DOI: https://doi.org/10.17921/1415-6938.2024v28n5p630-639

Flooded Pantanal Forests Absorb CO_2, While Grass-Dominated Savannas are Sources for the Atmosphere in South-Central Brazil

Florestas Inundadas do Pantanal Absorvem CO_2, Enquanto as Savanas Dominadas por Gramíneas são Fontes para a Atmosfera no Centro-Sul do Brasil

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Abstract

The Cerrado and the Pantanal are important ecosystems in the central region of Brazil. Cerrado vegetation has varying physiognomies that differ in height, cover and tree density, ranging from thick forests to pastures without woody vegetation. The Pantanal landscape consists of a mosaic of floodplain grasslands, open forests and temporary or permanent aquatic habitats. The present work aims to evaluate the energy balance and carbon (C) flows in an area of Cerrado (Campo Sujo) in the Baixada Cuiabana and forest areas in the Pantanal. Carbon flows in both areas were measured from micrometeorological towers equipped with eddy covariance sensors to measure energy and CO_2 flows. The annual net flow of carbon (NEE) depended on the availability of water in both areas, where, depending on the climate regime, the ecosystem behaved as a net emitter of C to the atmosphere or a sink for atmospheric CO_2. The Campo Sujo Cerrado became an emitter of NEE to the atmosphere (314 g C m^{-2}) during the study years, especially under dry soil conditions, while in the Pantanal, NEE emissions increased during the dry season and absorption increased during the rainy season. The mean annual NEE in the Pantanal biome was -262 g C m^{-2}, which proved to be a strong NEE sink. Therefore, it should be noted that the change in vegetation cover, mainly in the Pantanal, can have a significant impact on the NEE balance.
Keywords: Cerrado. Pantanal. NEE. Carbon Flow. Eddy Covariance.

Resumo

Na região central do Brasil, encontram-se dois dos mais importantes ecossistemas brasileiros: o Cerrado e o Pantanal. A vegetação do Cerrado tem uma fisionomia específica, variando em altura, cobertura e densidade de árvores, desde matas cerradas até pastagens sem vegetação lenhosa. A paisagem do Pantanal consiste em um mosaico de pastagens inundáveis, florestas abertas e habitats aquáticos temporários ou permanentes. O presente trabalho tem como objetivo avaliar o balanço de energia e os fluxos de carbono em uma área do Cerrado de Campo Sujo na baixada cuiabana e áreas de floresta no Pantanal. Nas áreas de estudo, foram instaladas torres micrometeorológicas equipadas com sensores para medir os fluxos de energia e CO_2. Em ambos os biomas, o fluxo líquido anual de carbono (NEE) depende da disponibilidade de água no sistema, onde, dependendo do regime de precipitação, o ecossistema pode se comportar como emissor ou sumidouro de NEE. O bioma Cerrado de Campo Sujo tornou-se um potencial emissor de NEE para a atmosfera (314 g C m^{-2} ano^{-1}) durante os anos de estudo, especialmente sob condições de solo seco. No bioma Pantanal, as emissões de NEE aumentaram durante a estação seca e a absorção cresceu durante a estação chuvosa. O NEE médio anual no bioma Pantanal foi de -262 g C m^{-2}, o que provou ser um forte sumidouro de NEE. Diante disso, observa-se que a mudança na cobertura vegetal, principalmente no Pantanal, pode ter um impacto significativo no balanço do NEE.
Palavras-chave: *Cerrado. Pantanal. NEE. Fluxo de Carbono. Eddy-Covariance.*

1 Introdução

Assessing the sources and sinks of greenhouse gases (GHG), both of anthropogenic and natural origin, is fundamental to estimating regional GHG budgets and understanding their trends in response to climate change. These analyses play a crucial role on guiding policy decisions aimed at reducing emissions, with the aim of meeting global warming limits established by the Paris Agreement. (Jones *et al*., 2023).

In the central region of Brazil, Cerrado and Pantanal make up two of the most extensive ecosystems in South America. Both ecosystems are formed by vegetation mosaics where grassland, woody and forest formations are interspersed (Eiten, 1972), however the biggest difference between the Cerrado and the Pantanal is mainly due to soil moisture (Tomas *et al*., 2019). The Cerrado and Pantanal experience seasonal variations in soil water availability, however, this variation is even greater in the Pantanal due to seasonal floods caused by river overflows (Girard *et al*., 2010). These important characteristics influence the carbon stocks and net primary production of these ecosystems (Vourlitis *et al*., 2022).

Brazil is home to one of the largest extensions of tropical forest in the world (Saatchi *et al*., 2011) and also one of the countries that records the most loss of forest cover (Gibbs *et al*., 2010, Keenan *et al*., 2015). GHG emissions, especially CO_2, are directly linked to the loss of carbon resulting from deforestation (Galford *et al*., 2010). It is estimated that in 2022 alone, the land use and cover change sector contributed with 49% of total CO_2 emissions in the country, with the state of Mato Grosso responsible for the majority (73%) of these emissions (Seeg, 2023).

Cerrado has faced an increase in the expansion of soybean and corn crops over the last five decades, with a 108% growth in soybean production between 2000 and 2014 (Carneiro Filho; Costa, 2016). Currently, it is estimated that 50% of the Cerrado's native vegetation has been deforested (Spera *et al*., 2016), and this percentage will likely increase, as only 7% of the Cerrado has legal protection. In the case of the Pantanal, approximately 13% of native vegetation has already been lost due to agricultural and livestock expansion, with projections indicating an increase to 17% by 2050 (Thielen *et al*., 2020).

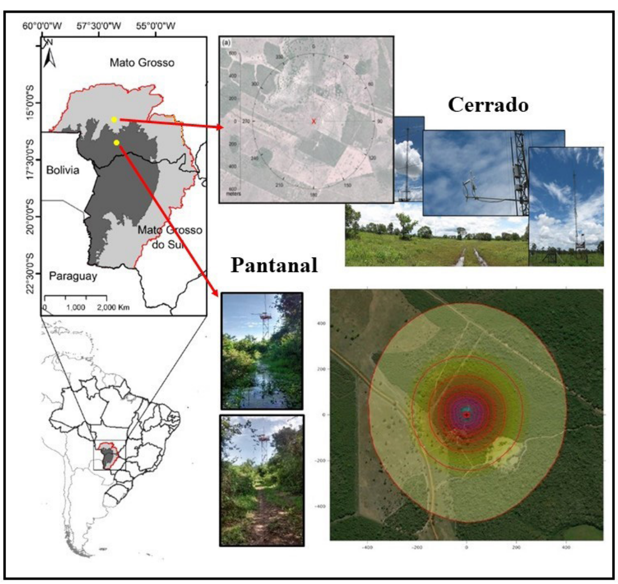
Given the above, the objective of this work was to compare and improve our understanding of how climate seasonality impacts the energy balance and carbon flows of two ecosystems in Mato Grosso.

2 Materials and Methods

2.1 Characterization of study areas

The research was carried out in two distinct areas, one characterized as Cerrado and the other as Pantanal. In both locations, there was a micrometeorology tower equipped to measure energy balance and CO_2 flows (Figure 1).

Figure 1 - Location of the study towers, the left side shows South America with the Cerrado (light gray) and Pantanal (dark gray) ecosystems and the right the location of the eddy covariance towers, as well as the area of footprint with the contour lines from 10% to 90% in 10% intervals



Source: Cerrado: Arruda (2014) e Pantanal: Dalmagro *et al*. (2019).

2.1.1 Cerrado

The 20-meter high micrometeorological tower is located at Fazenda Miranda, municipality of Cuiabá - MT (16°33'19"S, 56°17'11"W, with an average altitude of 157 m). The vegetation here is a mixture of C4 grasses, shrubs and trees, known locally as 'campo sujo', very common in the Cerrado (Arruda *et al*., 2016). Data were collected from 2011 to 2014.

The area's climate is classified as AW, also known as semi-humid tropical climate, with two well-defined seasons, one dry (autumn-winter) and the other wet (spring - summer). The average annual temperature and precipitation are approximately 24-26 ºC and 1335 mm, respectively (Biudes *et al*., 2012).

The soil is a dystrophic red-yellow latosol known locally as Concrecionário Distrófico Soil (Radambrasil, 1982), it is shallow (approximately 50–100 cm deep), consists of 60% rocks (by weight), 19 g kg^{-1} of soil organic matter and 700 g kg^{-1} of sand and are acidic (pH 4.95) and poor in nutrients (Vourlitis *et al*., 2013).

2.1.2 Pantanal

The 10 meter high micrometeorological tower is located in the Private Natural Heritage Reserve (RPPN) managed by the Brazilian Social Service of Commerce (SESC) Pantanal, located in the municipality of Poconé – MT (16°29'53"S 56°24' 46" W), 160 km from Cuiabá. Data were collected from 2015 to 2017. The local vegetation is typical of successional forests with an average height of 6 meters, dominated by *Combretum lanceolatum*, a species that is quite common on riverbanks and humid forests (Prado, 2015). Floods at the research site typically occur between December and June, with a depth of approximately 1 m. Floods occur due to local rains and flooding of the Cuiabá River 2 km from the study site (Girard *et al*., 2010).

The climate is type Aw according to Köppen's categorization, with two well-defined seasons, a dry season from April to October and a rainy season from November to March (Dalmagro *et al*., 2018). The highest temperature measured is 24.9 °C in the period and the average annual precipitation is 1486 mm (Vourlitis; Da Rocha, 2011).

The region's soil is classified as Gleissolo Districo (Couto *et al*., 2002) with an average concentration of 429 g kg^{-1} of sand, 254 g kg^{-1} of silt and 317 g kg^{-1} of clay, average soil organic matter (0–0.10 m depth) of 17 g kg^{-1}, and soil pH of 4.7 (Vourlitis *et al*., 2015).

2.2 Instrumentation and micrometeorological measurements

Both micrometeorological towers were equipped with sensors to measure energy and CO_2 flows. In both Cerrado and Pantanal, an open path infrared gas analyzer was used to measure fluctuations in CO_2 and H_2O vapor. Descriptions of all equipment used in the research are described in Table 1.

Table 1 - Description of the equipment used to measure micrometerorological variables and to calculate CO_2 fluxes in the respective study ecosystems (Cerrado and Pantanal).

Parameter	Name/ model	Manufacturer	Installed height (m)
Pantanal			
CO_2/H_2O concentration	LI-7500A	LI-COR Biosciences Lincoln, NB, USA	20
Wind speed	81000	R.M. Young Company Traverse City, MI, USA	20
Radiation balance	NR-LITE-L25	Kipp & Zonen, Delft, The Netherlands	20
*Precipitation	WXT520	Vaisala Inc. Helsinki, Finland	2
Temperature and relative humidity	HMP45AC	Vaisala Inc., Woburn, MA, USA	20
Volumetric water content, soil temperature	GS3	Decagon Devices Inc. Pullman, WA, USA	0,2
Cerrado			
CO_2/H_2O concentration	LI-7500A	LI-COR Biosciences Lincoln, NB, USA	10
Wind speed	CSAT-3	Campbell Scientific, Inc., Logan, UT, USA	10
Radiation balance	NR-LITE-L25	Kipp & Zonen, Delft, Netherlands	5
Precipitation	TR-525 M	Texas Electronics, Inc., Dallas, TX, USA	5
Temperature and relative humidity	HMP45AC	Vaisala Inc., Woburn, MA, USA	10
Soil heat flux	HFP01-L20	Hukseflux Thermal Sensors BV, Delft, Netherlands	0,01
Soil water content and soil temperature	CS616-L50	Campbell Scientific, Inc., Logan, UT, USA	0,2

*Installed in an open area so that precipitation would not be intercepted by the tree canopy

Source: Authors' private collection (2024).

2.2.1 "Eddy covariance" (EC) data processing

The sensors used to measure the CO_2 and energy flows were composed of a 3D sonic anemometer, used to measure orthogonal three-dimensional components of velocity (ux, uy, uz) and to determine high-frequency sound temperature fluctuations, as well as open path infrared gas analyzers for measuring CO_2 and H_2O vapor fluctuations (LI-7500A, LI-COR Biosciences, Lincoln, NE). The measurement equipment operated at a frequency of 10 Hz and the sensors were physically oriented in the direction of the prevailing wind, positioned 10 cm from the center of the sonic anemometer to minimize the potential for flow distortion.

In both towers the EC data were filtered to remove low quality data (QC > 1). This was done using quality flags provided by EddyPro (LI-COR Biosciences, Lincoln, Nebraska, USA), which provides a flag that ranges from 0 (best) to 2 (worst) after testing for turbulent and steady-state conditions (Foken et al., 2004). We also removed observations recorded during precipitation events and when they were physiologically irrational. Furthermore, we filtered out periods with insufficient turbulence (u*) (low < 0.11 m s^{-1} for Pantanal and < 0.23 m s^{-1} for Cerrado) using the online tool of the Max Planck Institute for Biogeochemistry (see below). After filtering, gaps in the datasets were filled using marginal distribution sampling, which considers the covariation of flows with meteorological variables, and fills the gap with the average value observed under similar meteorological conditions within a given time window (Reichstein et al., 2005).

After filtering and gap filling, half-hour net ecosystem exchange (NEE) values at each location were partitioned into gross primary productivity (GPP) and ecosystem respiration (Reco) using the 'REddyProc' package (Wutzler *et al*., 2018) and night partitioning (Reichstein *et al*., 2005).

2.2.2 Auxiliary data

To identify and compare key biophysical predictors of C flows between sites, we used site-specific meteorological measurements of air temperature (Tar), vapor pressure deficit (VPD), precipitation (PPT), and volumetric water content (SVWC) measured at depth 5-10 cm. All data were collected together with EC data and stored using a data logger (CR1000, Campbell Scientific, Inc., Logan, UT, USA) from measurements taken every 30s. Mean and total values (in case of PPT) were calculated and stored every 30 min.

2.3 Statistical analysis

Simple linear regressions of the energy balance variables were carried out to compare the two study sites, in this case, nighttime data and data with low friction values (u*) were excluded. NEE, GPP, Reco data were normalized using the Min-Max method, with a view to comparing different year horizons between ecosystems. To compare differences in NEE, GPP, Reco and micrometeorological data, between ecosystems and seasons, the bootstrap technique was used, which calculated a 95% confidence interval (CI) by constructing 1000 sets of sample data starting with sampling random (with replacement) of the observed daily series.

Statistically significant differences in mean values were determined by the degree of overlap in ±95% bootstrap CI (Efron; Tibshirani, 1994).

3 Results and Discussion

3.1 Micrometereological variables

The climate of the study areas is strongly influenced by seasonal changes in precipitation (PPT, mm), which affect soil moisture and interfere with energy balance and carbon flows. The average annual accumulated precipitation (PPT) in the Cerrado during the three years of the study was 1,059 mm year^{-1} while in the Pantanal it was 1,288 mm year^{-1}, which corresponds to 18% more than the total volume of precipitated water in relation to the Cerrado (Table 2, Figure 1a).

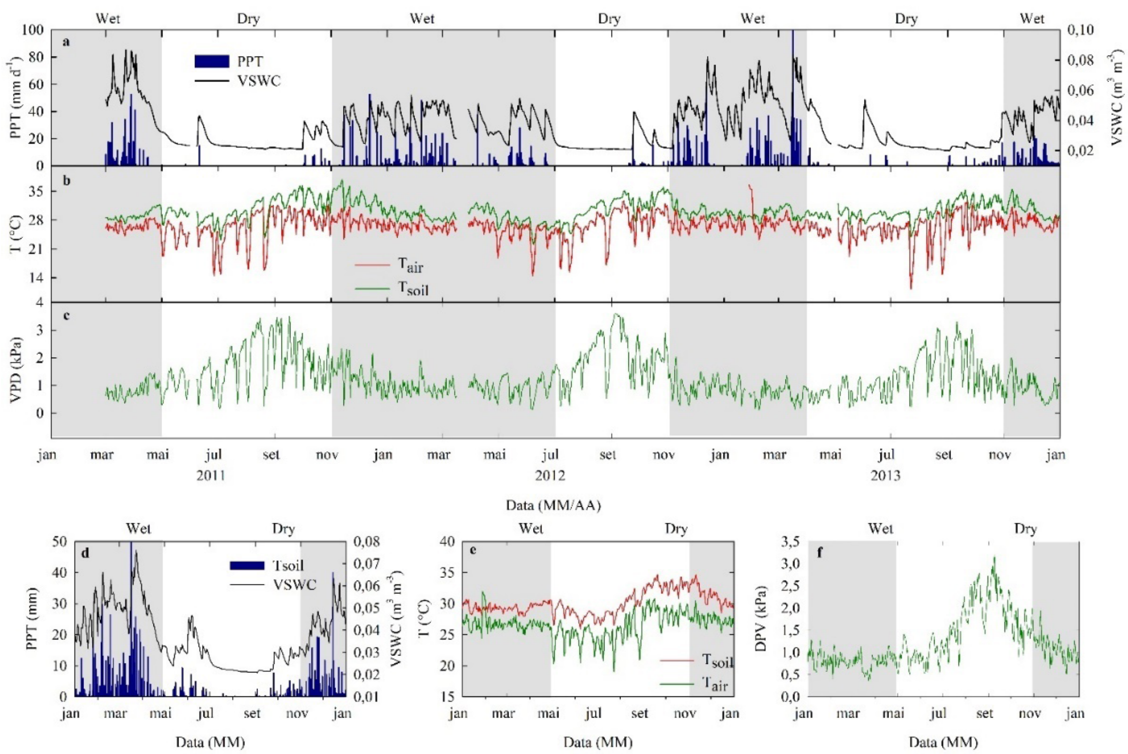
Table 2 - Mean (±95% Confidence Interval (CI)) Wet and Dry Season the annual integrated mean of the Vapor Pressure Deficit (VPD), volumetric soil water content (VSWC), Soil Temperature (T_{soil}), Air Temperature (T_{air}), Precipitation (PPT) for the Cerrado and Pantanal Ecosystems

Variables	Cerrado			Pantanal		
	Wet	Dry	Annual	Wet	Dry	Annual
VPD (kPa)	0.93±0.04	1.61±0.07	1.23±0.06	0.70±0.02	1.13±0.07	0.43±0.008
VSWC (m^3 m^{-3})	0.05±0.001	0.03±0.001	0.04±0.001	0.50±0.001	0.35±0.006	0.43±0.008
Tsoil (°C)	29.83±0.19	30.55+0.22	30.09±0.19	25.90±0.14	25.70+0.23	25.71±0.19
Tair (°C)	26.75±0.17	26.29±0.32	26.50±0.21	25.52±0.19	24.61±0.32	25.01±0.25
PPT (mm yr^{-1})			1059			1288

Source: the authors.

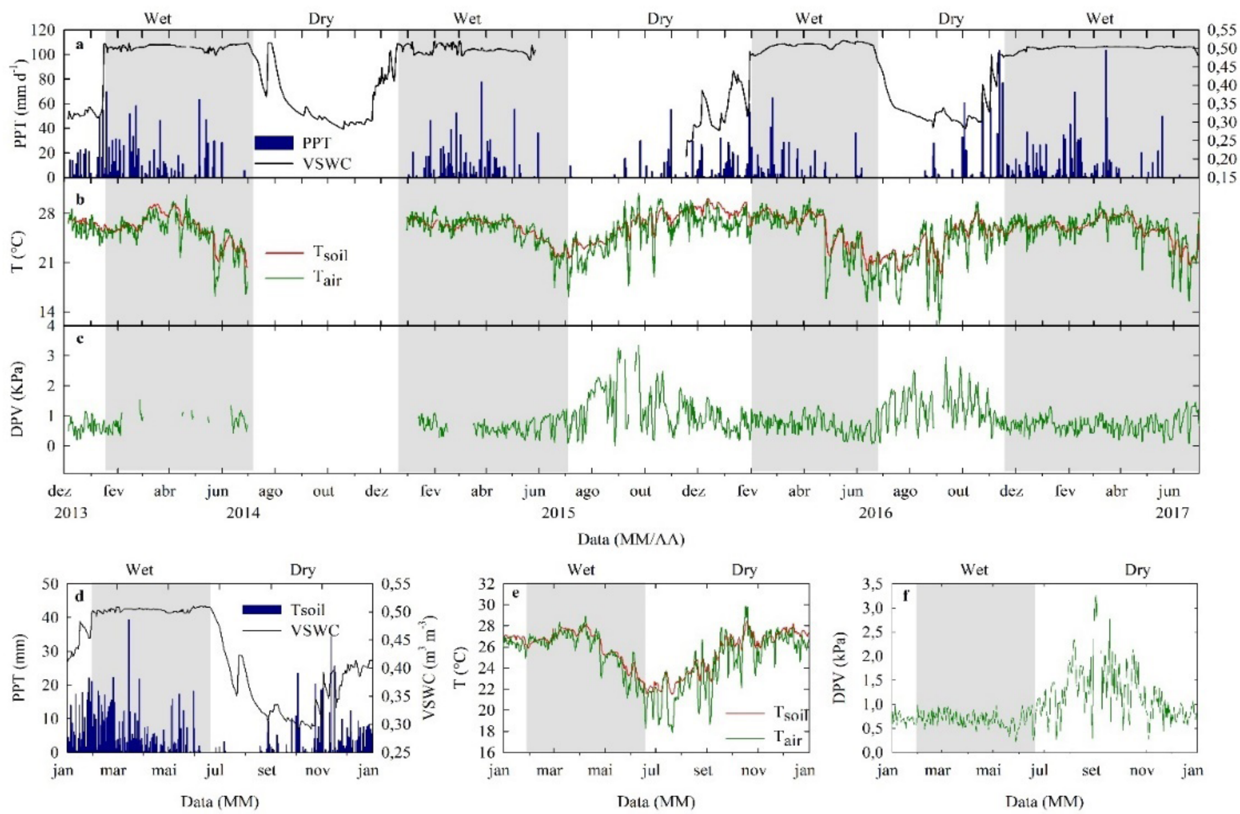
The volumetric soil water content (VSWC, m^3 m^{-3}) varied according to the rainfall regime. VSWC was significantly higher during the rainy season at both study sites. The average VSWC values in the Cerrado were 0.04± 0.001 m^3 m^{-3}, while in the Pantanal it was 0.43±0.008 m^3 m^{-3} (Table 2, Figure 2 and Figure 3). The reduction of VSWC in the Cerrado was rapid as precipitation decreased (Figure 3a). VSWC values for the Cerrado are substantially lower than those reported for the Pantanal and other Cerrado ecosystems (Giambelluca *et al*., 2009) due to differences in the regional soil type of the Cuiabá Basin. The soils of the Cuiabá Basin are dominated by shallow, rocky and coarse-grained soils that have high infiltration rates but low water retention capacity in the soil (Radambrasil, 1982), while the Pantanal soils have a higher percentage of clay (Vourlitis *et al*., 2013), and due to its flat topography, the soil experiences periods of monomodal and small-amplitude floods, which favors greater VSWC retention (Machado *et al.,* 2016).

Figure 2 - (a) Accumulated precipitation and daily average volumetric soil water content, (b) air and soil temperature and (c) vapor pressure deficit for the Cerrado ecosystem. Figures d-f are annual averages. Vertical gray shading indicates wet periods



Source: the authors.

Figure 3 - (a) Accumulated precipitation and daily average volumetric soil water content, (b) air and soil temperature and (c) vapor pressure deficit for the Pantanal ecosystem. Figures d-f are annual averages. Vertical gray shading indicates wet periods



Source: the authors.

Average annual air temperatures (T_{air}, °C) were significantly lower in the Pantanal (25.01 ± 0.25 °C) than in the Cerrado (26.50 ± 0.21 °C), being 6% higher in the Cerrado (Table 2), however, both study sites had lower T_{air} during the dry season and with higher temperatures during the rainy season. According to Machado *et al*. (2004) seasonality in T_{air} may be related to cold fronts that occur in southern South America during the austral winter. All these elements associated result in high atmospheric demand during the dry season.

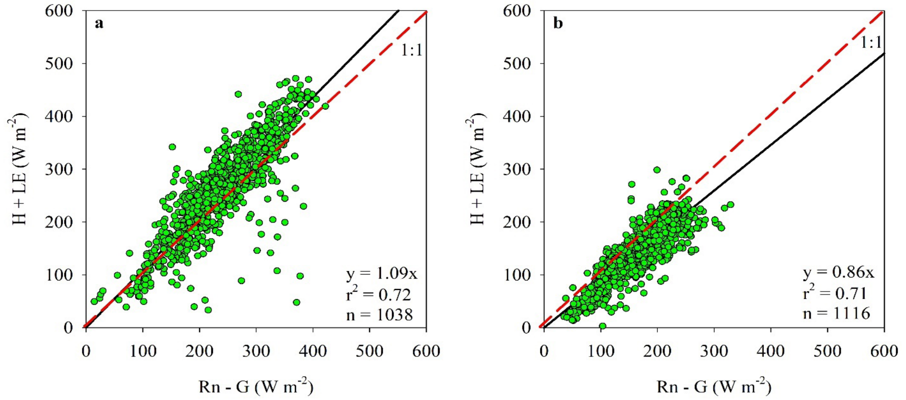
Air (T_{air}, °C) and soil (T_{soil}, °C) temperatures showed small fluctuations throughout the study period, but were significantly lower in the Pantanal compared to the Cerrado (Table 2, Figure 2b, Figure 3b). Despite being common in the region, the entry of cold fronts originating in southern Brazil (Grace *et al*., 1996), which cause fluctuations of up to 10 °C from week to week (Rodrigues *et al*., 2014), did not cause significant differences in T_{air} between dry and rainy periods in both study sites. However, differences as large as 3.6 °C were observed between T_{air} and T_{soil} in the Cerrado, due to vegetation cover and soil type (Table 2).

In both the Cerrado and Pantanal, the vapor pressure deficit (VPD, KPa) gradually increased during the dry season, mainly due to the lack of precipitation events (Figure 2c, Figure 3c). During the rainy season, VPD in the Cerrado was 33% higher than in the rainy season in the Pantanal (Table 2). Considering the entire study period, in the Pantanal, the annual VPD was significantly lower than in the Cerrado, that is, the scarcity of water in the soil and in the atmosphere caused the Cerrado to demand more moisture from the atmosphere, making the environment drier and with greater evapotranspiration (Rodrigues, *et al*., 2016).

3.2 Closing energy balance (FBL)

The closure of the energy balance (FBL) occurs through the sum of the sensible and latent heat flows (H + LE) measured from the EC sensors as the dependent variable and the difference between the net radiation and the soil heat flow (Rn - G) measured from the meteorological sensors as an independent variable (Foken *et al*., 2008). Considering the entire study period in both locations, the FBL was very close with a coefficient of determination (R^2) above 70%. The FBL demonstrates a straight line slope of 1.09 in the Cerrado area (Figure 4a) and an R^2 = 0.72 (n = 1038), however in the Pantanal region (Figure 4b) the straight line slope was 0.86 with a R^2 = 0.71 (n = 1116). The straight slope found was consistent with, and in some cases higher than, values found in several studies carried out in the Amazon Forest that used the EC method, for example 0.84 (Araújo *et al*., 2002), 0.86 (Da Rocha *et al*., 2004) and 0.76 (Stoy *et al*., 2013).

Figure 4 - Closing the energy balance in the Cerrado – Campo Sujo between the years 2011 to 2013 (a) and in the Pantanal – Floresta between the years 2013 to 2017 (b). Each point represents a daily average of the sensible and latent heat flow (H + Le) measured by the eddy covariance sensors (y-axis) and the difference in net radiation and soil heat flow (R_n - G) measured from the sensors micrometeorology (x-axis). The results of linear regression, slope, y-intercept = 0, coefficient of determination (R^2) and sample size are also shown. The dashed line represents a 1:1 ratio between H + Le and R_n - G



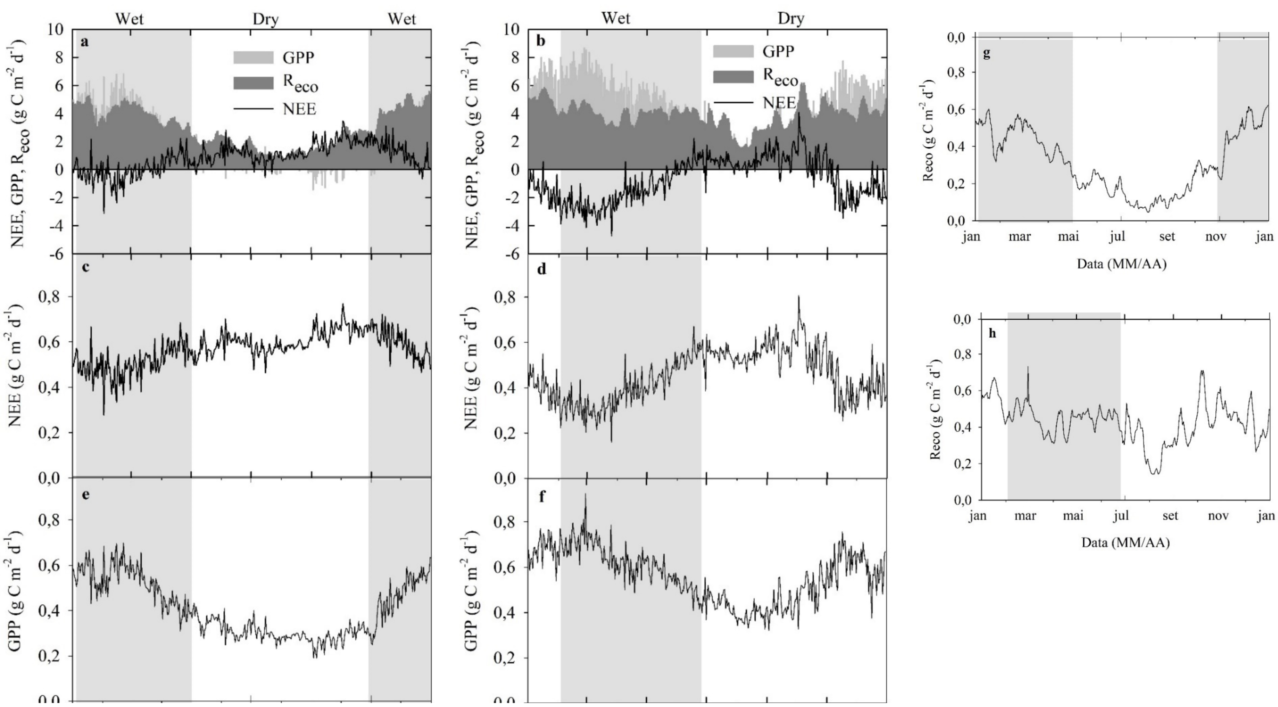
Source: the authors.

Finding a good closure for the energy balance provides confidence in the data and suggests that all systems are operating satisfactorily. This allows evaluating the quality of the energy flow data obtained by the turbulent vortex covariance method, since the measurements of net radiation, soil heat flow, latent and sensible heat flows are carried out using different methods.

3.3 NEE, GPP, and R_{eco}

NEE tends to have lower values during the rainy seasons, representing a greater assimilation of atmospheric carbon by the ecosystem during these periods. However, net CO_2 emission rates tend to be higher during the transition from the dry to the wet season (October – November), when the onset of rain events stimulates ecosystem respiration rates (R_{eco}) relatively faster than gross primary productivity (GPP) (Figure 5 a and b). Similar results were evidenced in studies carried out in humid and semi-deciduous tropical forests (Goulden *et al*., 2004; Vourlitis *et al*., 2005; 2011), and this phenomenon is due to the rapid decomposition of litter, accumulated on the surface during the dry season, when rain events continue. This phenomenon, associated with soil microbial activity, causes the efflux of CO_2 from the soil to increase, and consequently contributes positively to NEE (Pinto-Júnior *et al*., 2009).

Figure 5 - Daily average of CO_2 Net Primary Productivity (NEE), Gross Primary Production (GPP) and Ecosystem Respiration (Reco) for the Cerrado from 2011 to 2013 (a) and Pantanal from 2013 to 2017 (b)



Source: the authors.

The average daily NEE rates in the Cerrado in both periods (dry and rainy) were always positive, showing that the ecosystem behaves as a net source of CO_2 to the atmosphere (Table 3), which is typical for many Cerrado ecosystems (Miranda *et al*., 1997; Da Rocha *et al*., 2002; Santos *et al*., 2003; Vourlitis; Da Rocha, 2011). In the Pantanal, NEE during the rainy season acted as a strong CO_2 sink (-1.68±0.13 g C m^{-2} d^{-1}), which resulted in average annual values of -0.72 g C m^{-2} d^{-1}. The greater absorption of CO_2 in the Pantanal was clearly due to a higher GPP, as the proportion of R_{eco} between ecosystems is not that different (Table 3). The drought that occurs in both ecosystems limited gas exchange rates in trees (Dalmagro *et al*., 2013) and grasses (Santos *et al*., 2004), and was responsible for the decline in the GPP rate. Furthermore, the low VSWC values found in the Cerrado further contributed to the reduction in GPP. In general, the integrated average of NEE in the Cerrado was 314 g C yr^{-1} and the Pantanal -262 g C yr^{-1}, that is, the Cerrado is an emitter while the Pantanal is an absorber of C (Table 3, Figure 5a and 6a).

Table 3 - Mean, normalized mean (±95% confidence interval) and annual integrated mean of CO_2 Net Primary Productivity (NEE), Gross Primary Production (GPP) and Ecosystem Respiration (R_{eco}) for the Cerrado Ecosystem and Pantanal

Variable	Cerrado			Pantanal		
	Wet	Dry	Annual	Wet	Dry	Annual
NEE (g C m^{-2} d^{-1})	0.56±0.12	1.31±0.09	0.86±0.10	-1.68±0.13	0.24±0.16	-0.72±0.16
GPP (g C m^{-2} d^{-1})	3.38±0.17	0.51±0.10	2.10±0.20	5.63±0.15	3.88±0.22	4.64±0.19
R_{eco} (g C m^{-2} d^{-1})	3.94±0.10	1.82±0.07	2.96±0.14	3.95±0.10	4.12±0.16	3.93±0.09
NEE_N (g C m^{-2} d^{-1})	0.53±0.006	0.60±0.004	0.57±0.007	0.38±0.008	0.52±0.007	0.45±0.011
GPP_N (g C m^{-2} d^{-1})	0.51±0.006	0.30±0.003	0.40±0.012	0.62±0.007	0.48±0.010	0.56±0.012
R_{eco}_N (g C m^{-2} d^{-1})	0.46±0.007	0.17±0.005	0.31±0.017	0.45±0.005	0.39±0.012	0.43±0.011
NEE (g C m^{-2} yr^{-1})	-	-	314	-	-	-262
GPP (g C m^{-2} yr^{-1})	-	-	765	-	-	1698
R_{eco} (g C m^{-2} yr^{-1})	-	-	1079	-	-	1438

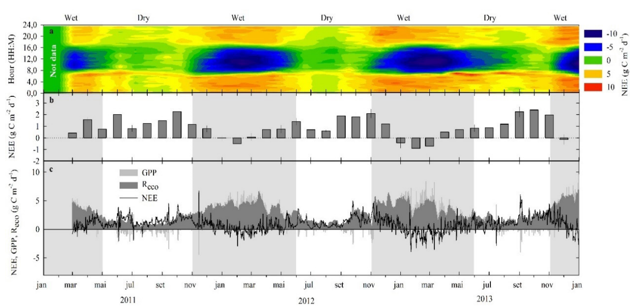
Source: the authors.

Normalized values of NEE, GPP, and R_{eco} are shown in Figure 5 C–H. The NEE_N differed significantly between ecosystems (Table 3), with the Cerrado having an average value of 0.57±0.007, while the Pantanal was 0.45±0.01. GPP_N showed similar behavior for both ecosystems, but the Cerrado experienced a more pronounced decrease during the dry season, while in the Pantanal, higher values were found during the rainy season (Figure 5 E-F). R_{eco}_N showed a significant difference between ecosystems, mainly influenced by the dry season, as no differences were identified between ecosystems during the rainy season (table 3, figure 5 G-H). Normalized values of NEE, GPP and R_{eco} showed that a greater absorption of C occurs in the Pantanal areas.

Higher absorptions of hourly NEE in the Cerrado (blue colors) are observed during the rainy seasons and decline between the rainy and dry transition (Figure 6a). This pattern can be explained by observing soil moisture at the end of the rainy season (April - May). Temporal variations in NEE coincided more with hydrological phases than with the amount of incident solar radiation (Dalmagro *et al*., 2022). Short-term emissions are also noted, in all months of the year, between 8:00 am and 12:00 pm local time, but these events tend to be more frequent and intense during the dry season. According to (Grace *et al*., 1995) this moment corresponds to the time at which the daytime winds begin, and thus, these high exchanges reflect the initiation of turbulent mixing, caused by the convection of the surface heating, of a previously stable atmosphere that accumulated CO_2 in the nocturnal period (Grace *et al*., 1996; Malhi *et al*., 2002).

The increase in frequency and intensity during the dry season probably occurs due to the fact that wind speed and frictional velocity are higher during this season. Thus, net daytime CO_2 assimilation increases abruptly during the dry-rainy season transition in October, coinciding with the beginning of the rainy season and when soil moisture begins to increase. Net CO_2 emission rates (Figure 6b) tend to be higher during the transition from the dry to the rainy season (October – November), when the onset of rain events stimulate ecosystem respiration rates (Reco) (Figure 6c) relatively faster than gross primary productivity (GPP) rates.

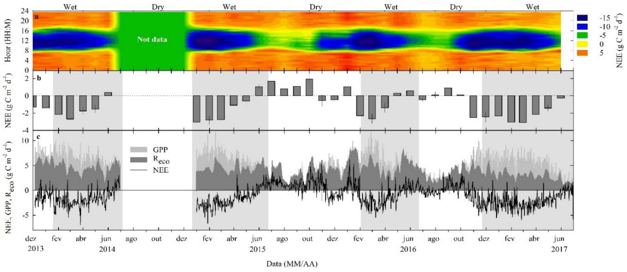
Figure 6 - (a) Hourly CO_2 flow, (b) monthly average CO_2 flow and (c) daily flow of Gross Primary Productivity (PPB), Net Primary Productivity (PPL) and Ecosystem Respiration (Reco) in an area of Cerrado during the years 2011 to 2013. Vertical gray shading indicates wet periods



source: the authors.

Hourly NEE variations (Figure 7a) in the Pantanal region were similar to those in the Cerrado, but there was greater NEE absorption in flooded soil conditions and in transition periods (flooded-dry, dry-flooded).

Figure 7 - (a) Hourly CO_2 flow, (b) monthly average CO_2 flow and (c) daily flow of Gross Primary Productivity (PPB), Net Primary Productivity (PPL) and Ecosystem Respiration (Reco) in an area of Pantanal during the years 2013 to 2017. Vertical gray shading indicates wet periods.



Source: the authors.

Positive pulses of CO_2 in response to rain events are common in different ecosystems, with variations in their magnitude and seasonality of flooding, in a peculiar way the vegetation characteristic of Pantanal plants present a high physiological performance, employing different strategies over a wide range of O_2 concentrations in the soil (Dalmagro *et al*., 2016).

4 Conclusion

In both ecosystems, it was evident that NEE is conditioned by soil water availability. The Campo Sujo Cerrado ecosystem was a consistent emitter of NEE into the atmosphere (314 g C m^{-2} $year^{-1}$), with positive values of NEE (emissions), mainly due to conditions of dry soil. Conversely, the Pantanal ecosystem shows increased absorption during the rainy season (wet soil) causing annual NEE averages to be -262 g C m^{-2}, showing that the Pantanal behaved as a NEE sink during the years of study. Therefore, these results confirm the hypothesis that seasonal climatic conditions act to regulate and alter the dynamics of NEE exchanges between the ecosystem and the atmosphere. Given this, it can be argued that differences in land cover, especially in the Pantanal, can have a major impact on the NEE balance, and the differences between biomes were confirmed in the normalized data.

Acknowledgements

The Coordination for the Improvement of Higher Education Personnel (CAPES) and the National Foundation for the Development of Private Higher Education (FUNADESP) with funding for master's and scientific initiation scholarships. Federal University of Mato Grosso (UFMT) and the University of Cuiabá (UNIC). group for their support in the field.

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