2012, it may have occurred changes in land uses. Another factor may be related to differences of image resolution, for the classes were based on images with higher spatial resolution (Landsat sensor), and the images used in the model are 250 m (MODIS), causing confusion among classes.

It is important to emphasize that land use change can affect the water balance of river basins, once the dynamics of rain, infiltration, surface runoff and ET are changed. Another important factor is that weather stations network in the Pantanal is sparse and can influence on estimates of parameters such as ET. According to Dahl (2006), to analyze floodable areas is a difficult task due to the dynamics of wet zones, for they present a high degree of temporal variability. The variability occurs due to seasonal fluctuations on water level caused by changes in rainfall, temperature and other environmental conditions, such as human interferences on nature. The advantage of applying the SAFER model is monitoring hard-to-reach areas without using images that have thermal band, making possible the application of the model with images from various sensors. Using MODIS images has the advantage of high temporal resolution, facilitating the application of data for the Pantanal biome monitoring.

CONCLUSIONS

According to the results we can conclude that the integrated analysis of satellite images with data from weather stations, using the SAFER model, permits monitoring evapotranspiration at regional scale.

The results were satisfactory, allowing better understanding about the evapotranspiration dynamics of floodable areas and their relation with air temperature, solar radiation and precipitation. The highest evapotranspiration values were found in the rainy season because of the increased availability of water due to precipitation and a higher solar radiation incidence.

SAFER model proved effective for the ET estimation at a large scale, both for the rainy and the dry season, being sensitive to the variations observed between the classes of land cover and land use. Thus, for future studies, we suggest the use of images with a higher spatial resolution and greater amount of data from weather stations, enabling the model functionality for hydrometeorological monitoring of the Pantanal.

REFERENCES

ABDON, M. M. **Os impactos ambientais no meio físico** – Erosão e assoreamento na bacia hidrográfica do rio Taquari, MS, em decorrência da pecuária. 2004. 302f. Tese (Doutorado em Ciências da Engenharia Ambiental) - Escola de Engenharia da Universidade de São Paulo, São Carlos, 2004.

ABDON, M. de M.; SILVA, J. dos S. V. da; SOUZA, I. de M. e S.; ROMON, V. T.; RAMPAZZO, J.; FERRARI, D. L. Desmatamento no bioma Pantanal até o ano 2002: relações com a fitofisionomia e limites municipais. **Revista Brasileira de Cartografia**, Rio de Janeiro, v. 59, n. 1, p. 17-24, 2007.

ADAMI, M.; FREITAS, R. M. de; PADOVANI, C. R.; SHIMABUKURO, Y. E.; MOREIRA, M. A. Estudo da dinâmica espaço-temporal do bioma Pantanal por meio de imagens MODIS. **Pesquisa Agropecuária Brasileira**, Brasília, v. 43, n. 10, p. 1371-1378, 2008.

ALLEN, R.G., PEREIRA, L.S., RAES, D., SMITH, M. Crop evapotranspiration, Guidelines for computing crop water requirements, **FAO Irrigation and Drainage Paper** 56. Rome, Italy, 300 pp., 1998.

ALLEN, R.; TASUMI, M.; TREZZA, R. Satellite-based energy balance for mapping evapotranspiration with internalized calibration (METRIC) model. **Journal of Irrigation and Drainage Engineering**, v. 133, n. 4, p. 380-394, 2007a.

ALLEN, R.; TASUMI, M.; TREZZA, R. Satellite-based energy balance for mapping evapotranspiration with internalized calibration (METRIC) applications. **Journal of Irrigation and Drainage Engineering**, v. 133, n. 4, p. 395-405, 2007b.

ANDRADE, R. G.; SEDIYAMA, G. C.; BATISTELLA, M.; VICTORIA, D. de C.; PAZ, A. R.; LIMA, E. de P.; NOGUEIRA, S. F. Mapeamento de parâmetros biofísicos e da evapotranspiração no Pantanal usando técnicas de sensoriamento remoto. In: SIMPÓSIO DE GEOTECNOLOGIAS NO PANTANAL, 2., 2009. Corumbá, MS. **Anais...** Campinas: Embrapa Informática Agropecuária; INPE, 2009. p. 695-704.

ANDRADE, R. G.; PAZ, A. R. da; VICTORIA, D. de C.; DELGADO, R. C.; LIMA, E. de P. Análise da evapotranspiração real diária em diferentes classes de uso e cobertura da terra na região do Pantanal. In: CONGRESSO BRASILEIRO DE METEOROLOGIA, 16., 2010. Belém, PA. **Anais...** Belém, PA: SBMET, 2010.

ANDRADE, R. G.; SEDIYAMA, G. C.; PAZ, A. R.; LIMA, E. P.; FACCO, A. G. Geotecnologias aplicadas à avaliação de parâmetros biofísicos do Pantanal. **Pesquisa Agropecuária Brasileira**, Brasília, v. 47, n. 9, p. 1227-1234, 2012.

BASTIAANSSEN, W. G. M.; MENENTI, M.; FEDDES, R. A.; HOLTSLAG, A. A. M. A remote sensing surface energy balance algorithm for land (SEBAL): 1. Formulation. **Journal of Hydrology**, v. 212/213, p. 198-212, 1998a.

BASTIAANSSEN, W. G. M.; PELGRUM, H.; WANG, J.; MA, Y.; MORENO, J. F.; ROERINK, G. J.; VAN DER WAL, T. A remote sensing surface energy balance algorithm for land (SEBAL): 2. Validation. **Journal of Hydrology**, v. 212/213, p. 213-229, 1998b.

DAHL, T. E. **Status and trends of wetlands in the conterminous United States 1998–2004**. Washington, DC: Fish and Wildlife Service, 2006.

EMBRAPA. **Levantamento e mapeamento dos remanescentes da cobertura vegetal do bioma Pantanal, período de 2002 na escala de 1:250.000**. Campinas: Embrapa Informática Agropecuária, ago. 2004. 43p.

FRAGA, C. I. M. **Evapotranspiração e fator de desacoplamento em área de cambarazal no Pantanal**. 2009, 56f. Dissertação (Mestrado em Física e Meio Ambiente) - Instituto de Física, Universidade Federal de Mato Grosso, Cuiabá, 2009.

GOULART, M. A.; SANCHES, L.; VILANI, M. T.; PINTO JÚNIOR, O. B. Análise da evapotranspiração por wavelet de Morlet em área de Vochysia divergens Pohl no Pantanal. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.19, n.2, p.93–98, 2015.

GRIZIO-ORITA, E.V.; SOUZA FILHO, E.E.; Modificação da evapotranspiração e disponibilidade hídrica no sistema do Rio Paraguai, **Revista Geonorte**, Edição Especial 4, n. 1, v. 10, p.233 - 239, 2014.

HASENACK, H.; CORDEIRO, J. L. P.; HOFMANN, G. S. **O clima da RPPN SESC Pantanal**. Porto Alegre: UFRGS, 2003. 27 p.

HENRIQUE, F. A. N.; DANTAS, R. T. Estimativa da evapotranspiração de referência em Campina Grande, Paraíba. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v.11, n.6, p.594-599, 2007.

LATHUILLIÈRE, M. J.; JOHNSON M. S.; DONNER, S. D. Water use by terrestrial ecosystems: Temporal variability in rainforest and agricultural contributions to evapotranspiration in Mato Grosso, Brazil. **Environmental Research Letters**, v.7, p.1-12, 2012.

MATSUMOTO, K.; OHTA, T.; NAKAI, T.; KUWADA, T.; DAIKOKU, K.; IIDA, S.; YABUKI, H.; KONONOV, A. V.; VAN DER MOLEN, M.. K.; KODAMA, Y.; MAXIMOV, T. C.; DOLMAN, A. J.; HATTORI, S. Responses of surface conductance to forest environments in the Far East. **Agricultural and Forest Meteorology**, v. 148, 1926-1940, dez. 2008.

OLIVEIRA, M. B. L.; VON RANDOW, C.; MANZI, A. O.; ALVALÁ, R. C. S.; ORTEGA-FARIAS, S. O.; CUENCA, R. H.; EK, M. Daytime variation of sensible heat flux estimated by the bulk aerodynamic method over a grass canopy. **Agricultural and Forest Meteorology**, v. 81, p. 131-143, set. 1996.

OLIVEIRA, M. B. L.; VON RANDOW, C.; MANZI, A. O.; ALVALÁ, R. C. S.;SÁ, L. D. A.; LEITÃO, M. M. V. B.R.; SOUZA, A. Fluxos turbulentos de energia sobre o Pantanal sul mato-grossense. **Revista Brasileira de Meteorologia**, v. 21, p. 371-377, Dezembro, 2006.

OLIVEIRA, B. S.; PEREIRA, B. Avaliação da evapotranspiração em diferentes usos do solo no Pantanal utilizando dados do sensor Terra-MODIS. In: SIMPÓSIO DE GEOTECNOLOGIAS NO PANTANAL, 4., 2012. Bonito, MS. **Anais...** Campinas: Embrapa Informática Agropecuária; INPE, 2012. p. 870 -878.

TEIXEIRA, A. H. DE C. Determining regional actual evapotranspiration of irrigated and natural vegetation in the São Francisco river basin (Brazil) using remote sensing and Penman-Monteith equation. **Remote Sensing**, v. 2, 1287-1319, 2010.

TEIXEIRA, A. H. DE C.; HERNANDEZ, F. B. T. ; ANDRADE, R. G. ; LEIVAS, F. L.; VICTORIA, D. DE C. ; BOLFE, E. L. Irrigation performance Assessments for corn crop with Landsat mages in the São Paulo state, Brazil. In: INTERNATIONAL INOVAGRI MEETING, 2., 2014, Fortaleza. **Proceedings...** Fortaleza: INOVAGRI, 2014b. p. 739-748.

TEIXEIRA, A. H. DE C.; HERNANDEZ, F. B. T.; LOPES, H. L.; SCHERER-WARREN, M.; BASSOI, L. H. A Comparative Study of Techniques for Modeling the Spatiotemporal Distribution of Heat and Moisture Fluxes in Different Agroecosystems in Brazil. In: PETROPOULOS, G. G. (Org.). **Remote Sensing of Energy Fluxes and Soil Moisture Content**. 1ed. Boca Raton, FL: CRC Group; Taylor and Francis, 2014a, p. 169-191.

TEIXEIRA, A. H. DE C.; SCHERER-WARREN, M.; HERNANDEZ, F. B. T.; ANDRADE, R. G.; LEIVAS, J. F.; Large-Scale Water Productivity Assessments with MODIS Images in a Changing Semi-Arid Environment: A Brazilian Case Study. **Remote Sensing**, v. 11, p. 5783-5804, 2013.

TEIXEIRA, A. H. DE C.; HERNANDEZ, F. B. T. ; LOPES, H. L. Up Scaling Table Grape Water Requirements in the Low-Middle São. **Acta Horticulturae**, v. 1038, p. 655-662, 2014

VAREJÃO-SILVA, M. A. **Meteorologia e climatologia**. Versão digital 2. Recife, Brasil, 449p, 2006.

VICTÓRIA, D. DE C.; ANDRADE, R. G.; PAZ, A. R. Série temporal de imagens EVI/ MODIS para discriminação de formações vegetais do Pantanal. **Geografia**, Rio Claro, v. 34, número especial, p. 721-729, 2009.