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Energy balance in the Cerrado of Ecological Station of Assis – Assis, São Paulo State, Brazil

Edson Xavier Fernandes[1*] and Jonas Teixeira Nery[2]

*[1]Instituto de Geociências, Universidade Estadual de Campinas, Rua João Pandiá Calógeras, 51, 13083-870, Cidade Universitária, Campinas, São Paulo, Brazil. [2]Departamento de Geografia, Universidade Estadual Paulista "Júlio de Mesquita Filho", Ourinhos, São Paulo, Brazil. *Author for correspondence. E-mail: exf_geografia@hotmail.com*

ABSTRACT. This article presents the results of the net radiation partitioning (Rn) between latent heat (LE) and sensible heat fluxes (H) and its relationship with water availability (rain) in an area with Cerrado vegetation in the state São Paulo, Brazil. Heat fluxes follow the energy standard available in the environment, with higher values during the rainy season and lower values in the dry season. However, in the dry season, increased sensible heat flux over the latent heat flux was observed, which could be due to the lower water availability in the environment. Similar studies that have examined the dynamics of natural systems can contribute to the development of public policies for preservation and conservation of natural resources in a context in which the man-nature relationship is marked by imbalances in view of the form of use of natural resources based on predatory model adopted by society over the past 200 years.

Keywords: latent heat, sensible heat, eddy covariance, net radiation.

Balanço de energia no Cerrado da Estação Ecológica de Assis – Assis/SP, Brasil

RESUMO: O presente artigo apresenta os resultados do particionamento da radiação líquida (Rn) entre os fluxos de calor latente (LE) e calor sensível (H), bem como sua relação com a disponibilidade hídrica (chuva) em uma área com vegetação de cerrado no estado de São Paulo, Brasil. Os fluxos de calor seguem o padrão da energia disponível no ambiente, com maiores valores no período de chuvas e menores valores no período de seca. Todavia, na fase seca é perceptível um aumento do fluxo de calor sensível em detrimento do fluxo de calor latente, em função da menor disponibilidade hídrica no ambiente. Estudos desse tipo, que analisam as dinâmicas dos sistemas naturais, podem contribuir para a elaboração de políticas públicas de preservação e conservação de recursos naturais, em um contexto em que a relação homem-natureza é marcada por desequilíbrios, tendo em vista a forma de apropriação dos recursos naturais pautada em um modelo predatório adotado pela sociedade ao longo dos últimos 200 anos.

Palavras-chave: calor latente, calor sensível, covariância de vórtices turbulentos, radiação líquida.

Introduction

As two important components of the climate system, atmosphere and vegetation are in constant interaction, especially due to exchanges of energy, mass and 'momentum' held in their interface. The understanding of energy exchanges between surface and atmosphere assists in the characterization of the microclimate in relation to variations in the climate of a region and also in the identification of the effects of human activities or natural factors on different environmental issues in the region (BIUDES et al., 2009).

Oliveira et al. (2006a) emphasized that energy balance measurements are critical for understanding the role that ecosystems play in regulating local, regional and global climate, as well as their responses to changes in environmental conditions. To Foley et al. (2003), the way energy is partitioned between latent heat flux and sensible heat flux changes surface fluxes and therefore the climate. Wilson et al. (2002) reported that partition between latent heat fluxes linked to the evapotranspiration process and sensible heat flux is critical to determine the water cycle, boundary layer development, weather and climate. According to Andrade et al. (2009), the knowledge and quantification of processes linked to energy balance are important for the formulation of environmental and climate policies.

In addition, this interaction allowed inferring how environmental conditions may be favorable to vegetation, especially with regard to metabolism and carbon assimilation capacity, for example.

The aim of this study was to present considerations related to energy balance in the Ecological Station of Assis, performed from the analysis of micrometeorological data collected in area with predominance of Cerrado vegetation. The results obtained by the analysis of the variability of fluxes on a monthly and daily scale contribute to greater understanding of natural dynamics within the Conservation Unit and serve to support and expand these areas or ensure their conservation and protection.

Material and methods

Belonging to the Western São Paulo plateau region (from 22º 33'S to 22º 38'S and from 50º 21'W to 50º 24'W), the Ecological Station of Assis (EEcA) covers 3.8% of the city of Assis (southwestern state of São Paulo), and represent 10.0% of protected cerrado areas of the state of São Paulo (DURIGAN et al., 2010). It has an area of approximately 1,760.64 ha, of which 1,312.68 ha are occupied by *lato sensu* native Cerrado vegetation, whose predominant physiognomy is cerradão (approximately 91.0%) established over a wavy relief with altitudes ranging from 510 to 596 m (PINHEIRO; DURIGAN, 2009) (Figure 1).

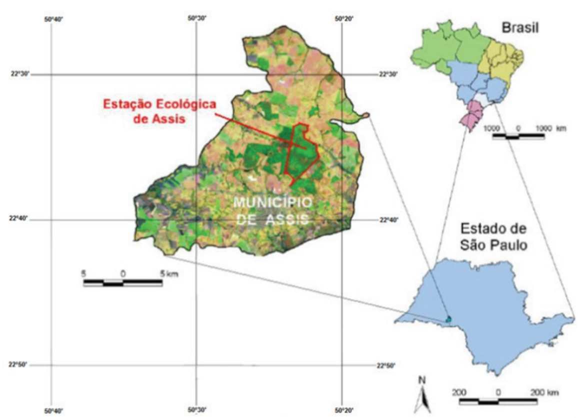

Figure 1. Location of the study area (DURIGAN et al., 2010).

The surface energy balance is understood as the partition of energy available in the environment between turbulent heat fluxes and what is stored by the environment. By analyzing this partition, it is necessary to draw attention to the fact that this is a complex function, in which considerations should be given to the long-term interactions between the biogeochemical cycle and climate, and the short-term interactions and the relationship between the plant physiology and time variations, considering the development of the boundary layer, for example (WILSON et al., 2002).

For vegetated surfaces, the available energy (net radiation: Rn) is used to heat the environment in the form of sensible heat (H), evaporate water in the form of latent heat (LE), soil heating (G), photosynthesis (P) and storage in biomass (S). Thus, the energy balance in vegetated surfaces can be given by the following equation 1:

$$Rn = H + LE + G + P + S \quad (1)$$

In this study, only net radiation or balance radiation (Rn), sensible heat flux (H) and latent heat (LE) were considered and analyzed along with rainfall, whose data were collected by a micrometeorological station located within the EEcA.

The sensors of this weather station that are responsible for flux data collection and storage are provided with the eddy covariance system. The net radiation, whose average measures were stored by the datalloger system (CR-1000, Campbell Scientific do Brasil) every hour, was collected by a net radiometer (model CMP-3, Kipp and Zonen).

Heat flux data were collected by a three-dimensional sonic anemometer (model CSAT-3, Campbell), responsible for measuring wind speed in horizontal, vertical and diagonal directions. These measurements were performed at high frequency (several times per second) and when crossed with temperature and relative humidity measurements collected at the same altitude by the eddy covariance system, provide heat flux data. The system stores the average of every thirty minutes of measurement.

Fluxes greater than 700 W m^{-2} and lower than -30 W m^{-2} for latent heat flux and higher than 500 W m^{-2} and lower than -50 W m^{-2} for sensible heat flux were considered as spurious data. Flux data measured every half hour as mentioned above were grouped and analyzed also every hour in order to establish greater connection with net radiation data.

All data were exported for tabulation and treatment in Excel spreadsheets (Office 2007), which enabled performing calculations of monthly averages, average monthly hours, total monthly hours, daily averages and totals. To calculate the determination coefficient (R^2) and the construction of the linear regression graph, data were processed in the Statistica 7.0 software. The study period is 10 months, from 1 December 2012 to 30 September 2013.

Results and discussion

The linear regression analysis shows that there is a marked association among the energy available in the environment (Rn) the latent heat (LE) and the sensible heat fluxes (H) together (R^2 = 0.81) (Figure 2). This determination coefficient value is similar to others found in studies in the Amazon rainforest (ROCHA et al., 2004; with R^2 = 0.86), in Amazon-Cerrado transition areas (VOURLITIS et al., 2001; with R^2 = 0.84) and in Caatinga (OLIVEIRA et al., 2006b; with R^2 = 0.97), for example. It is noteworthy that all these works considered heat flux on the ground (G) along with Rn as independent variable, assuming that Rn - G = LE + H. For this work, G values were not considered due to the lack of sensor at the micrometeorological station.

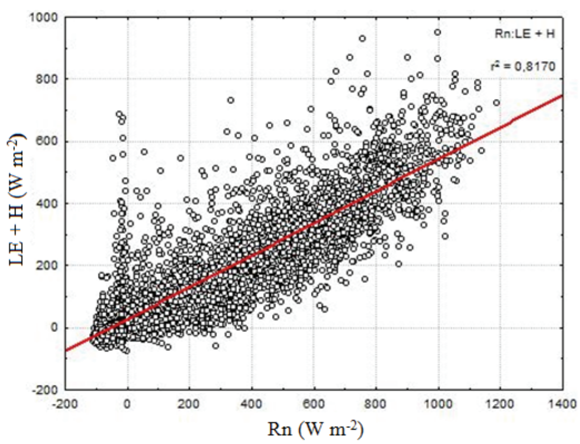

Figure 2. Relationship between Rn and heat fluxes (n = 6.712), values refer to hourly averages.

From the annual rainfall variability, it was possible to select two periods: a wet season, which lasted from December to April and a dry season from May to September. The total rainfall for the period was 1.962,2 mm. Of this total, 1,513 were recorded during the wet season, corresponding to 68.0% of all precipitation over the ten months. Rainfall for the dry season was 32.0% of the total, with cumulative rainfall of 714 mm (Figure 3).

According to the average daily values, LE and H together accounted for 73.0% of the net radiation (Rn), and separately, each heat flux corresponded to 55.0 and 18.0%, respectively. The highest monthly average Rn value was recorded in December 2012 (223 W m^{-2}) and the lowest was recorded in June 2013 (97 W m^{-2}), according to the annual evolution of solar radiation with higher values in summer and lower in winter. The average monthly latent heat flux values revealed that LE was higher in the wet season and lower in the dry season, and the highest monthly Rn average was recorded in December 2012 (135 W m^{-2}) and the lowest was recorded in June 2013 (52 W m^{-2}). In turn, the sensible heat flux can be analyzed under two aspects. The first is that from December 2012 to June 2013, its monthly evolution is very similar to the net radiation evolution. The other aspect is that from July there was a marked increase in its values, which is attributed to the lack of rain in that period (Figure 4).

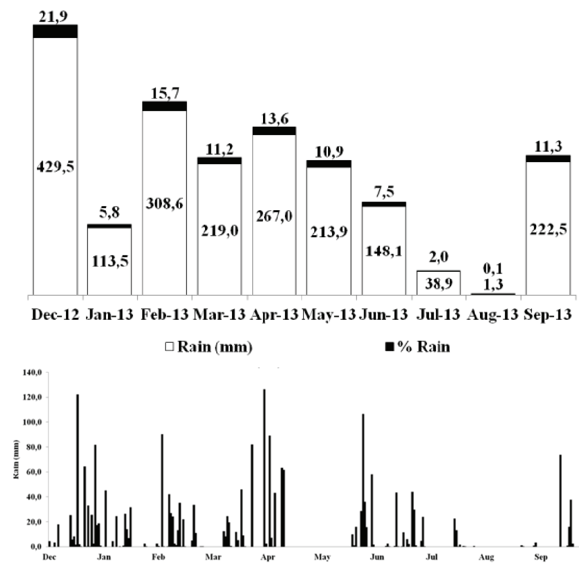

Figure 3. Total monthly rainfall and respective percentages of each month in relation to the total of the entire period (above) and total daily rainfall (below).

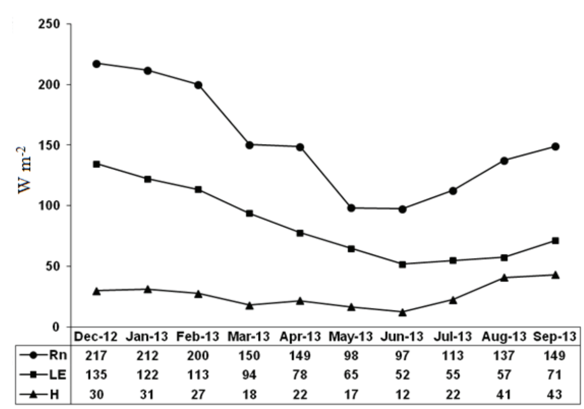

Figure 4. Monthly averages of the energy balance components.

The highest monthly average H value was recorded in September 2013 (43 W m^{-2}) and the lowest was recorded in June 2012 (12 W m^{-2}). This increase in H, verified in the last three months, is associated with the water deficit in almost the entire month of August and much of September, in addition to the fact that in July, the monthly rainfall was only 63 mm, with rainfall concentrated in only a few days of the month.

The Bowen ratio (β), which is the sensible heat flux divided by the latent heat flux, is a parameter used to verify the water conditions of the environment, and the lower its value, the greater the water availability, and the inverse is true and an indication that in drought conditions, a larger portion of the energy available in the environment is used to heat the atmosphere (sensible heat flux). In this study, the largest β monthly values were 0.71 and 0.60 in August and September, respectively, which is in line with the increase in the average monthly H value in the same period (Table 1).

Table 1. Bowen ratio (calculations were made from monthly average latent heat flux and sensible heat flux values).

Month	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13
$\beta = {}^{H}/_{LE}$	0,22	0,26	0,24	0,19	0,28	0,26	0,24	0,41	0,71	0,60

Malhi et al. (2002) reported that in the dry season, due to the increased evaporative demand associated with high leaf temperatures and atmospheric vapor deficit, there is stomatal closure of plants to prevent water loss, reducing evapotranspiration. Consequently, the consumption of energy to heat up the air increases. These same authors also reported that in a study in the Amazon, the H flux showed similar relationship with radiation balance. However, with the extension of the dry season, there was an increase in the sensible heat flux values due to limited evaporation.

The analysis of the daily cycle of Rn, LE and H based on hourly monthly averages of each season, shows that the net radiation and latent heat suffer drop in their daily maximum value from the wet season to the dry season, while the sensible heat flux increases.

The maximum Rn value in the wet and the dry seasons was 735.2 W m^{-2} and 605.8 W m^{-2}, respectively, both at 01:00 pm. These values represent a reduction of 18.0% from one season to another. The LE values decreased from 323.5 W m^{-2} at 01:00 pm in the wet season to 197.6 W m^{-2} at 02:00 pm in the dry season. Therefore, there was a drop of 39.0% from the wet season to the dry season. The H flux increased 11.0% from the wet season to the dry season, with a peak of 127.4 W m^{-2} (noon) in the first and 141.3 W m^{-2} (01:00 pm) in the second (Figure 5). This greater range observed in the latent heat flux from one period to the other also reveals how water availability is important for the regulation of energy exchanges between vegetation and atmosphere.

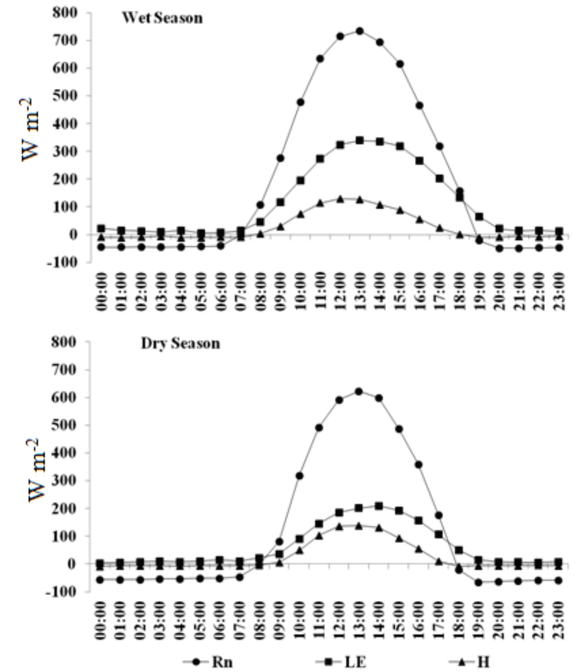

Figure 5. Evolution of the daily cycle of net radiation (Rn), latent heat flux (LE) and sensible heat flux (H) for each period.

Conclusion

The analysis of ten months of data allowed determining the existence of two distinct climatic periods and assessing the seasonality of the interaction between vegetation and atmosphere in the Cerrado through energy fluxes. The water availability, conditioned by climate dynamics, appears as an important regulator of heat fluxes. The energy balance showed that with the lack of water in the dry season, the latent heat flux shows the largest drop, while the sensible heat flux increases, as a large portion of the energy available in the environment is used to heat the air, since evapotranspiration decreased.

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