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# Patterns of energy exchange for tropical ecosystems across a climate gradient in Mato Grosso, Brazil

Marcelo Sacardi Biudes[a,*], George Louis Vourlitis[b], Nadja Gomes Machado[a,c], Paulo Henrique Zanella de Arruda[a], Geraldo Aparecido Rodrigues Neves[a], Francisco de Almeida Lobo[a], Christopher Michael Usher Neale[d], José de Souza Nogueira[a]

[a] Programa de Pós-Graduação em Física Ambiental, Instituto de Física, Universidade Federal de Mato Grosso, Cuiabá, Mato Grosso, Brazil
[b] Biological Sciences Department, California State University, San Marcos, CA, USA
[c] Laboratório de Biologia da Convervação, Instituto Federal de Mato Grosso, Cuiabá, Mato Grosso, Brazil
[d] Civil and Environmental Engineering, Utah State University, Logan, UT, USA

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ABSTRACT

The spatial and temporal variations in the partitioning of energy into latent (LE) and sensible (H) heat flux for tropical ecosystems are not yet fully understood. In the state of Mato Grosso State, Brazil, there are three different ecosystems (Cerrado, Pantanal and the Amazon Rainforest) with distributions that vary across rainfall and humidity gradients. Our goal was to analyze the seasonal variation in microclimate, spectral reflectance, LE and H for these ecosystems and quantify how energy partitioning varies across the regional climate gradient. We used the Bowen ratio energy balance method to estimate the LE and H of a dense, evergreen ombrophylous forest near Alta Floresta (AFL), a semi-deciduous forest in the Amazon-Cerrado transition zone near Sinop (SIN), a savanna grassland at Fazenda Miranda (FMI), a managed savanna pasture at Fazenda Experimental (FEX), a seasonally flooded woodland at Baía das Pedras in the Pantanal (BPE), and a riparian forest dominated by *Vochysia divergens* Pohl (CAM) in the Pantanal. Annual rainfall decreased from north to south, and 83% of the annual rainfall occurred during the wet season. However, the seasonal amplitude of volumetric soil water content (VSWC) increased from north to south, because of the increased potential for seasonal flooding. The vapor pressure deficit (VPD), air temperature, solar radiation ($R_g$) and net radiation ($R_n$) also increased from north to south, which directly affected the seasonal amplitude in the enhanced vegetation index (EVI). Our data suggest that energy partitioning in the wettest sites (AFL and CAM) were driven by solar radiation instead of soil water availability, while seasonal variation in rainfall was more important for the Amazon-Cerrado transitional forest (SIN), Cerrado (FMI and FEX) and Pantanal scrublands (BPE). These patterns are discernable using appropriate satellite vegetation indices, such as the EVI, allowing spatial and temporal variations in energy partitioning to be quantified across diverse landscapes like the Amazon Basin.



## 1. Introduction

Quantifying the partitioning of energy into latent (LE) and sensible (H) heat in the tropics, and its variation across landscapes, is critical for assessing hydrological cycles, understanding soil–plant–atmosphere interactions, and improving regional and global climate models. Energy partitioning varies between ecosystems due to interactions between biogeochemical cycling, plant physiology, soil water availability, and climate (Fisher et al., 2008; da Rocha et al., 2009; Costa et al., 2010). In Brazil, the distribution of land cover types is driven by climatic variations and anthropogenic influences, and in particular, the state of Mato Grosso has three different ecosystems, savanna (Cerrado), wetland (Pantanal) and Amazonian rainforest that are arrayed along broad climate gradients.

Although large regions of the Amazon Basin exhibit high annual rainfall there can be pronounced seasonality in rainfall and soil moisture due to the seasonal migration of Inter-Tropical Convergence Zone (ITCZ) (Machado et al., 2004; Marengo et al., 2011). Satellite measurements indicate that canopy greenness in the Amazon is negatively correlated with precipitation pattern (Saleska et al., 2003), with an increase in greenness and higher evapotranspiration and productivity during the dry season (Myneni et al., 2007; Huete et al., 2008) because productivity

* Corresponding author. Tel.: +55 65 3615 8738; fax: +55 65 3615 8738.
*E-mail address:* marcelo@fisica.ufmt.br (M.S. Biudes).

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and evapotranspiration is limited more by radiation than water availability (Hutyra et al., 2007; Juárez et al., 2007; da Rocha et al., 2009). These patterns are opposite to those in more seasonal tropical ecosystems where dry season declines in precipitation create a water deficit that causes declines in evapotranspiration and productivity (Werth and Avissar, 2004; Giambelluca et al., 2009; Vourlitis et al., 2008, 2014; Costa et al., 2010; Rodrigues et al., 2014).

High spatial heterogeneity and climate–land surface interactions make patterns of tropical energy partitioning uncertain (Hasler and Avissar, 2007; Costa et al., 2010; Rodrigues et al., 2014). Such high spatial and temporal variation are particularly striking in the state of Mato Grosso, where three major ecosystems, Amazon forest, savanna (Cerrado), and wetlands (Pantanal), vary along climate gradients that vary in space and time. Moreover, within these regional ecosystems are landforms that vary substantially in physiognomy, due to a variety of variables such as soil type and fertility and exposure to seasonal flooding (Lopes and Cox, 1977; Furley and Ratter, 1988; Nunes da Cunha and Junk, 2004; Vourlitis et al., 2013). These ecosystems have experienced significant deforestation over the last several decades (Carvalho et al., 2009), and Mato Grosso has the dubious distinction of having some of the highest rates of deforestation in Brazil (Fearnside, 2003; Soares-Filho et al., 2006). Thus, within the state there is a mosaic of natural and managed forests, woodlands, plantations, croplands and pastures (Jasinski et al., 2005), which have widely varying hydrology and/or climate seasonality.

These spatial variations in hydrology and vegetation type alter the pattern of partitioning between LE and H, which feeds back on regional and global climate by affecting atmospheric humidity, thermal stability of the boundary layer, and regional precipitation (Hasler and Avissar, 2007; Costa and Pires, 2010). Deforestation can cause a decrease in evapotranspiration due to an increase in albedo, a decrease in surface roughness, and a decline in leaf area index (von Randow et al., 2004; Sheil and Murdiyarso, 2009). In turn, a decrease in evapotranspiration is typically linked with an increase in surface temperature, which acts to increase H (Biudes et al., 2012; Dubreuil et al., 2012). The ratio of LE/H may vary little above an intact forest, while above managed ecosystems, especially grass-dominated pastures and savanna, these fluxes have high variability throughout the year (Priante-Filho et al., 2004; Fisher et al., 2008; Biudes et al., 2009; Rodrigues et al., 2014). In turn, areas with higher H also have a convective boundary layer that can be up to 500 m higher than over intact forest (Fisch et al., 2004). The shift in the surface energy balance can influence regional, and potentially global, circulation and hydrology depending on the scale of the deforestation (Snyder, 2010; Bagley et al., 2014).

The high natural and anthropogenic variations in land cover type and climate highlight the need to understand seasonal and spatial variability of partitioning between LE and H. Here we exploit the high spatial and temporal variation of Amazon forest, Cerrado, and the Pantanal in the state of Mato Grosso to analyze the seasonal variation in microclimate, spectral reflectance, and LE and H in the dominant landforms of tropical Brazil. We hypothesize that (1) the seasonal amplitude of micrometeorology, spectral reflectance, and LE and H flux will increase from Amazon to Pantanal, and (2) the seasonality in LE and H will be driven by seasonal variation in precipitation and soil water content in all sites.

## 2. Materials and methods

### 2.1. Site descriptions

This study was conducted in six different ecosystems located across Mato Grosso, Brazil, two that were located within Amazon rainforest, two in the Cerrado and two in the Pantanal (Fig. 1). The periods in which data were available can be found in Table 1. The northernmost site was in a dense, evergreen ombrophilous forest located 39 km NE of the city of Alta Floresta (AFL) in the southern Amazon Basin (9°36′2.83″ S:55°55′22.22″ W). The vegetation is composed of *Tetragastris altissima* (22%), *Celtis schippii* (17%) and *Pseudolmedia* sp. (6%), with an average canopy height of 30 m but with some emergent trees reaching up to 45 m in height (Santos, 2005). The 30-year mean annual temperature in the Alta Floresta region is 25.7 °C, and rainfall is approximately 2230 mm year$^{-1}$ with a dry season from June to September (Dubreuil et al., 2012). The soil is classified as a Vetic Acrisol (Hyperdystric), and it is acidic (pH = 4.5) with low level in phosphorus, extractable cation, and organic matter content (Quesada et al., 2010).

Further south, the next experimental area was in a dense, semi-deciduous forest located in the Amazon-Cerrado transition zone 50 km NE near the city of Sinop (SIN) (11°24′44.28″ S: 55°19′28.77″ W). Mean canopy height is 22–25 m, and leaf area index (LAI) varies between 2.5 m$^2$ m$^{-2}$ during the dry season and approximately 6.0 m$^2$ m$^{-2}$ during the wet season (Biudes et al., 2014a), and the vegetation is dominated by the tree species *Brosimum lactescens*, *Qualea paraensis* and *Tovomita schomburkii*

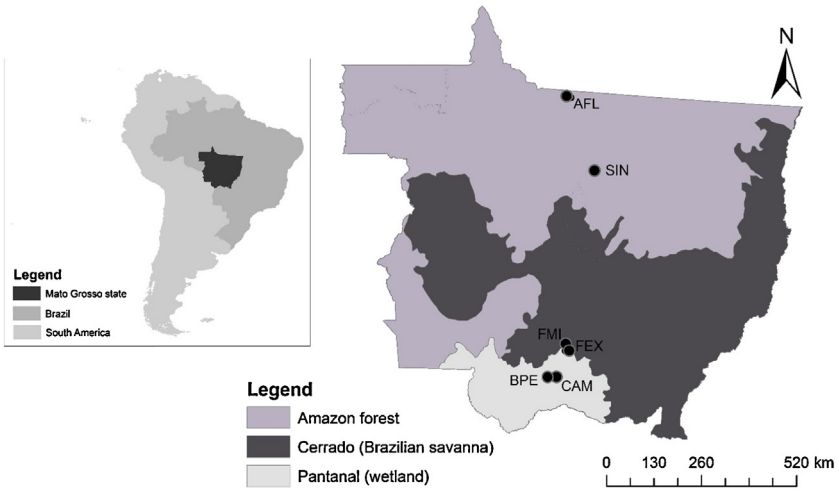


**Fig. 1.** Location of Mato Grosso, Brazil flux towers in a dense, evergreen ombrophylous forest at Alta Floresta (AFL), semi-deciduous transitional forest at Sinop (SIN), savanna mixed grassland-woodland (*campo sujo*) at Fazenda Miranda (FMI), *Brachiaria humidicola* pasture at Fazenda Experimental (FEX), seasonally flooded woodland at the Baía das Pedras (BPE) and the *Vochysia divergens* riparian forest (CAM) in the Pantanal.