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SEASONAL AND INTERANNUAL PATTERN OF METEOROLOGICAL VARIABLES IN CUIABÁ, MATO GROSSO STATE, BRAZIL

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ABSTRACT. Cuiabá is located on the border of the Pantanal and Cerrado, in Mato Grosso State, which is recognized as one of the biggest agricultural producers of Brazil. The use of natural resources in a sustainable manner requires knowledge of the regional meteorological variables. Thus, the objective of this study was to characterize the seasonal and interannual pattern of meteorological variables in Cuiabá. The meteorological data from 1961 to 2011 were provided by the Instituto Nacional de Meteorologia (INMET – National Institute of Meteorology). The results have shown interannual and seasonal variations of precipitation, solar radiation, air temperature and relative humidity, and wind speed and direction, establishing two main distinct seasons (rainy and dry). On average, 89% of the rainfall occurred in the wet season. The annual average values of daily global radiation, mean, minimum and maximum temperature and relative humidity were 15.6 MJ m^{-2} y^{-1}, 27.9°C, 23.0°C, 30.0°C and 71.6%, respectively. The maximum temperature and the wind speed had no seasonal pattern. The wind speed average decreased in the NW direction and increased in the S direction.

Keywords: meteorological variables, climatology, ENSO.

RESUMO. Cuiabá está localizado na fronteira do Pantanal com o Cerrado, no Mato Grosso, que é reconhecido como um dos maiores produtores agrícolas do Brasil. A utilização dos recursos naturais de forma sustentável requer o conhecimento das variáveis meteorológicas em escala regional. Assim, o objetivo deste estudo foi caracterizar o padrão sazonal e interanual das variáveis meteorológicas em Cuiabá. Os dados meteorológicos de 1961 a 2011 foram fornecidos pelo Instituto Nacional de Meteorologia (INMET). Os resultados mostraram variações interanuais e sazonais de precipitação, radiação solar, temperatura e umidade relativa do ar e velocidade e direção do vento, estabelecendo duas principais estações distintas (chuvosa e seca). Em média, 89% da precipitação ocorreu na estação chuvosa. Os valores médios anuais de radiação diária global, temperatura do ar média, mínima e máxima e umidade relativa do ar foram 15,6 MJ m^{-2} y^{-1}, 27,9°C, 23,0°C, 30,0°C e 71,6%, respectivamente. A temperatura máxima e a velocidade do vento não tiveram padrão sazonal. A velocidade média do vento diminuiu na direção NW e aumentou na direção S.

Palavras-chave: variáveis meteorológicas, climatologia, ENOS.

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INTRODUCTION

Many studies has been developed about local and regional climate around the world (Gash & Nobre, 1997; Leung et al., 2003; Xie et al., 2003; Christensen et al., 2008; Biudes et al., 2015), allowing researchers and decision-makers assess possible future climates, explore societal impacts, and approach policy responses from a risk-based perspective (Maurer et al., 2007). In summary, the climate is a generalization of the different weather conditions prevailing in a particular place and considers the frequency of meteorological phenomena more common place and conditions mean time (Diniz et al., 2008). The weather varies in a short period in time (i.e. one day) while the climate varies from one location to another mainly due to variations in intensity, amount and distribution of climatic elements, such as solar radiation, temperature, relative humidity, wind and precipitation (Pereira et al., 2002).

The largest fluctuations in solar radiation, air temperature and atmospheric humidity is associated with rainfall patterns, verifying that, at the time of the rainy season, there is a reduction in air temperature and solar radiation and an increasing in air humidity, occurring the opposite in periods of low rainfall (Bastos et al., 1997). The hydrologic cycle is an integral part of the climate, which links directly to the latent heat flux and evapotranspiration and has been affected by a continuous deforestation and burning, rising greenhouse gases concentration in the atmosphere and changing the national and regional hydrographic feature (Diniz et al., 2008; Biudes et al., 2009, 2012).

In recent years, many studies are concerned with the interaction between climatic conditions and land surface changing (Delire et al., 2004; Snyder et al., 2004; Bonan, 2008; Biudes et al., 2012, 2014a). The physical and biological factors of the surface determine the interaction between the atmospheric humidity, precipitation, runoff and energy balance in the form of latent and sensible heat (Diniz et al., 2008; Biudes et al., 2009). The microclimate changes in a specific region occur both by anthropogenic influences such as urbanization and agriculture (Kalnay & Cai, 2003), and by alterations on the concentration of greenhouse gases (Biudes et al., 2014b; Souza et al., 2014).

The climatology studies have advanced in Brazil, but regional and local studies are still concentrated in the Southeast of Brazil, with some advances in the Northeast and North (Amazon Forest) and a great lack of information for the Midwest, making it necessary new approaches aimed at filling the gaps as the diversity of the Brazilian climate (Alves et al., 2011). The Midwest Climate is Tropical with dry winter and lower temperature between May and September and wet summer and higher temperature between

October and March and is very dependent of the South Atlantic Convergence Zone (SACZ) (Alves, 2009). The SACZ is characterized by an oriented NW/SE cloudiness band semi-stationary associated with a zone of convergence of moisture, which extends to the middle troposphere, during several days (4 to 20 days) and extending from the Amazon to South Atlantic Ocean (Rao et al., 1996). The Midwest temperature is also highly controlled by the geographical position and the terrain (altitude). The lowest elevation areas (such as the Pantanal) have high temperatures, while the highest areas (such as the Plateau of Mato Grosso and Goiás) have low temperatures (Gomes et al., 2012).

Mato Grosso State is recognized as one of the largest agricultural producers of the world, which is strongly influenced by climate, especially the occurrence and distribution of precipitation (Fietz et al., 2008). Mato Grosso is one of the states from Midwest region of Brazil, whose dominant climate is the tropical with a dry period occurring in the winter season (Aw according to Köppen Classification). On the other hand, the Northern region of Mato Grosso is a small portion where the monsoon climate takes place (Am according to Köppen Classification) (Peel et al., 2007). Based on total annual precipitation and duration of the rainy season, Mato Grosso can be divided into five homogeneous rainfall regions in which the North region has the highest pluviometric indices followed by Central, East and South, respectively (Fietz et al., 2008). The major climatological studies in Mato Grosso State were conducted specially on its capital Cuiabá by looking at the relation between micrometeorological variables and land use (Xavier et al., 2009; Callejas et al., 2011; Santos, 2013).

The soil of the region is dominated by unconsolidated alluvial deposits of the formation of the Pantanal, Quaternary fluvial origin of age. The terrain is slightly hilly and the altitude varies between 146 and 266 m (Zeilhofer, 2001). The vegetation of Cuiabá consists of remnants of Cerrado, Cerradão, riparian forests and exotic vegetation, represented by fruit, ornamentals and grasses (Guarim Neto, 1991).

The high amount of rivers and streams in urban area of Cuiabá, the large volume of precipitation during the wet season, the impermeability of the urban soil (asphalt and concrete) and the presence of obstructions (as garbage) have caused historical disasters by flooding (Zamparoni, 2012). In addition, there is no detailed research about the meteorological patterns in Cuiabá, which highlight the importance to study its climate. Thus, the present study aimed to characterize the seasonal and interannual pattern of the meteorological variables in Cuiabá, Mato Grosso State, Brazil.

MATERIAL AND METHODS

Study Area

Cuiabá is located in the central southern of Mato Grosso State, between Cerrado and Pantanal, with an area of 22,851.10 km^2 (Fig. 1), bordering the municipalities of Jangada, Acorizal, Chapada dos Guimarães, Cuiabá, Várzea Grande, Nossa Senhora do Livramento, Rosário Oeste, Nobres, Alto Paraguai, Diamantino, Planalto da Serra, Nova Brasilândia and Campo Verde (Chiaranda et al., 2012). The regional climate is Aw according to Köppen classification, which represents a Semi-humid Tropical Climate (Brasil, 1997), or Tropical Savanna Climate (Brasil, 1982). The average annual rainfall is 1335 mm and its regime presents two distinct periods: rainy (October to April) and dry (May to September) (Chiaranda et al., 2012). The average of annual temperature ranges from 22 to 25°C (Brasil, 1997) and relative humidity is 74.3% (Chiaranda et al., 2012).

Data Collection and Analysis

The data were obtained from Instituto Nacional de Meteorologia (INMET) between 1961 to 2011. As the data had gaps, we used only years with daily data for all days of the year. Were analyzed 25 years of solar radiation, 28 years of precipitation, 31 years of maximum temperature, 27 years of mean temperature, 29 years of minimum temperature, 28 years of relative humidity, 34 years of wind speed, and 26 years of wind direction (Table 1).

To analyze the occurrence of dry and rainy days were considered dry days when no precipitation occurred. Wind directions were specified according to Dallacort et al. (2010). They used the wind rose, which specifies eight wind directions and their symbology and degrees (Table 2). The predominant winds directions were characterized by the frequency analysis of daily observations from each month of the year. The daily average air temperature was calculated based on the compensated temperature equation Eq. (1):

$$T_{avg} = \frac{\left(T_{\max} + T_{\min} + T_{12} + 2T_{24}\right)}{5} \tag{1}$$

where $T_{\max}$ and $T_{\min}$ are the daily maximum and minimum temperature registered, T_{12} is the temperature at noon GMT and T_{24} is the air temperature at midnight GMT.

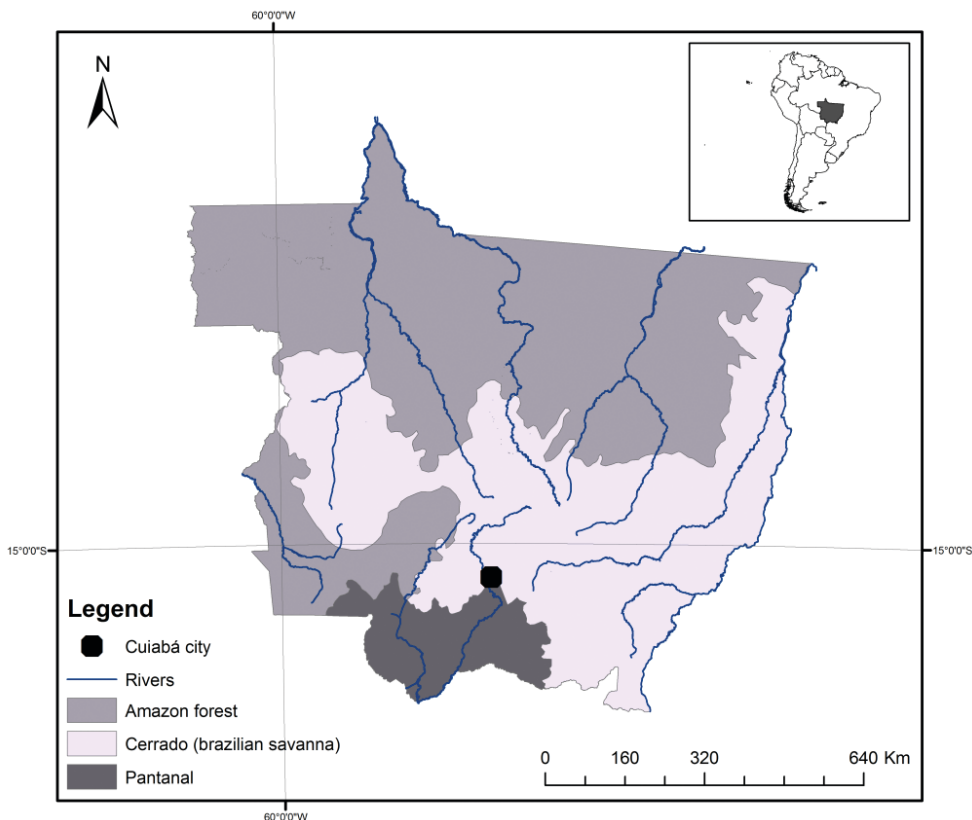The Mann Whitney test (Wilks, 2011) was used to verify if the

Figure 1 – Location of Cuiabá, Mato Grosso, Brazil.

Table 1 – Solar radiation (Rg), precipitation (Ppt), maximum air temperature (Tmax), average air temperature (T), minimum air temperature (Tmin), relative air humidity (RH), wind speed (Wspeed) and direction (Wdirection) used to characterize climate in Cuiabá.

Year	Rg	Ppt	Tmax	T	Tmin	RH	Wspeed	Wdirection
1961	X		X			X	X	X
1962	X	X	X	X	X	X	X	X
1963	X	X	X	X	X	X	X	X
1964	X	X	X	X	X	X	X	X
1965	X	X	X	X	X	X	X	X
1966	X	X	X	X	X	X	X	X
1968	X	X	X	X	X	X	X	X
1969	X	X	X	X	X	X	X	X
1970	X	X	X	X	X	X	X	X
1971	X	X	X			X	X	X
1972	X	X	X	X	X	X	X	X
1973	X	X	X	X	X	X	X	X
1974	X	X	X			X	X	X
1975	X		X	X	X	X	X	X
1976	X	X	X	X	X	X	X	X
1977	X	X	X	X	X	X	X	X
1979	X	X	X	X	X		X	
1980	X	X	X	X	X		X	
1981	X	X	X	X	X		X	
1982	X	X	X	X	X		X	
1983	X	X	X	X	X	X	X	X
1984	X	X	X	X	X	X	X	X
1985	X	X	X	X	X	X	X	X
1986	X	X	X	X	X	X	X	
1987		X	X	X	X		X	
1988		X	X	X	X		X	
1989		X			X		X	
1998			X	X	X		X	X
1999			X			X	X	X
2000			X	X	X	X	X	X
2001					X	X	X	X
2003	X					X	X	X
2004		X				X	X	X
2007		X				X	X	X
2010			X	X	X	X		
2011		X	X	X	X	X		

seasons (the rainy season from October to April, and dry season from May to September) caused significant variations (p-value <0.05) in meteorological variables.

RESULTS AND DISCUSSION

The interannual variability of the precipitation corresponded to a maximum value of 1829.6 mm y^{-1} in 1983, a minimum of 999.2 mm y^{-1} in 1969, and a mean value of 1372.2 mm y^{-1} (Fig. 2a). There were 17 years that the precipitation was lower and 11 years higher than the average precipitation of the study period, which corresponded to 68 and 32% of years, respectively.

The annual precipitation accumulated in this study was similar to the values of 1347.8 mm found in Santo Antônio do Leverger (Diniz et al., 2008), 1578.9 mm in Barra do Garças (Alves

Table 2 – Wind directions, symbology and direction in degrees.

Wind directions	Symbology	Degrees
North	N	0 to 23° and 337 to 360°
Northeast	NE	24 to 68°
East	E	69 to 113°
Southeast	SE	114 to 158°
South	S	159 to 203°
Southwest	SW	204 to 248°
West	W	249 to 293°
Northwest	NW	294 to 336°
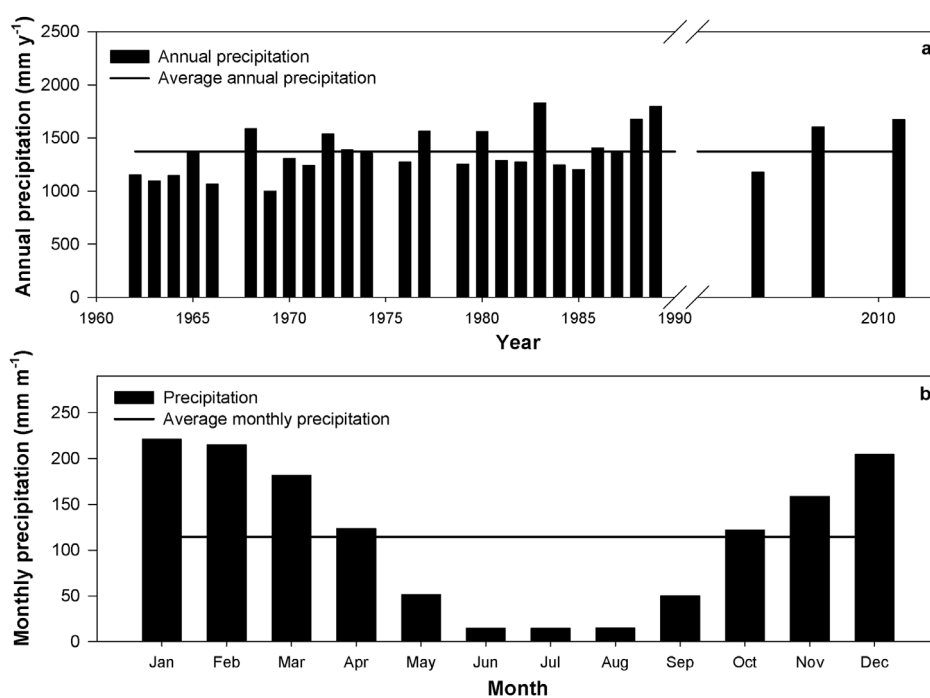
Figure 2 – Interannual (a) and monthly (b) variability of accumulated precipitation in Cuiabá.

et al., 2011) and approximately 1300 mm in Cáceres (Silva Neves et al., 2011; Pizzato et al., 2012). However, the average of precipitation was lower than values of 1830 mm found in Tangará da Serra (Dallacort et al., 2011) and of 2750 mm in municipalities further North of Mato Grosso (Sousa et al., 2006). Other studies also suggest that there is interannual variability of precipitation in several places in Mato Grosso (Rosa et al., 2007; Diniz et al., 2008; Alves et al., 2011; Dallacort et al., 2011; Silva Neves et al., 2011; Marcuzzo et al., 2012; Pizzato et al., 2012), which should be related with the altitude and vegetation aspect of each place Apparently, the interannual precipitation had a random variation a long of the study period. Probably the interannual variability is related with large scale climatological phenomenon, such as El Niño South Oscillation (ENSO), which is an oscillation coupling ocean-atmosphere interaction. The alteration on the Sea Surface Temperature (SST) modify the air pressure and wind and tropical convection is noticed which interferes in the whole atmospheric pattern circulation and switch the precipitation regime in many places around the word, including Brazil (Grimm, 2009).

During the study period, the mean annual occurrence of rainy days was 123 days and 242 dry days (Fig. 3a). The year 2004 had the longer of dry days with 265 days and the year 1977 had the longer rainy days with 213 days. The mean monthly occurrence of rainy days was 15 days in the rainy season while the
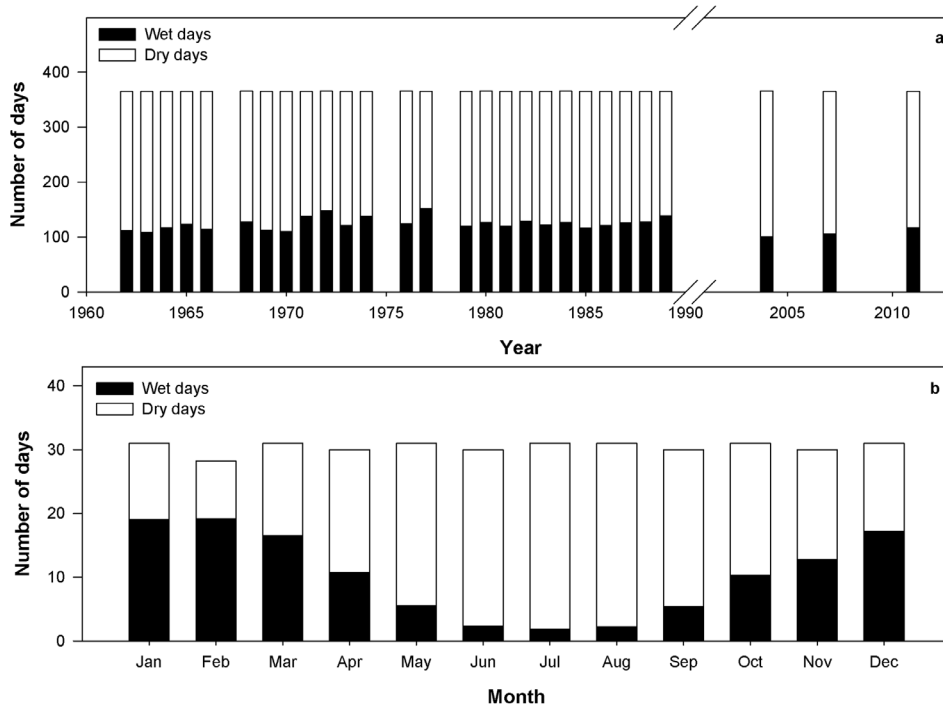
Figure 3 – Interannual (a) and monthly (b) variability of dry and wet days in Cuiabá.

occurrence of dry days was 27 days in the dry season (Fig. 3b). February had the longer period of rainy days with 19 days and July had the longer period of dry days with 29 days.

Table 3 – Mann-Whitney Test for seasonal effect (dry and wet season) in precipitation (ppt), solar radiation (gr), maximum temperature (Tmax), average temperature (T), minimum temperature (Tmin), relative humidity (RU), and wind speed (Wspeed).

Variables	Treatment	W	p-value
Ppt	season	35	0.002
Gr	season	33	0.010
Tmax	season	22	0.530
T	season	34	0.005
Tmin	season	35	0.002
RU	season	32	0.017
Wspeed	season	26	0.202

There was a significant seasonal variation in the precipitation (Table 3). The rainy season from October to April corresponded to 89% of precipitation while dry season from May to September corresponded to 11%. The monthly variability of precipitation reaches to a maximum value of 220.9 mm m^{-1} in January and a minimum of 14.6 mm m^{-1} in July, whereas the mean value is 114.4 mm y^{-1} (Fig. 2a). Studies also indicate that there is

monthly variability of precipitation in several places in Mato Grosso with drought period from June to August (Sousa et al., 2006; Diniz et al., 2008; Dallacort et al., 2011; Silva Neves et al., 2011; Biudes et al., 2012). The Continental Equatorial Mass act in Cuiabá during the summer, which is characterized by strong air convection and the consequent formation of clouds with great vertical development. It is formed in low-pressure areas in the Amazon region due to large availability of heat, humidity and especially by the convergence of the winds from the SE Atlantic. In addition, the Continental Tropical Mass act during this period. Its origin associated with the thermal depression of the Chaco, where is a low-pressure region that attract the humidity from the Amazon and increase the amount of precipitable water (Nimer, 1989).

The annual variability of solar radiation corresponded to a maximum value of 17.5 MJ m^{-2} d^{-1} in November, a minimum of 13.5 MJ m^{-2} d^{-1} in June, and an average value of 15.6 MJ m^{-2} d^{-1} (Fig. 4a). There was a significant seasonal variation in solar radiation (Table 3), with the highest values registered during the rainy season (16.3 MJ m^{-2} d^{-1}) and the lowest values during dry season (14.6 MJ m^{-2} d^{-1}). The difference on the amount of solar radiation between both seasons here discussed agreed with austral period. In November, for example, is right before the official summer on the south hemisphere, besides that this month

the sun cross exactly the latitude of Cuiabá. It implies that the sun rays will reach the surface perpendicularly, and consequently less radiation tends to be attenuated due to the smallest Zenith Angle and the smallest atmospheric optical way (Iqbal, 1983; Querino et al., 2006, 2011). On the other hand, the lowest values in June coincides with beginning of the winter period on the south hemisphere, as a result less radiation on the top of the atmosphere.

Others factors that determine the variation of solar radiation in the Amazon forest region are seasonal changes in cloud cover and vegetation burn (da Rocha et al., 2004). A recent study in Cuiabá had detected a large number of burning and hot spots during the dry season due to the low precipitation and relative humidity (Machado et al., 2014). Querino et al. (2006) have noticed smaller values of incoming solar radiation over pasture areas than over natural forest in Amazônia due to the fire during the amazon dry season. Artaxo et al. (2006) observed an increment on the aerosols concentration in the atmosphere because of burning, which increases the solar radiation attenuation (almost 70% of the photosynthetically active radiation is absorbed), and modifies the radioactive balance.

The mean annual temperature was 26.9°C, the average maximum and minimum annual temperature 32.8°C and 21.2°C, respectively (Fig. 4b). The average mean and minimum temperature were significantly higher during the rainy season (27.9 and 23.0°C) and lower during the dry season (25.5 and 18.7°C), but the seasonal average maximum temperature (30.0°C) had no significant difference (Table 3). The temperature gradient was greater in the dry season than in the wet season. The temperature followed seasonal pattern of the region (Biudes et al., 2012; 2014a). The highest values of temperature in the rainy season are related to higher availability of solar radiation (Biudes et al., 2012), which corroborates with the solar radiation results here presented. Besides the lowest values and the highest amplitude of the temperature observed during the dry season could be in response to the periodic appearances of cold fronts locally called "*friagem*" (Marengo & Nobre, 2009; Biudes et al., 2012).

According to Seluchi (2009), *friagem* normally happen because of a well-defined synoptic pattern. The main characteristics of this system are a low precision over the South Atlantic Ocean and a high pressure on the medium and up level of the atmosphere over the Pacific Ocean. The combination of both systems determine the presence of a cold migratory anticyclone on the low level of the atmosphere and the contact between two different air masses (cold from the polar mass and warm from the continent) with distinct thermodynamic characteristic originate the cold fronts (Silva et al., 2014). Satyamurty & Mattos (1989) have

identified on the center-south of the South America that this region is located between two subtropical anticyclones and affirm that the cold front is associated to the baroclinic perturbation originally from the Pacific, that usually cross the Andes in medium latitude. The polar air commonly changes the atmospheric pressure and wind fields decreasing the temperature of the air when it is advancing through the continent (Rodrigues et al., 2004; Seluchi, 2009).

The mean annual relative humidity was 71.6% with maximum value in February (80%) and minimum in August (56.7%) (Fig. 4c), which implies higher relative humidity average during the rainy season (75.9%) than dry season (65.5%) (Table 3). The increase in relative humidity during therainy season is associated to the cold fronts systems that use to be stationary on the South Atlantic Ocean for 3 or more days. Such condition, organizes a moisture canal, which extends from south of Amazônia until the southeast of Brazil, increasing the presence of water vapor in the air, associated with large amount precipitation, named South Atlantic Convergence Zone (SACZ) (Kousky, 1988; Kodama, 1992, Quadro, 1994; Alves et al., 1999; Carvalho et al., 2004; Escobar, 2014).

Besides the SACZ the Intertropical Convergence Zone (ITCZ) is also placed more to the south in the rainy season. It helps the transport of the moisture from the ocean to the countryside. According to Melo et al. (2009) ITCZ is formed by the confluence of the trade winds, is characterized by a convective cloud band and is considered one of the most important precipitation maker on equatorial regions. The authors affirmed also that the association with others system such SACZ is extremely important to define the quality of the rainy period on north region of Brazil, and consequently corroborating to the elevation or reduction of relative humidity.

The lowest values of relative humidity in the dry season are associated to lowest availability of soil water, which causes a decrease in evapotranspiration and consequent increase in sensible heat flux (Wright et al., 1996; Biudes et al., 2009). During the dry season, the Continental Tropical Mass has no significant activity and the influence of Continental Equatorial Mass about Cuiabá is reduced, and the Atlantic Tropical Mass and the Atlantic Polar Mass activity increase. These masses are anticyclone systems that cause atmospheric stability and prevent the formation of convective cloud because tends to bring the dry air from up atmosphere to the surface and as consequence, precipitation is suppressed and relative humidity decrease (Nimer, 1989).

According to Marengo & Nobre (2009), during the winter the circulation on high level of the atmosphere is characterized by
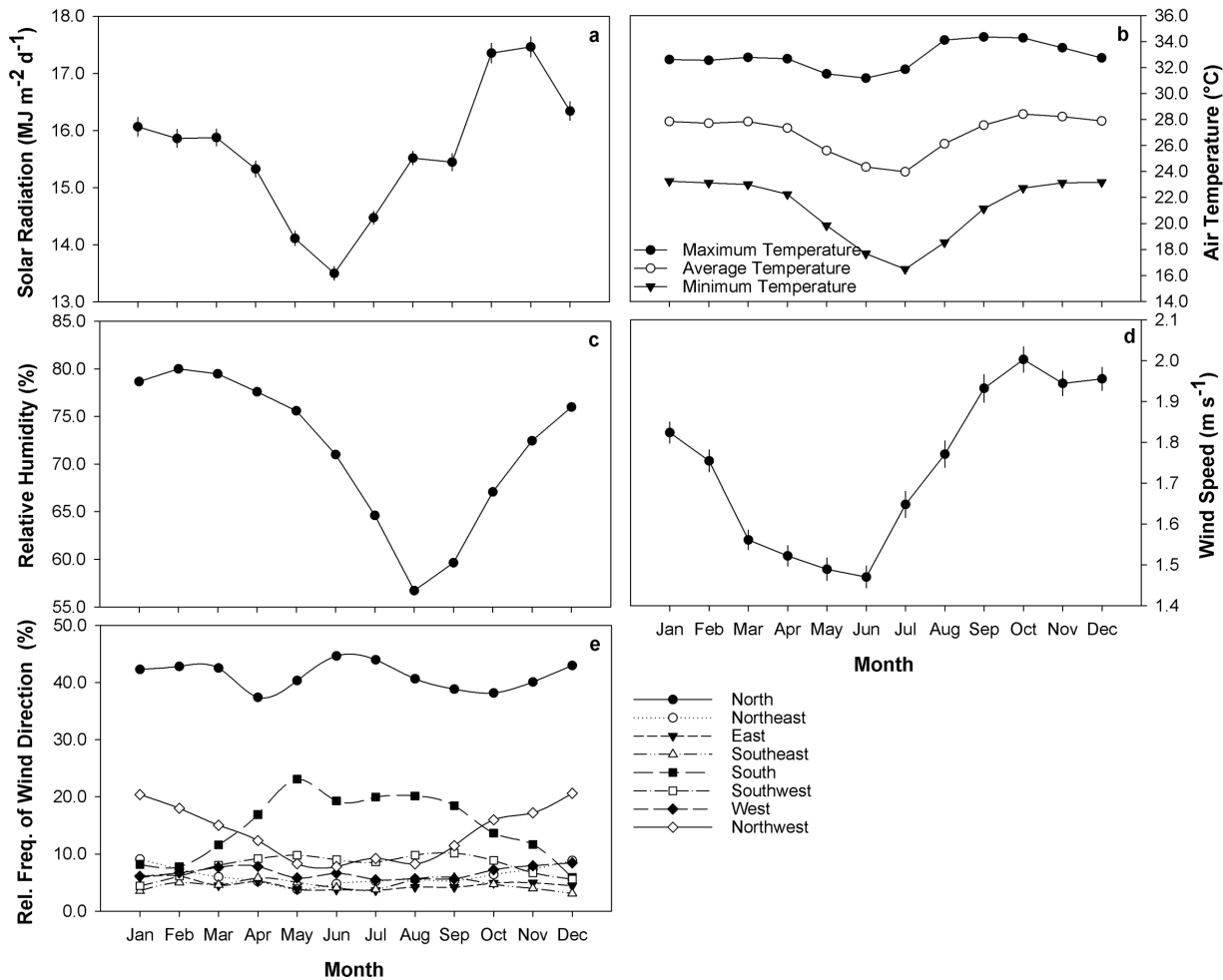
Figure 4 – Monthly average and standard error of solar radiation (a), maximum, average and minimum air temperature (b), relative humidity (c), wind speed (d), and wind direction (e) in Cuiabá, Mato Grosso, Brazil.

the weakening of the air fluxes over the tropic region. It means that the subtropical wind jet on high level becomes stronger and positioned close to the equator than in the summer season, in agreement with the downdraft of the Hadley's Circulation. The authors also observed that in low level of the atmosphere ITCZ is positioned on the north hemisphere reducing the moisture transport into the continent. Those combinations of factors result in relative humidity decline.

The annual mean of wind speed was 1.7 m s^{-1}, the maximum value occurs in October (2.0 m s^{-1}) and the minimum in June (1.5 m s^{-1}) (Fig. 4d). There was no significant seasonal difference between the rainy (1.8 m s^{-1}) and dry (1.7 m s^{-1}) seasons. The wind occurs due to the gradient pressure between two points (Pereira et al., 2002), but it's also influenced by the Earth rotation, centrifugal force to its movement, as well as the topography

(Tubelis & Nascimento, 1984). Cuiabá is located in a depression surrounded by Plateaus, which causes low frequency and average wind speed, minimizing heat exchange by convection (Vilanova & Maitelli, 2009). The wind speed is higher in near towns localized in higher altitudes than Cuiabá and the maximum and minimum wind speed occurs in different period, as the example of Tangará da Serra, which has higher values in August (3.5 m s^{-1}) and minimum in March (2.5 m s^{-1}) (Dallacort et al., 2010).

There was a predominance of wind from the North (N) in Cuiabá (Fig. 4e). In the dry season, there was a decreasing in the frequency of wind direction from Northwest (NW) and a increasing of the occurrence of wind from the South (S). This wind pattern characterizes a typical monsoon regime (Santanna et al., 2008), which causes rainy summers and dry winters due to seasonal reversal of wind direction (Gan et al., 2009). This study area

is located under the influence of the Atlantic Tropical Mass and the Atlantic Polar Mass to beyond the Chaco and Amazon depressions during the winter (Keller-Filho et al., 2005).

It is noteworthy that, the seasonal pattern of meteorological variables are mainly controlled by large and mesoscale systems in the Central-West Region of Brazil where the study area is located. The Central-West Region of Brazil is under climatic influence of tropical and subtropical atmosphere systems (Alves, 2009). During wet season, South Atlantic Convergence Zone (SACZ) is associated to a humidity convergent outflow from Amazônia to Brazilian Southeast passing through Central-West Region, which is responsible by rain extreme events. On the other hand, SACZ absence can cause rain suppression and long periods of drought (Carvalho & Jones, 2009). There are still cold surges, or *friagem*, caused by outbreaks of polar air during wintertime (May-August), with low temperatures in midlatitudes, which affect southern Brazil with considerable cooling in central and northern Amazônia (Parmenter, 1976; Marengo et al., 1997).

CONCLUSIONS

The climate of Cuiabá is characterized by two distinct seasons, a dry (May to September) and a wet (October to April) and it is mainly driven by large scale climatological phenomenon. The rainiest month is January in while the driest is July. Cuiabá has drier days than rainier days during the year. The interannual variability of precipitation is driven by meso-large scale atmospheric system, such as cold fronts, SACZ, ITCZ. The peak of solar radiation is reached on the beginning of summer season and it is basically due to astronomical factors. Maximum and minimum average temperatures present the same standard of solar radiation reaching its values in November and July, respectively. Other important factor was the predominance of *friagem* during the winter (dry season) that decreases the average temperature. The highest values of relative humidity occur during the rainy season, mainly due to the SACZ and the Continental Tropical Mass. On the other hand, the lowest values of relative humidity occur during the dry season due to the displacement of atmospheric systems, as well as the total inhibition of others, such Bolívia High Pressure. The wind speed is low in Cuiabá and had no seasonal variation due to the topography. The wind direction is predominantly from N during whole year. Although, South direction frequency is commonly observed during the winter season due to the advance of polar mass through the continent.

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