Study of the Radiation Balance in the Southern Mato Grosso Pantanal Wetland

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Abstract. The results from two micrometeorological data sets obtained during both the dry season of 1999 (September), and the transition from the dry to the rainy season of 2000 (September to November) in the Southern Mato Grosso Pantanal are described. The components of the radiation balance were evaluated, as well as the estimation of the net radiation, through the global incident radiation and the short wave radiation balances. The estimation of the ratio between the photosynthetically active radiation and the global incident radiation was obtained for both data sets. The analysis of the net radiation in the near infrared region, plus the evaluation of the variability of the albedo in the short wave, PAR and near infrared regions, and the estimation of the albedo as a function of the solar zenith angle were carried out. The results show that, from one year to the other, there were significant variations in certain components of the radiation balance. They were due specially to the differences in the surface conditions, that is, drier vegetation in 1999, opposed to a greener subsequent year. The average value of the ratio between incident photosynthetically active and global incident radiations for the 1999 period was 0.48±0.02, while for the 2000 period it was 0.46±0.01. The average albedo of the solar (α_K), of the PAR (α_{PAR}) and of the NIR (α_{IR}) radiations, for the days considered in 1999 were, respectively, 0.17±0.02, 0.08±0.01 and 0.26±0.03; for 2002, they were, respectively, 0.17±0.02, 0.06±0.01 and 0.26±0.06. Finally, it should be noted that the variation of the microclimatic and the radiation parameters between 1999 and 2000 are related with the different conditions observed in both periods, that is, the presence of aerosols in the atmosphere due to the occurrence of fires in the region in 1999, and the occurrence of rainfall and the changes in the cloudiness in 2000.

Keywords: Pantanal, Wetland, Radiation Balance, Albedo, Photosynthetically Active Radiation.
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INTRODUCTION

The Pantanal, one of the greatest wetlands in the world, is located in the central western part of South America. It has very peculiar environmental and ecological characteristics, a great biodiversity and an irregular hydrological cycle, which often presents floods during the wet season and droughts and fires during the dry season. Even though Pantanal is considered a very important ecosystem, few meteorological investigations were effected in this region. Thus, as part of a program to study the Southern Mato Grosso Pantanal, the Brazilian National Institute for Space Research (INPE) and the Southern Mato Grosso Federal University, in collaboration with other institutions, conducted the Interdisciplinary Pantanal Experiment. It included intensive micrometeorological field campaigns carried out to provide an adequate characterization of the surface layer structure over the wetland surface, as well as to obtain useful data for a better understanding of the surface energy budget components associated with both the dry and the shallow water layers, and some meteorological variables characteristic of the surface–atmosphere turbulent exchange processes. So, as some of the results, analyses of 22 months, from September 2000 to June 2002, of measurements of turbulent sensible and latent heat fluxes, net radiation and soil heat flux were presented [1]. Also, studies were performed concerning the nocturnal atmospheric boundary-layer thermal structure above Pantanal [2], as well as to verify the validation of the Monin–Obukhov similarity theory on the Pantanal, during a transition period from wet to dry season. Additionally, the surface energy budget and other surface layer turbulent parameters were computed, discussed and compared with other research results over complex and flooded terrains [3].

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This study describes the variability of the radiation components over the Southern Mato Grosso Pantanal, considering measurements of the radiation components and of the micrometeorological variables obtained during both the dry season of 1999 (Sep.), and the transition from the dry to the rainy season of 2000 (Sep. to Nov.).

EXPERIMENTAL SITE AND DATA

The experimental site is located in the southern region of Pantanal wetland (19°33'48"S; 57°00'53"W, altitude 80 m), state of Mato Grosso do Sul, Brazil. This state has a significant area of tropical savanna grasslands, of which Pantanal is an immense sedimentary prairie characterized by a seasonal flooding pattern and peculiar fetch conditions. The climate of Pantanal presents a quasi-regular hydrological cycle with some inter-annual oscillation, which often presents floods during the wet season (November–March), and natural and anthropogenic fires during the dry season (July–October). The rainfall oscillates between 1000 mm year^{-1} and 1500 mm year^{-1} and almost 80% of this precipitation occurs in the summer season, between the months of November and March [4]. The vegetation is typical of an open arboreal savanna region, composed by trees, called Paratudal, rooted floating plants or free floating plants. There are also grass and natural pasture [5].

The main observation periods in the present study (08 to 29 September, 1999 and 18 September to 02 December, 2000) represent respectively the dry season and the transition from the dry to the rainy season in the region.

All radiation instruments were mounted at a height of 21 m at the top of an aluminum-scaffolding tower. They were mounted perfectly leveled at the end of 4 m booms oriented to north. The incident (K↓) and reflected (K↑) solar radiations were measured with CM5 pyranometers (Kipp & Zonen, Delft, the Netherlands), the incident (PAR↓) and reflected (PAR↑) photosyntetically active radiations were measured with two LI-190SA quantum sensors (Li-COR, Nebraska, USA), and the incident (L↓) and reflected (L↑) longwave radiations were obtained with CG3 pyrgeometers (Kipp & Zonen, Delft, the Netherlands). The net radiation (R_n) was measured with Q*6 net radiometer (REBS, Seattle, WA, USA), as well as with the CNR1 net radiometer (Kipp & Zonen, Delft, the Netherlands). All the radiation instruments used were previously calibrated. The measurements of temperature and humidity in 1999 were made with aspirated psycrometers composed by wet and dry bulb platinum resistance thermometers (Didcot Instuments, Abingdon, UK), while in 2000 they were obtained with a HMP45C thermohygrometer (Vaisala, Finland). The data, in September 1999 and September-October 2000, were sampled every 10 s and recorded as ten and thirty minutes averages, respectively, using two CR10X data loggers (Campbell Scientific, Shepshed, UK).

RESULTS AND DISCUSSION

Table 1 shows daily mean values of the measured components of the radiation budgets and the vapour pressure for both periods studied. During September 1999, the daily net radiation (Rn) ranged from 2.1 MJ m^{-2} day^{-1} (DOY 258) to 14.96 MJ m^{-2} day^{-1} (DOY 265), which was the clearest day of the period, while daily accumulated R_n in 2000 range from 1.75 MJ m^{-2} day^{-1} (DOY 318) to 19.91 MJ m^{-2} day^{-1} (DOY 320). Table 1 also shows that PAR↓ and PAR↑ were, respectively, 9% and 14% greater in 1999. The daily accumulated R_n value indicate that the differences in the average values of Rn were 16% greater in 2000, which is significant, although K↓ (L↓) were 8% (5%) smaller in average, in 2000. On average, for the total period, L↓ was 5% greater in 2000 during all the day, due to the more availability of water vapor in the atmosphere, while L↑ was less than 1% superior in 1999 during the period between 13 and 14 local time. The maximum values of L↓ for the total period for 1999 and 2000 were, respectively 438.7 W m^{-2} e 459.8 W m^{-2}, while the respectively values for L↑ were 535.4 W m^{-2} e 533.0 W m^{-2}. The performance of seven parameterizations to estimate L↓ for clear sky conditions was also evaluated [6]. Considering separately clear sky days in 1999 (8 days) and in 2000 (16 days), it was observed that the parameterizations of L↓ for 1999 data agreed fairly with the measurements, with the biases varying between –29.25 Wm^{-2} to –2.01 Wm^{-2}, for the seven parameterizations considered. The adjustment of the parameterizations to the local conditions in 1999 indicated that the one proposed by Prata (1996)[7] should be preferred because, besides having a physical basis, it presented both the highest coefficient of determination (0.97) and the highest probability according to the algorithm of Box and Hill (Π=0.17). The validation of the adjusted parameterizations with data from 2000 showed that the ones from 1999 are more representative of the conditions of dry soil and with the presence of aerosols found during that year, than representative of the conditions of wet soil observed in 2000. The adjustment of the parameterizations for the conditions of 2000 indicated that the one proposed by Brunt (1932) [8] is the most representative for the dry season in Pantanal with the absence of fires in the region. It was noticed that the variation of the components of the

net shortwave radiation was influenced by the presence of aerosols in the atmosphere, due to the occurrence of fires in the region in 1999, and the occurrence of rainfall and the changes in cloudiness in 2000.

TABLE (1). Daily average values of measured radiation fluxes (MJ m^{-2} dia^{-1}) and the vapour pressure (hPa).

	Rn	K↓	K↑	L↓	L↑	PAR↓	PAR↑	P_v	Q
	08 – 29 Sep. 1999 (21 days, except for L↓ and L↑ – 18 days)								
Average	11.7	20.2	3.4	35.1	40.1	9.8	0.8	24.1	34.4
STD	2.8	4.5	0.8	1.9	1.4	2.2	0.2	10.0	1.0
	18 Sep. – 02 Dec. 2000 (68 days)								
Average	14.0	22.0	3.5	37.1	41.3	8.8	0.6	23.3	38.6
STD	4.2	5.9	0.9	2.0	1.8	7.0	0.2	3.7	2.2

R_n, net radiation; K↓, K↑, downward and upward solar radiation; L↓, L↑, downward and upward longwave radiation; PAR↓, PAR↑, downward and upward photosynthetically active radiation, Q, irradiance at the top of the atmosphere; Pv, vapour pressure; STD – standard deviation

The overall 10 minutes sampled averages, as well as the absolute maximum and minimum values of the components of the solar radiation and the photosynthetically active radiation, for different cloud conditions in both periods, are presented in Table 2. The values of PAR↓ for both clear and total period were 3% higher in 2000, less than the instrumental error. The values of PAR↑ were approximately 15% (16%) higher in 1999 in the clear (cloudy and partially cloudy) period and 30% higher in the cloudy days. Thus, except for the cloudy conditions period, PAR↓ did not show a significant difference between 1999 and 2000, indicating that the greener vegetation in 2000 absorbed radiation more effectively than in 1999, which is consistent with the variation of the albedo.

TABLE (2). Statistical values of the measured components of the shortwave and PAR radiation components (W m^{-2}) at different cloud conditions for both periods.

	Clear Days		Cloudy and Partially Cloudy Days		Total Period	
	K↓ / PAR↓	**K↑ / PAR↑**	**K↓ / PAR↓**	**K↑ / PAR↑**	**K↓ / PAR↓**	**K↑ / PAR↑**
			1999			
Average	497.84 / 241.82	84.14 / 18.43	239.81 / 107.25	41.88 / 8.56	432.83 / 210.27	72.89 / 16.16
Maximum	916.29 / 450.70	146.12 / 32.42	513.77 / 255.32	90.54 / 20.19	820.75 / 402.98	132.58 / 29.63
N*	10	10	02	02	18	18
			2000			
Average	537.34 / 247.30	84.61 / 15.64	201.34 / 93.22	32.65 / 6.06	469.82 / 216.47	74.45 / 13.64
Maximum	927.99 / 427.41	136.20 / 25.54	389.89 / 181.14	62.72 / 12.17	803.05 / 370.44	118.98 / 22.50
N*	46	46	08	08	68	68

N* – number of days considered.

The relationship of photosynthetically active radiation to shortwave radiation (η) ranged from 0.48±0.02 for the total period of 1999 to 0.46±0.01 in 2000. The values for 1999 are 20% higher than those estimated by other authors for different latitudes [9, 10, e.g.]. This is related to large amounts of smoke, which are common in the area during the dry season, when a great deal of burning of overgrown pastures takes place. The average values of albedo for solar (α_K), photosynthetically active (α_{PAR}), and infrared radiation (α_{IR}), for both periods are shown on Table 3. The mean value of α_K was approximately 10% higher for the clear days in 1999, while those for the cloudy and the total period were of the same magnitude, if compared with the corresponding values for 2000. During both periods, the albedo was approximately constant in clear days, except in the early morning and evening hours. This is due to the large amount of energy received when the sun is high. In summary, the mean values of α_{PAR} in 1999 were 20.8, 46.6 and 26.1% higher, respectively, for the three sky cover conditions, if compared with those for 2000. These differences occurred due to the fact of the second data set includes values of October and November, months of the beginning of the wet season in the region. The computed net radiation obtained through both K↓ and net solar radiation K* showed high correlation. In 1999 (2000), approximately 28% (23%) of K↓ was lost by reflection and re-radiation from the vegetation during the diurnal period, indicating that these proportions are relatively higher than

the respective albedo. With rain, α_{PAR} decreased, indicating that the vegetation was green; thus, the chlorophyll absorbed the radiation more effectively (more than 90%). The values of α_K are satisfactorily consistent with other values found for tropical grass [11].

TABLE (3). Statistical values of the albedo at different cloud conditions for both periods.

	Clear Days			Cloudy and Partially Cloudy Days			Total Period		
	α_K	α_{PAR}	α_{IR}	α_K	α_{PAR}	α_{IR}	α_K	α_{PAR}	α_{IR}
					1999				
Average	0.18	0.08	0.26	0.17	0.08	0.26	0.17	0.08	0.26
Maximum	0.21	0.10	0.32	0.20	0.08	0.31	0.21	0.09	0.31
Minimum	0.15	0.07	0.23	0.16	0.08	0.24	0.11	0.07	0.22
STD	0.02	0.01	0.02	0.04	0.00	0.02	0.02	0.01	0.03
N*	10	10	10	2	2	2	18	18	18
					2000				
Average	0.16	0.07	0.25	0.17	0.05	0.26	0.17	0.06	0.26
Maximum	0.20	0.08	0.29	0.26	0.06	0.35	0.22	0.07	0.44
Minimum	0.15	0.06	0.22	0.15	0.02	0.24	0.15	0.06	0.23
STD	0.02	0.01	0.03	0.03	0.01	0.09	0.02	0.00	0.06
N*	46	46	46	8	8	8	68	68	68

N* – number of days considered; STD - Standard deviation

The average air temperature (amplitude) in both periods (1999 and 2000) were 26.3°C (25.0°C) and 27.3°C (23.7°C), respectively. During the transition period of 2000, the rainfall was higher than 80 mm day^{-1} on DOY 329. The humidity increases due to the passage of cold fronts or occurrence of rainfall. The maximum wind speed at 22 m varied from 5.9 m/s to 14.9 m/s in 1999 and from 3.2 m/s to 10.6 m/s in 2000, indicating that the winds may be strong in the region studied. A detailed analysis of the local weather during the field campaign in 1999, based on GOES 8 images, sky imagery, radiosonde dataset, and electrical discharge data, showed that the period was generally characterized by stable atmospheric conditions (Sep. 14, 16 to 19 mornings, and 22 to 23), except for two cold front disruptions (Sep. 15 and 19 to 20). The sky imagery showed fires surrounding the studied region, which was corroborated by the Brazilian satellite-based system for detection, monitoring and prediction of forest fires. The number of fire focus in Mato Grosso do Sul varied from approximately 4000 in Sep. 1999 to nearly 500 in Sep. 2000 [12].

Finally, the results presented constitute the first incomplete data set of radiation balance for Southern Pantanal, Brazil, in a region covered by a water layer during the wet season and a very important ecosystem, although measurements for the wet season still need to be analyzed. Finally, they also indicates that further studies, including the annual variation of the components of the radiation balance, should be made, to be compared with measurements of radiation collected in the scope of AERONET for Northern Pantanal (Cuiabá-Miranda) and specially to validate the predictions of climate and weather forecasting models, with subsequently improvement of their performance.

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