

Inter Seasonality of the Energy Fluxes in Brazilian Savana—Mato Grosso—Brazil

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Abstract

Dynamics of flows of matter and energy these biomes are relevant to understanding of environmental processes that govern the biosphere-atmosphere interactions and between ecosystems. This study analyzed inter season and season of energy fluxes in Brazilian Savana through Bowen Ration Method. Results show differences in patterns LE in all season, LE predominant in wet while H in dry. This inversion in patterns of predominant components of the energy balance in wet and dry season because in wet season increase water content in soil and atmosphere due precipitation in this season providing more lost energy for atmosphere in shape LE through soil evaporation and plant transpiration, this results in LE and H in all season of the Brazilian Savana show higher variation in dynamics energy fluxes between surface and atmosphere, as well as energy partition in this biome. Statistics analyses presents than many climate variables influences LE and H in each season indicating complexity in this fluxes. More study is necessary to higher understand patterns energies fluxes in Brazilian Savana.

Keywords

Patterns Energies; LE; H; Bowen Ration

1. Introduction

The state of Mato Grosso encompasses three of main biomes of South America—Amazon Rainforest, Cerrado and Pantanal, and the latter two have gained attention from researchers who study the phenomena that promote balance between human activities and nature because the dynamics of flows of matter and energy these biomes

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are relevant to understanding of environmental processes that govern the biosphere-atmosphere interactions and between ecosystems.

The Cerrado is a corridor connecting the Pantanal to Caatinga, occupying the region between the two largest Neotropical rainforest: the Amazon rainforest and the Atlantic forest.

Neotropical savannas, and in particular the Cerrado, contain a mixture of many tree and herbaceous species having different responses to variations in environmental conditions. The climate is extremely seasonal with about five rainless months and a long period with high rainfall. Evaporative demand is substantially higher during the dry season when environmental conditions induce plant water stress in the shallow-rooted herbaceous species and for some relatively shallow-rooted woody species. In contrast, most trees have deep roots capable of tapping abundant and stable soil water resources [1].

Climate and vegetation strongly influence the water cycle on local to regional scales. A change in the surface energy and water balance, especially in dry climatic regions, can have a significant impact on local water availability [2], as well as in energy balance partition in the region.

According to the modelling approaches, ET can be estimated by multiplying crop coefficients by reference ET data from different kinds of models using measured microclimatological and underlying surface information. However, there are some limits in the modelling approaches. In addition, direct measurement methods, such as eddy covariance method and weighing lysimeter have not been widely used because of the high cost and difficulties of operation especially in wetlands [3] [4].

The quantification of LE and H by Bowen ratio method have been widely used in the last decade, for determining the energy balance in many studies about the energy dynamics of forest and management availability of water for certain crops by evapotranspiration estimated by the latent heat flux [5] [6].

The energy balance, based on the physical principle of energy conservation, lists the densities of energy flows available in the vegetation (net radiation) with the energy used, especially in the evaporation latent heat and sensible heat in variations air temperature and soil [7]. Micrometeorological methods quantify these flows and to assess the transformation of radiant energy into latent and sensible heat, thus representing the accounts of these interactions.

Latent and sensible heat are important parameters that directly drive variations in climate and can, in turn, alter the environmental variables driving the mass and energy exchange between the ground and the atmosphere [8]. Thus, latent and sensible heat fluxes are important variables in meteorological, hydrological and ecological analyses. By dividing energy flux components into latent and sensible heat, we can determine the water vapor and heat content of the atmosphere and better understand the regional and global scale climatological processes.

At present, the majority of our knowledge regarding wetland ecosystem energy balance is confined to the temperate, boreal, and arctic zones, with data principally collected only during the growing season. Little is known about energy exchange in wetlands of the subtropics and tropics where seasonality is best characterized by wet and dry seasons. The potential for year-round plant growth at low latitudes is likely to affect wetland energy balance differently during wet and dry periods of the year, as has been observed in some tropical terrestrial ecosystems [7] [9].

Energy, water, and carbon cycles in forest ecosystems are tightly coupled through the evapotranspiration (ET) processes [10]. Although land managers are more interested in water and carbon balances, quantifying forest energy balance offers insights to how management affects the forest microclimate and the feedbacks of land use change to climate change at a regional scale. Uncertainty about the combined consequences of afforestation or deforestation on regional climate and greenhouse gas emissions indicates the need for more research on the physical effects of forest management [11] [12].

Thus the purpose of this study was to evaluate the inter seasonality the latent and sensible heat flux and the relationship with the atmospheric variables in Brazilian Savana.

2. Materials and Methods

2.1. Study Area

The experimental site was located in Santo Antonio de Leverger, MT, Brazil, which is 15 km south of Cuiabá (15°43'S : 56°04'W). The study site is within a grass-dominated cerrado that was degraded approximately 35 years ago after the partial clearing of cerrado woodland vegetation. According to Koppen, the climate of region is characterized as Aw, tropical semihumid, with dry winters and wet summers. Annual rainfall oscillates be-

tween 800 and 1500 mm and annual temperature oscillates between 26.0°C and 27.5°C, respectively, and rainfall is seasonal with a dry season extending from May to September [13]. The research area is on flat terrain at an elevation of 157 m above sea level. The regional soil type is a rocky, dystrophic red-yellow latosol locally known as a Solo Concrecionário Distrófico.

2.2. Micrometeorological Measurements

Termohygrometers and anemometers are installed at three heights, 5 m, 10 m and 18 m height above ground level. The balance radiometer, the piranômetro and photosynthetically active radiation sensor are installed to 5 m high. The plate heat flux is installed in the soil to 1.0 cm deep. Soil moisture is measured only 20 cm deep, due to the characteristic litólica of the soil.

2.3. Calculcs

An alternative for obtaining data latent heat flux in this study was the energy balance equation. According Amiro [14], latente heat flux (LE) obtained like energy balance residue is a viable option when you have good data. Balance energy can be obtained through Equation (1).

$$R_n = LE + H + G \quad (1)$$

$$LE = R_n - H - G \quad (2)$$

Where, R_n is net radiation ($\text{W}\cdot\text{m}^{-2}$), LE latente heat flux ($\text{W}\cdot\text{m}^{-2}$), H sensible heat flux ($\text{W}\cdot\text{m}^{-2}$), G is a flux in soil ($\text{W}\cdot\text{m}^{-2}$).

Sensible heat flux (H) was calculated for Bowen ration method (Equation (3)), and errors of the estimated values were minimized using conditions proposed by Perez *et al.* (1999).

$$H = (R_n - G) \frac{\beta}{(1 + \beta)} \quad (3)$$

$$\beta = \gamma \frac{\Delta T}{\Delta e} \quad (4)$$

where β is Bowen ration, ΔT is temperature difference ($^{\circ}\text{C}$) between two height, Δe is the vapor pressure difference (kPa) and γ is psychrometric constant ($\text{kPa}\cdot^{\circ}\text{C}^{-1}$).

The sky coverage can be expressed in terms of the index of atmospheric transmissivity (Nkemdirim, 1972), determined for day index (K_T) (Equation (5)), calculated through ration between Global radiation (R_g) and irradiation in atmosphere top (R_0).

$$\frac{R_g}{R_0} = K_T \quad (5)$$

According Dallacort *et al.* [15], $0 \leq K_T \leq 0.3$ defined like cloudy, between $0.3 \leq K_T \leq 0.65$ partly cloudy and between $0.65 \leq K_T \leq 1$ clear sky.

2.4. Statistic

In this study was used mean with Mean Absolut Error (MAE) according recommended for Willmott and Matsuura [16]. To analyses seasons was used Bootstrap [17].

3. Results and Discussion

3.1. Microclimate Variables in Wet and Dry Season

In this study, wet and dry season were chosen according accumulated precipitation in the month. So to wet season were chosen months with accumulated precipitation higher to 50 mm and below this values was considered dry season. **Figure 1** presents precipitation between may/2009 and February/2012.

Months of wet season in site were January, February, March, April, October, November and December, while other months characterized dry season.

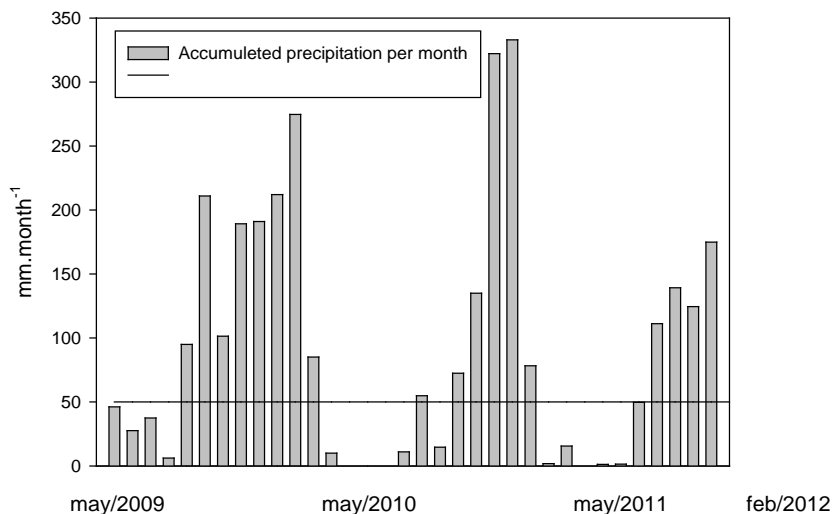


Figure 1. Accumulated precipitation per month between May/2009 and February/2012 in Brazilian Savana.

In wet seasons, average value temperature ($^{\circ}\text{C}$) was 27.75 ± 1.77 between 10/2009 and 04/2010, 28.11 ± 1.71 between 10/2010 and 04/2011 and 28.58 ± 1.50 between 10/2011 and 02/2012. While in dry season this values were 26.40 ± 3.18 in 2009, 27.24 ± 3.99 in 2010 and 27.83 ± 3.80 in 2011. **Figure 2** presents temperature daily average values in wet and dry seasons.

Temperature have been higher variation patters in dry season due air moisture was lower this season while wet season. Thus, water is better conductor than dry air, so due higher air moisture in wet season caused lower variation patter in temperature air values, it indicate than water is a thermic regulator in air temperature. About values temperature was higher in wet season which dry season, its due wet season in site was in spring and summer, two seasons which sun is in south, thus the higher global radiation in site was in this season, and higher global radiation caused higher temperature values. Chen *et al.* [5] studding energy balance in northern hemisphere found also higher temperature values in July (summer in this hemisphere).

Thus, two factors characterized local temperature: first—higher patters variation in dry season and higher values in wet season. Theses factor were determined for two different causes: first—air moisture controls the variation patterns in air temperature and sun localization (due year season) controls global radiation in surface.

Global radiation and net radiation values in wet season were respectively, in $\text{W}\cdot\text{m}^{-2}$, 202.82 ± 45.37 and 177.39 ± 45.37 , 203.83 ± 45.08 and 216.29 ± 69.13 , 216.03 ± 42.40 and 274.30 ± 61.43 between 2009/2010, 2010/2011, 2011/2012. In dry seasons these values were 179.34 ± 40.19 and 209.16 ± 47.32 , 188.15 ± 27.68 and 183.03 ± 41.97 , 195.07 ± 34.21 and 179.79 ± 73.55 in 2009, 2010 and 2011 respectively. **Figure 3** and **Figure 4** present global and net radiation values in wet and dry season between 2009 and 2012.

In general global radiation values were higher in wet season due sun localization (spring and summer in southern Hemisphere) and net radiation patterns are like global radiation due this variable influences directly net radiation.

3.2. Seasonal and Inter-Seasonal Variation in LE and H

According to **Table 1**, higher variation in LE was in wet seasons in 2009/2010 and 2010/2011, while H values were against LE values. Schedlbauer *et al.* [18], in Everglades Florida study found similar patterns in LE and H this local. The author also relate despite environmental extremes, fluxes of H and LE from this short-hydroperiod marsh are relatively predictable and highly related to variation in R_n , provided that the site's hydroperiod mirrors south Florida's climatic seasonality. Other environmental factors influencing H and LE vary seasonally and are at least partly under human control. Higher water content in atmosphere and in soil, and larger global radiation in this season contribute for soil evaporation and plant transpiration causing great latent heat flux in site.

Relationship between LE/R_n and H/R_n were respectively, 0.48 and 0.42, 0.48 and 0.45, 0.42 and 0.41 in wet seasons; 0.20 and 0.59, 0.08 and 0.90, 0.53 and 0.59 in dry seasons. Note when LE values decreases, increases H

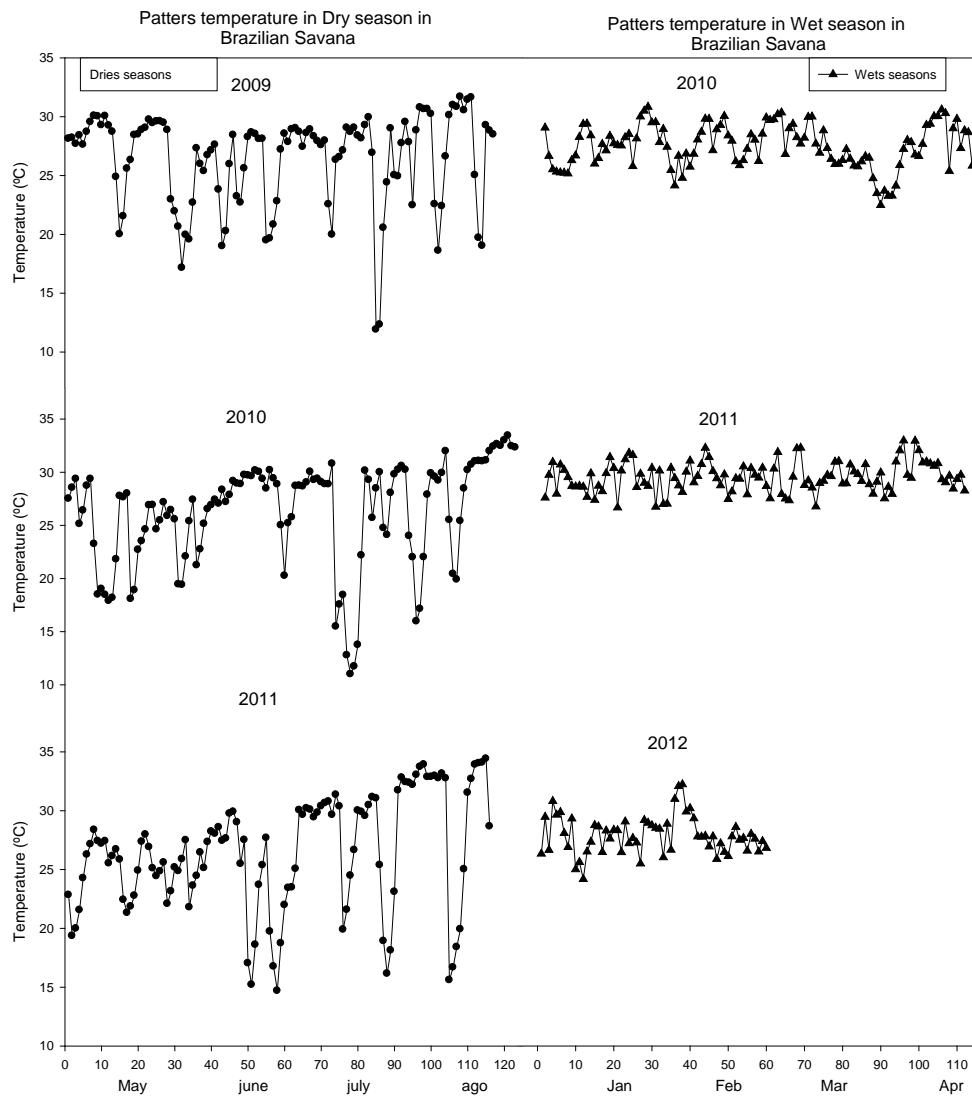


Figure 2. Daily average values of temperature in wet and dry season during 2009 and 2012 in Brazilian Savana.

Table 1. Higher, lower and average values of latent and sensible heat fluxes in wet and dry season between 2009 and 2012 in Brazilian Savanas.

		Wet seasons			Dry seasons		
		2010	2011	2012	2009	2010	2011
LE ($W \cdot m^{-2}$)	Higher	331.55	339.29		126.57	134.97	261.00
	Lower	17.71	0.81		5.79	1.61	0.62
	Average	163.67 ± 54.98	174.28 ± 50.84		56.7 ± 23.54	36.73 ± 22.53	72.10 ± 44.40
H ($W \cdot m^{-2}$)	Higher	235.46	264.08		212.06	255.74	262.38
	Lower	11.79	14.54		22.27	6.37	1.12
	Average	133.22 ± 32.62	144.84 ± 39.37		132.50 ± 33.58	131.18 ± 54.82	61.85 ± 52.32

values and higher values LE were in wet seasons while H were in dry season, similar patterns found in Chen *et al.* [5] in Asia study. GiambelUCA *et al.* [6] in two different Savana study found LE/R_n and H/R_n values respectively 0.52 and 0.28, 0.44 and 0.31 in wet season, 0.42 and 0.37, 0.3 and 0.55 in dry season. Thus, there are different spatial values in energy partition in Savana due vegetation type in local.

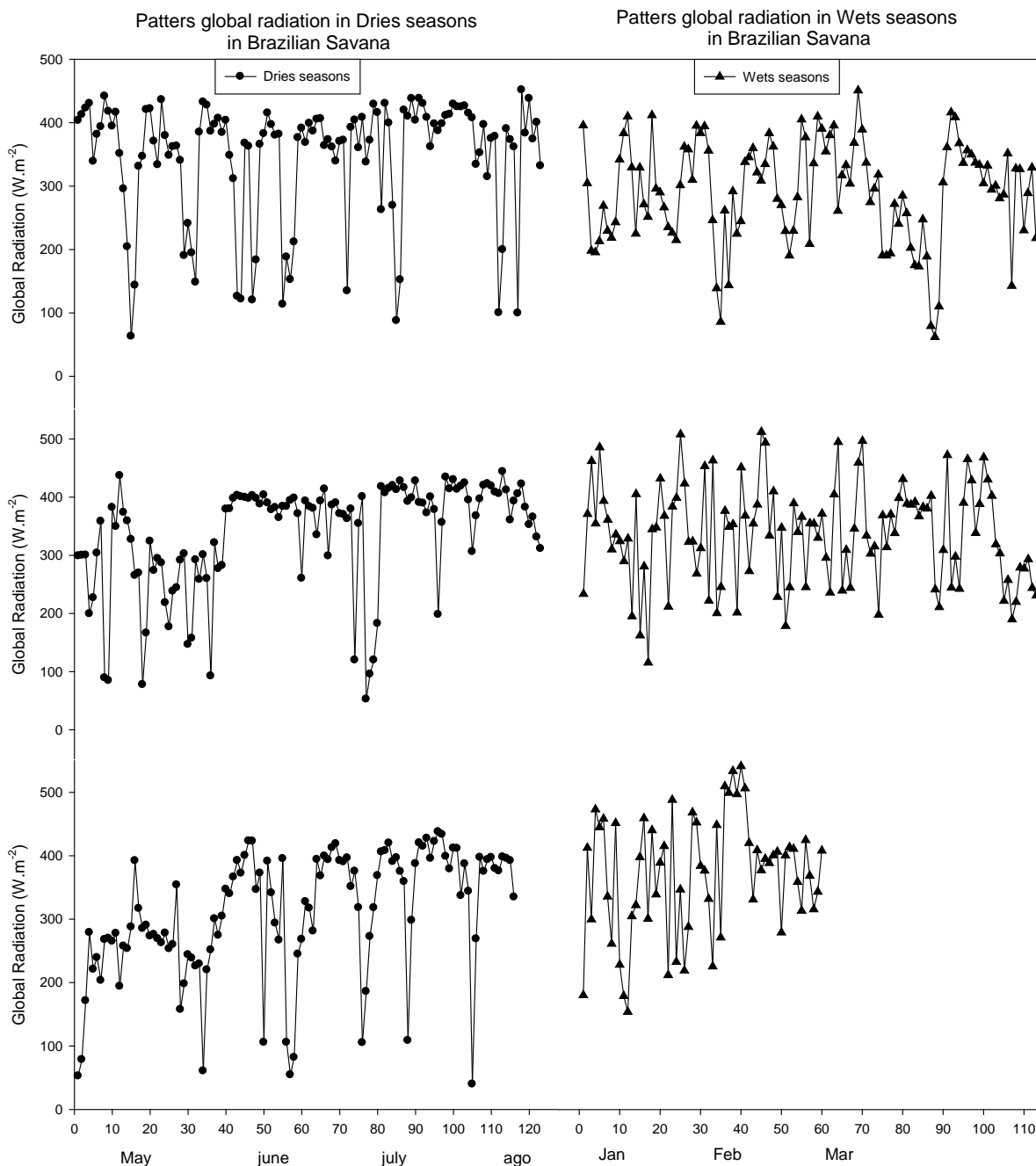


Figure 3. Daily average values of global radiation in wet and dry season during 2009 and 2012 in Brazilian Savana.

In all season sum of LE and H was above 80% of energy balance indicating that great contributes for energy balance closure were because these two variables. Schedlbauer *et al.* [18] in wetlands study found values sum of LE and H above 70%, indicating also this biome the patterns in energy balance closure is similar Brazilian Savana.

LE values is many important to understand energy change fluxes between atmosphere and surface because Throughout much of the tropics, LE fluxes strongly dominate energy losses from terrestrial ecosystems year-round [9] [13]. **Figure 4** and **Figure 5** present LE Bootstrap and LE an H in wet and dry seasons, respectively.

According to **Figure 5**, note LE predominant in wet season, while in dry season H predominates over LE. This is a justification about inversion in patterns of predominant components of the energy balance in wet and dry season

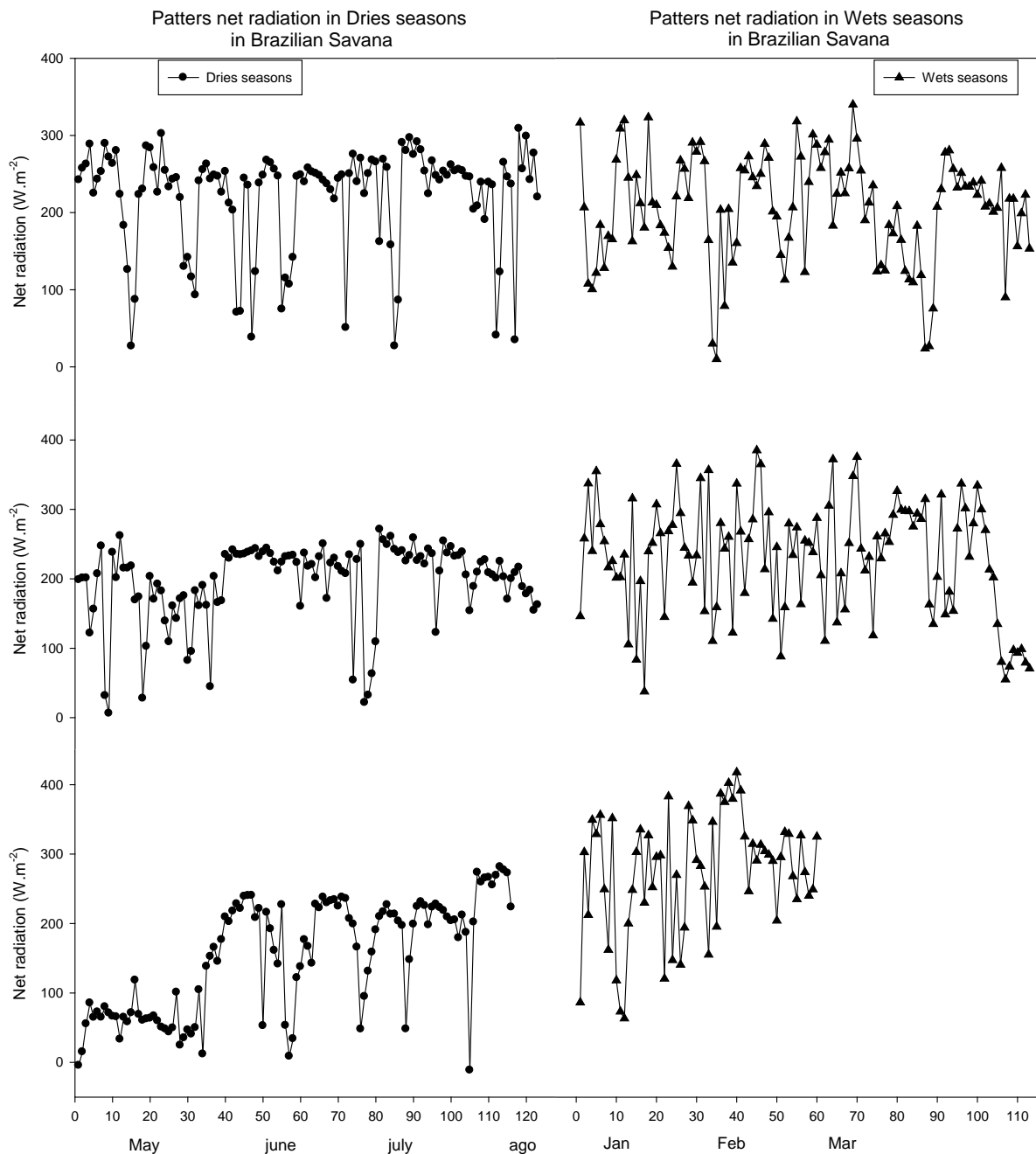


Figure 4. Daily average values of net radiation in wet and dry season during 2009 and 2012 in Brazilian Savana.

because in wet season increase water content in soil and atmosphere due precipitation in this season providing more lost energy for atmosphere in shape LE through soil evaporation and plant transpiration. Sun *et al.* [19] in study in loblolly pine plantations in North Carolina, USA and Lenters *et al.* [2] in study about wetlands in Nebraska, USA found similar patterns in increase H and decrease LE in dry season.

This results in LE and H in all season of the Brazilian Savana show higher variation in dynamics energy fluxes between surface and atmosphere, as well as energy partition in this biome.

According to Bootstrap analyses (Figure 6 and Figure 7) note LE were different in all seasons. These results indicate rainfall was determinant factor in season and inter-season in site, great precipitation in wet season and very lower precipitation in dry season caused different patterns in energy partition with inversion between LE and H

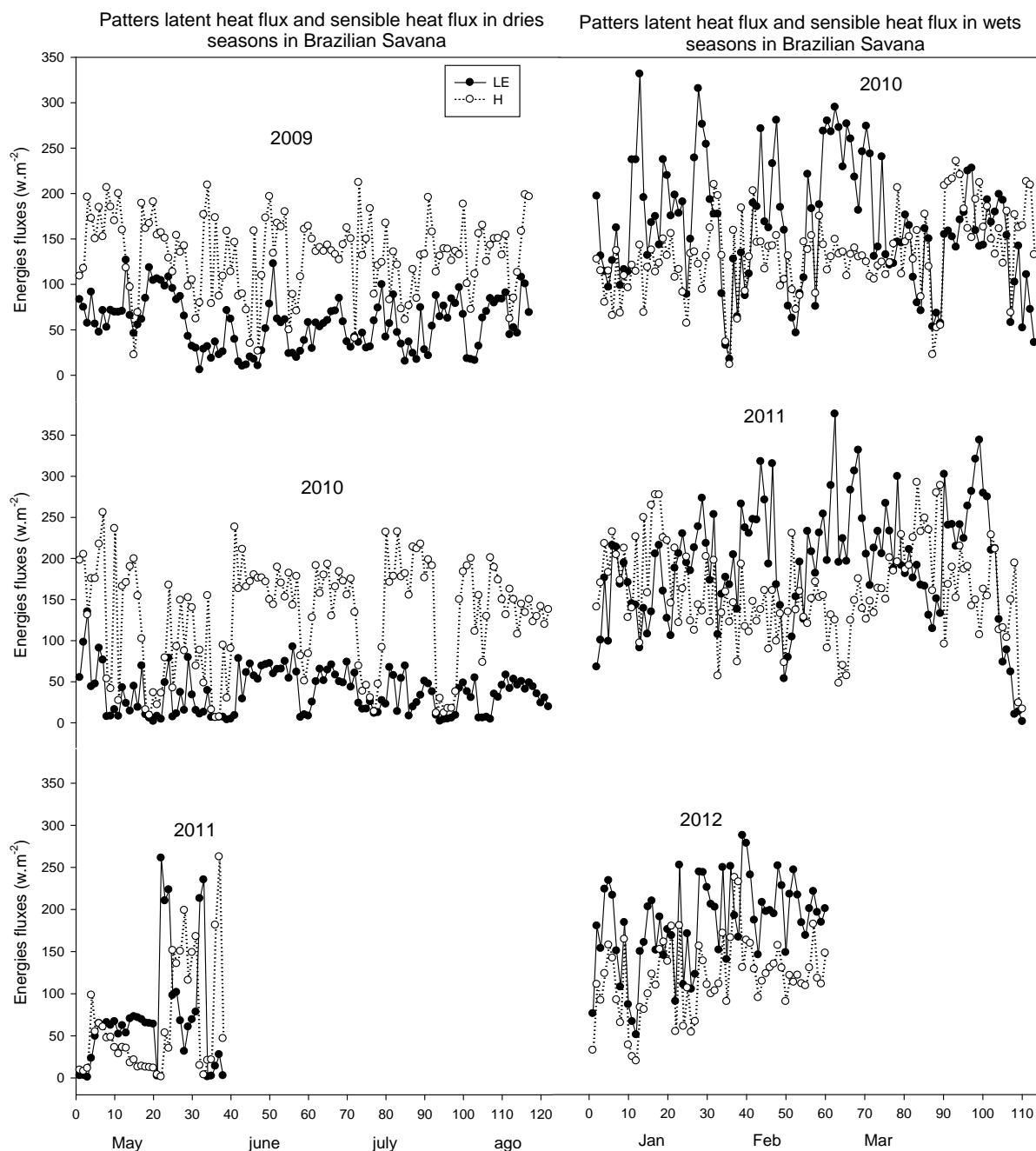


Figure 5. Daily average values of LE and H in wet and dry season during 2009 and 2012 in Brazilian Savana.

in two seasons. Higher water content in soil and atmosphere due precipitation resulted in higher LE in energy partition in wet season. About inter-seasons, differences in LE in same season in three progressive years were due differences in accumulated precipitation in each wet season (see **Figure 8**), different patterns in precipitation caused differences in energy partition in annual seasons.

3.3. Climatic Controls of Latent and Sensible Heat Fluxes

Analyses of climatic controls of LE and H were done through Pearson correlation ($p < 0.05$) between LE, H and some climatic variables. Correlation results show variables controls LE and H changed in different seasons and also the same season in different years. **Table 2** presents these correlations.

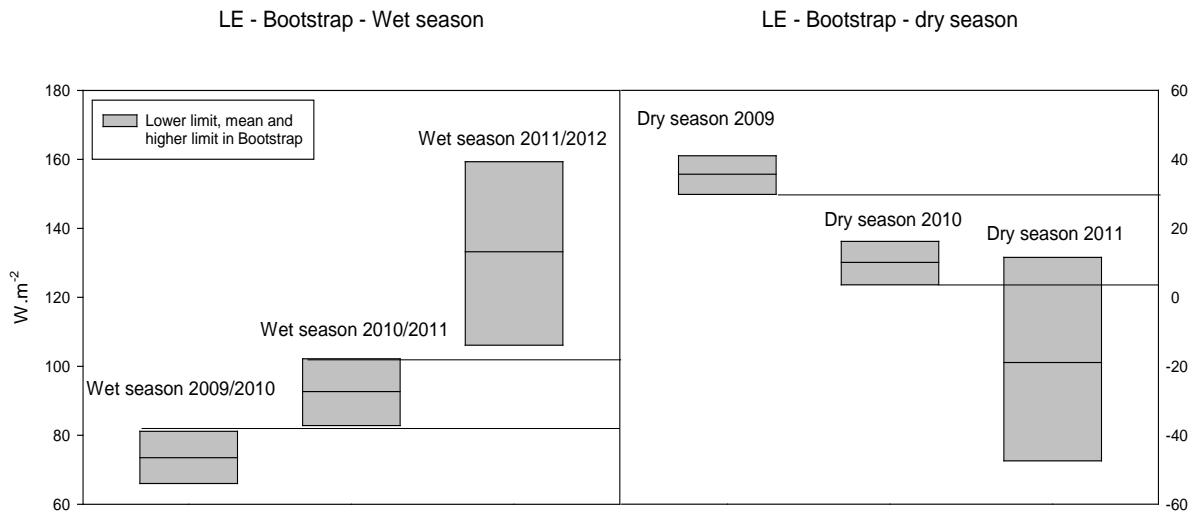


Figure 6. LE Bootstrap in wet and dry season between 2009 and 2012.

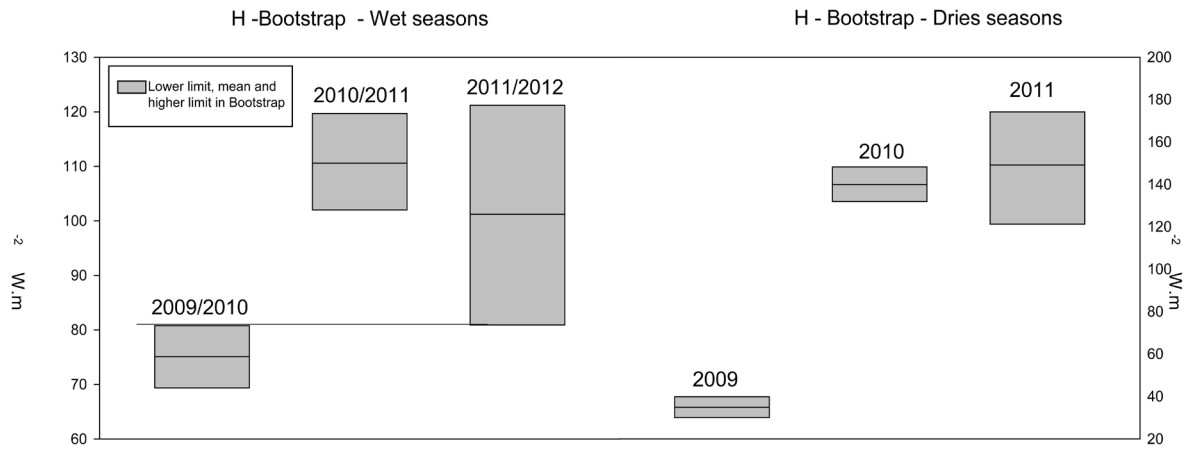


Figure 7. H Bootstrap in wet and dry season between 2009 and 2012.

Table 2. Pearson correlation ($p < 0.05$) between latent heat flux (LE), sensible heat flux (H), net radiation (R_n) temperature (T), relative humidity (RH), vapor deficit pressure (VDP), solar radiation (R_g), and sky coverage (K_T) for the wets seasons 2009-2012 in Brazilian Savana.

	DRIES SEASONS						WETS SEASONS					
	2009		2010		2011		2010		2011		2012	
	LE	H	LE	H	LE	H	LE	H	LE	H	LE	H
LE	1		1		1		1		1		1	
H	0.68	1	0.76	1	0.91	1	0.42	1	0.43	1	0.68	1
R_n	0.52	0.64	0.47	0.68	0.38	0.54	0.89	0.74	0.75	0.58	0.64	0.73
T	0.5	0.19	0.64	0.49	0.44	0.2	0.74	0.44	0.48	0.55	0.5	0.19
UR	-0.4	-0.3	0.45	0.35	0.42	0.29	0.77	0.55	0.83	0.54	0.29	0.32
DPV	0.4	0.19	0.69	0.5	0.45	0.22	0.8	0.45	0.37	0.81	0.4	0.19
R_g	0.55	0.63	0.56	0.63	0.21	0.36	0.87	0.74	0.5	0.79	0.63	0.66
K_T	0.69	0.33	0.67	0.65	0.16	0.38	0.78	0.77	0.74	0.53	0.65	0.69

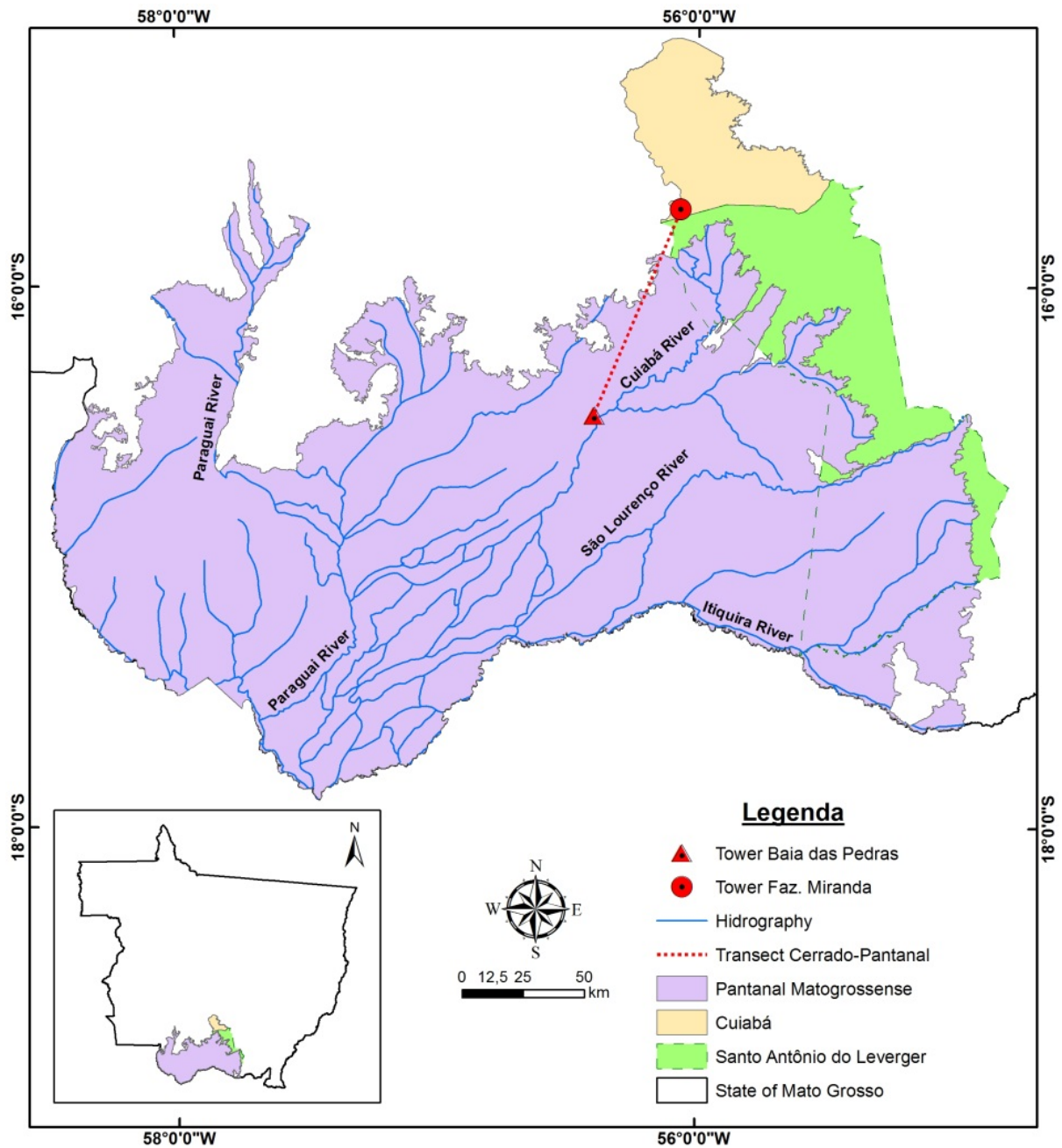


Figure 8. Micrometeorological tower localization of Brazilian Savana and Pantanal.

Correlation values show complexity in relation between LE, H and climatic variables. LE and H are well correlated with R_n and R_g in all seasons, other variables correlate with energy fluxes like air temperature, soil moisture in wet season and Pressure Vapor Deficit, air temperature, day index in dry season. This results show some atmospheric variables influences LE and H in wet and dry season indicating higher complexity in these variables.

4. Conclusions

In general global radiation values were higher in wet season due sun localization (spring and summer in southern Hemisphere) and net radiation patterns are like global radiation due this variable influences directly net radi-

ation

In all season sum of LE and H was above 80% of energy balance indicating that great contributes for energy balance closure were because these two variables. LE predominant in wet season due higher water content in atmosphere, but in dry season there was inversion being H higher in energy balance.

According Bootstrap analyses LE were different in all seasons indicating rainfall was determinant factor in season and inter-season in site, great precipitation in wet season and very lower precipitation in dry season caused different patterns in energy partition with inversion between LE and H in two season.

Many climates variables influence LE and H in seasons, being R_n and R_g in all season and other variables in wet or dry season indicating higher complexity in LE and H patterns.

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