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Evaluation of methods for estimating atmospheric emissivity in Mato-Grossense Cerrado

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ABSTRACT

This study analyzed the performance of the Brunt (1932), Swinbank, (1963), Idso and Jackson (1969), Brutsaert (1975), Idso (1981), and Bignami *et al.* (1995) methods to estimate atmospheric emissivity under grass-dominated savannas (known as *campo sujo Cerrado*), in the region of Baixada Cuiabana. The estimates were compared with data obtained by energy balance equation in two seasons, dry season (May to August), and wet season (September to December) of 2009. The Swinbank and Idso and Jackson methods, that consider only air temperature, show better performances for the wet season. However, methods that consider water vapor pressure and air temperature (Brunt, Brutsaert, Bignami and Idso) show good performances for the dry season. The Idso and Brutsaert methods show the highest index of agreement and are recommended to estimate atmospheric emissivity for the region.

Keywords: air temperature, campo sujo Cerrado, water vapor pressure.

Avaliação de métodos para estimativa da emissividade atmosférica no cerrado Mato-Grossense

RESUMO

Este trabalho analisou o desempenho dos métodos de Brunt (1932), Swinbank (1963), Idso and Jackson (1969), Brutsaert (1975), Idso (1981) e Bignami *et al.* (1995) para estimativa da emissividade atmosférica para dados obtidos na região do Cerrado *Campo Sujo*, na baixada cuiabana. As estimativas foram comparadas com dados calculados pela equação do balanço de energia para dois períodos estudados, seco (maio a agosto) e chuvoso/úmido (setembro a dezembro) de 2009. Os métodos de Swinbank e Idso and Jackson, que levam em consideração apenas a Temperara do ar, obtiveram melhor desempenho durante o período chuvoso. Em contrapartida, os métodos que levam em consideração a pressão de vapor d'água e a temperatura do ar (Brunt, Brutsaert, Bignami e Idso) tiveram melhor desempenho durante a estação seca, sendo as equações de Idso e Brutsaert que apresentaram melhor desempenho para o local e período estudados, obtendo os maiores índices de concordância, e sendo assim, as equações mais indicadas para a estimativa da emissividade atmosférica para o local de estudo.

Palavras-chave: campo sujo Cerrado, pressão de vapor d'água, temperatura do ar.

1. INTRODUCTION

Tropical savannas cover approximately 12% of the Earth's land area (Scholes and Archer, 1997) and are characterized by high plant species diversity (Giambelluca *et al.*, 2009). The Brazilian savanna (locally known as Cerrado) covers about 24% of the territory and is the dominant vegetation in areas subjected to a prolonged dry season (San José *et al.*, 1998). In the last decades, the anthropic activities in the Cerrado have been causing strong changes in this biome, in particular, in its conversion to pastures and the production of soybean and sugarcane (Klink and Moreira, 2002; Rodrigues *et al.*, 2014), besides the high rates of deforestation that are causing a mosaic of natural forests and arable land (Biudes *et al.*, 2015). That mosaic implies land cover changes, provoking changes in the distribution of solar energy that is available to the environment (Novais *et al.*, 2015; Faria *et al.*, 2018), which affects directly the biophysical process linked to regional energy balance (Rodrigues *et al.*, 2016).

One way to observe changes caused by anthropogenic action is by characterizing variations in surface radiation balance values, because the fluctuation of these values results in energy partitioning. For example, outgoing longwave radiation (OLR) is very important for meteorological studies, such as predicting diurnal temperature variations, frosts, and nighttime fog, as well as evaluations of radiation cooling of buildings at night (Jimenez *et al.*, 1987). However, it is the hardest variable of radiation balance components to measure (Aguiar *et al.*, 2011).

Since atmospheric emissivity (ε) is a determining factor for longwave radiation (OLR), many studies have been committed to analyze atmospheric behavior. Considering that atmospheric gases absorb and emit radiation, atmospheric emissivity (ε) can be presented as a function, the variation of which depends on water vapor content in the atmosphere and air temperature (Heitor *et al.*, 1991), as water vapor acts as a thermoregulator by absorbing infrared radiation.

According to the Stefan-Boltzmann Law (Equation 1), every body emits radiant energy, which depends on its temperature and emissivities, and the latter is calculated by a ratio of the energy radiated by the body to the energy radiated by a black body for the same wavelength. Any object that is not a real black body has an emissivity value under 1 and higher than 0 (Equation 1).

$$R = \sigma \, \varepsilon \, T^4 \tag{1}$$

Where $\sigma = 5.6697 \times 10^{-8}$ W m^{-2} K^{-4} is the Stefan-Boltzmann Constant, T (K) is the air temperature, ε is the emissivity, and R is the radiant energy.

Then, R can be considered as longwave radiation under clear sky conditions, being modelled as a function of air temperature (*Tar*), or actual water vapor pressure (e*a*), or both. Therefore, any method used to estimated of ORL can be rewritten using the Stefan-Boltzmann Law and estimates atmospheric emissivity (ε).

The majority of equations that estimate atmospheric emissivity using longwave radiation are only valid for clear sky days, and show better results when a daily basis or a long-term average is considered (Von Randow and Alvalá, 2006).

Curado *et al.* (2011), studying the Pantanal Mato Grossense, obtained higher atmospheric emissivity values during the wet season, because during this period there were a higher content of water in the atmosphere and quantity of clouds compared to the dry season. Following the same line of research, Nogueira and Lima (2011) assured that the higher radiation absorption by the clouds cause the rise of air temperature, and consequently raises its emission; i.e., the bodies that absorb more radiation also are the ones that emit more radiation (black body radiation law)

Considering how important is effect of *campo sujo* Cerrado on the climate of Mato Grosso state and the lack of information about atmospheric emissivity for this biome, the objective of this study was to assess the performance of the Brunt (1932), Swinbank (1963), Idso and Jackson (1969), Brutsaert (1975), Idso (1981), and Bignami *et al.* (1995) models on atmospheric emissivity (ε) estimates for *campo sujo* Cerrado from May to December 2009, compared with emissivity values obtained by the energy balance equation.

2. MATERIALS AND METHODS

2.1. Study Area

The study was conducted at the Fazenda Miranda (FM) in the region of Baixada Cuiabana, located 15 km away from Cuiaba, Mato Grosso, Brazil (15°43'53" S; 56°04'18" W; 157 m). The study site was a mixed forest-grassland (locally known as *campo sujo* or “dirty field”) that was partially deforested approximately 35 years ago (Rodrigues *et al.*, 2014).

Vegetation consists predominantly of grasses and tree species *C. americana* and *Diospyros hispida* A. DC. According to the Köppen climate classification system, the climate in this area is Aw, tropical semi-humid, with dry winters and wet summers (Rodrigues *et al.*, 2016). Mean annual rainfall and temperature are 1420 mm and 26.5°C, respectively, and rainfall is seasonal (Vourlitis and Da Rocha, 2011). The range of mean monthly air temperature is wider than tropical and subtropical moist forests, with a minimum of 23.5°C in June and a maximum of 28.6°C in September (Vourlitis and Da Rocha, 2011). The research area is on a flat terrain at an elevation of 157 m above sea level. The soil type is a rocky, dystrophic red-yellow latosol locally known as *Solo Concrecionário Distrófico* (CPRM, 1982).

2.2. Instrumentation

Micrometeorological measurements were conducted between May to December 2009, where two local defined seasons can be observed: the dry season, with rainfall below 100 mm (May to August); and the wet season, with rainfall above 100 mm (September to December). A micrometeorological tower enabled the collection of data on air temperature (*Tar*), relative humidity (RH), wind speed (u), precipitation (Ppt), soil temperature (Ts), soil heat flux (G), net radiation (Rn) and solar radiation (Rs).

Tar and RH were measured 10 m above the ground level using a thermohygrometer (HMP45AC, Vaisala Inc., Woburn, MA, USA). Wind speed was measured 10 m above the ground level using anemometer (03101 R.M. Young Company), and G was measured using heat flux plates (HFP01-L20, Hukseflux Thermal Sensors BV, Delft, Netherlands) installed 1.0 cm below the soil surface, with one placed in a sandy soil type and the other placed in a laterite soil type, which were typical of the local soil in the tower footprint. Rn and Rs were measured 5 m above ground using a net radiometer (NR-LITE-L25, Kipp and Zonen, Delft, Netherlands) and a pyranometer (LI200X, LI-COR Biosciences, Inc., Lincoln, NE, USA), respectively. Precipitation was measured using a tipping bucket rainfall gauge (TR-525M, Texas Electronics, Inc., Dallas, TX, USA). The sensors were connected to a data logger

(CR1000, Campbell Scientific, Inc., Logan, UT, USA) that scanned each sensor every 30 s and stored average, and in the case of Ppt, total quantities every 30 min.

2.3. Atmospheric Emissivity Calculation

According to Duarte *et al.* (2006), since atmosphere does not have constant temperature, a local parametrization of atmospheric emissivity (ε) is necessary, which depends on air temperature.

We tested six different models that can be used in the local temperature range (Table 1). The first two models to estimate emissivity (ε) were proposed by Swinbank (1963), and Idso and Jackson (1969). Both models were chosen because they only consider temperature in their estimates, in a range of 2 to 29°C and -29 to 37°C, respectively. Table 1 also shows the models proposed by Brutsaert (1975), Brunt (1932), Bignami (1995) and Idso (1981), that were chosen because they work in a temperature range between -40 and 45°C and consider actual water vapor pressure (*ea*) in hPa (Equation 2) (Idso, 1981; Prata, 1996; Duarte *et al.*, 2006).

Table 1. Equations used to estimate atmospheric emissivity (ε), where σ is the Stefan-Boltzmann constant (5.6697×10^{-8} W m^{-2} K^{-4}), e_a is the actual water vapor pressure (hPa), and T*ar* is the air temperature (K) next to the surface.

Model	Equation
Brunt (1932)	$\varepsilon = 0{,}52 + 0{,}065 \sqrt{e_a}$
Swinbank (1963)	$\varepsilon = 9{,}2 \,.\, 10^{-6}\, {T_{ar}}^2$
Idso and Jackson (1969)	$\varepsilon = 1 - 0{,}26\, exp[-7{,}77 \,.\, 10^{-4}\, (273 - T_{ar})]$
Brutsaert (1975)	$\varepsilon = 1{,}24\, (e_a/T_{ar})^{1/7}$
Idso (1981)	$\varepsilon = 0{,}7 + 5{,}95 \,.\, 10^{-5} e_a\, exp(1500/T_{ar})$
Bignami (1995)	$\varepsilon = 0{,}684 + 0{,}0056\, e_a$

Actual water vapor pressure (*ea)* is described as Equation 2.

$$e_a = \frac{e_s \,.\, RH}{100} \tag{2}$$

Where e_s is the saturation water vapor pressure determined by the Tetens Equation (Tetens, 1930) (Equation 3).

$$e_s = 6{,}1078 \,.\, 10^{\frac{7{,}5\,.\,T_{ar}}{273{,}3 + T_{ar}}} \tag{3}$$

It is important to highlight that the methods used in this study were originally created to estimate ORL and by Equation 1 we could estimate ε.

The emissivity over fully vegetated surface show low variability, with its value usually ranging between 0.94 to 0.98 according to Food And Agriculture Organization Of The United Nations (1991). Nevertheless, the most-used value for surface emissivity is 1.

The atmospheric emissivity values estimated by the six methods presented in Table 1 were compared with emissivity values calculated by the energy balance equation (Equation 4). Its input data were measured during the study period by the instrumentation cited in Section 2.2.

$$\varepsilon = \frac{Rn - Rg + rRg + \sigma Ts^4}{\sigma Tar^4} \tag{4}$$

Where Rn (Wm^{-2}) is the net radiation, Rg (Wm^{-2}) is the incident global radiation, rRg (Wm^{-2}) is the surface albedo, σTar^4 (K^4) is the energy emitted by the atmosphere, σTs^4 (K^4) is the energy emitted by the soil, and ε is the atmospheric emissivity.

All the equations analyzed in this study make the assumption that ε is a function of temperature and/or vapor pressure near the ground.

2.4. Statistical analysis

The performance in atmospheric emissivity for each equation was assessed statistically using Mean Absolute Deviation (MAD), Mean Squared Error (MSE), and coefficient of determination (R^2) by linear regression without interception. Also were used Willmott's index of agreement (d), which indicates the estimation agreement level when compared with measured values (Willmott *et al.*, 1985), the Pearson correlation coefficient (r), which indicates the correlation level between observed and estimated values, and the confidence coefficient or Camargo and Sentelhas performance (c). The value of d and r must varies from 0 to 1, indicating non-concordance and perfect concordance, respectively (Machado *et al.*, 2015).

3. RESULTS AND DISCUSSION

3.1. Air temperature and relative humidity seasonal variation analysis

Sky conditions are directly related to atmospheric emissivity; therefore, a study of air temperature (*Tar*) and relative humidity (RH) seasonal variation is needed, since atmospheric conditions, as well as its components, mainly water vapor, have a strong influence on longwave radiation quantity that is irradiated to Earth's surface.

Mean monthly air temperature for the dry season varied from 11.22 to 31.95°C, with an average of 26.03°C. For the wet season, air temperature values ranged from 17.58 to 34.22°C, with an average of 28.33°C (Figure 1).

Relative humidity varied between 31.56% and 94.31% for the dry season and 35.21% and 94.75% for wet season, with average values of 60.59% and 64.99%, respectively. It was not possible to observe a pattern during the year, considering that its value in dry season decreases in comparison with wet season. This relation can be observed due to rainfall regularity, from September to March, and absence, from May to August.

Thus, it is expected for atmospheric emissivity values to be higher in the wet season than in the dry season, since higher values of relative humidity and air temperature can be observed during the wet season.

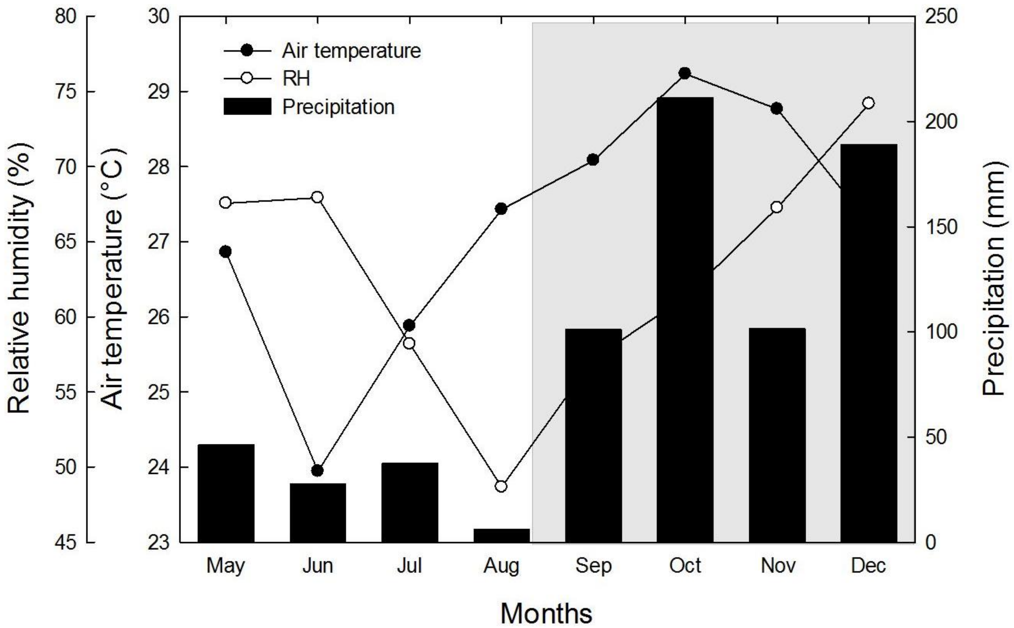

Figure 1. Mean monthly air temperature, relative humidity, and accumulated rainfall in 2009. The shaded area represents wet season, i.e., when rainfall > 100 mm.

Accumulated rainfall average value was equal to 29.38 mm for the dry season and 149.08 mm for the wet season. The lowest value was observed in August, 6.20 mm, while the highest was observed in October, 211 mm.

3.2. Atmospheric emissivity behavior analysis

The method used as reference in this study, the energy balance equation, has small instrumental errors inherent to micrometeorological data collection. Therefore, due to intrinsic errors related to the method, we found atmospheric emissivity values above 1.00, which is theoretically a black body emissivity. Table 2 shows the Mean Absolute Deviation (MAD) and Mean Squared Error (MSE) values.

Table 2. Minimum (Min), average (Avg), and maximum (Max) values of monthly atmospheric emissivity computed by energy balance (BE), Brutsaert (BT), Bignami (BG), Brunt (BR), Idso (ID), Idso and Jackson (IJ), and Swinbank (SW) equations under *campo sujo* Cerrado at the Fazenda Miranda.

Dry season												
	May			**June**			**July**			**August**		
	Min	**Avg**	**Max**	**Min**	**Avg**	**Max**	**Min**	**Avg**	**Max**	**Min**	**Avg**	**Max**
BE	0.93	0.98	1.06	0.88	0.95	1.05	0.88	0.94	1.00	0.86	0.93	1.08
IJ	0.79	0.85	0.87	0.80	0.84	0.86	0.76	0.84	0.87	0.74	0.83	0.89
SW	0.77	0.82	0.84	0.78	0.82	0.84	0.74	0.82	0.84	0.69	0.80	0.86
BT	0.84	0.88	0.91	0.82	0.87	0.91	0.82	0.86	0.91	0.80	0.83	0.89
BR	0.80	0.90	0.94	0.82	0.89	0.93	0.76	0.90	0.94	0.81	0.92	0.98
BG	0.77	0.83	0.85	0.78	0.82	0.85	0.76	0.81	0.84	0.77	0.80	0.84
ID	0.83	0.90	0.94	0.84	0.89	0.94	0.84	0.87	0.92	0.82	0.85	0.93
Wet Season												
	September			**October**			**November**			**December**		
	Min	**Avg**	**Max**	**Min**	**Avg**	**Max**	**Min**	**Avg**	**Max**	**Min**	**Avg**	**Max**
BE	0.89	1.03	1.11	0.97	1.04	1.09	0.92	1.04	1.12	0.85	1.03	1.09
IJ	0.80	0.86	0.90	0.85	0.87	0.89	0.83	0.86	0.88	0.83	0.87	1.00
SW	0.82	0.83	0.87	0.84	0.84	0.86	0.87	0.84	0.85	0.88	0.71	0.84
BT	0.81	0.86	0.90	0.90	0.87	0.89	0.86	0.88	0.91	0.69	0.76	0.91
BR	0.78	0.92	1.00	0.83	0.93	0.98	0.84	0.93	0.96	0.68	0.88	0.94
BG	0.78	0.82	0.85	0.82	0.85	0.87	0.82	0.86	0.87	0.82	0.83	0.87
ID	0.84	0.88	0.90	0.88	0.91	0.89	0.91	0.93	0.88	0.92	0.80	1.00

The energy balance method was adopted due to lack of local values of atmospheric emissivity in literature that could be considered as reference values, specifically for *campo sujo* Cerrado. Regarding the other six models, they have small instrumental errors too; they also show small errors related to each method, since the models have local parameters from where the model was initially proposed (constant values presented in each equation). Those parameters were not modified to the study area, as we wanted to evaluate the performance of each method in their original proposes.

Therefore, the results show that the six models have errors close to the instrumental errors used in this study, which makes this model an alternative to estimate atmospheric emissivity in the *campo sujo* Cerrado, using only two variables: air temperature (*Tar*) and relative humidity (RH).

These unique parameters (local constants) are extremely important to evaluate which method is more appropriate for *campo sujo* Cerrado. The Swinbank, and Idso and Jackson equations consider air temperature only, while the Brunt, Brutsaert, Idso, and Bignami equations consider, besides *T*, relative humidity, which is an effect of water vapor volume in the atmosphere. It is expected of those models that consider *T* only to estimate better values of atmospheric emissivity during dry seasons, considering the mean precipitation to be close to 0. For the other models, it is likely that they estimate better values of ε during wet seasons, because water volume in atmosphere increases significantly, raising RH values.

During the study period, the mean daily atmospheric emissivity (ε) calculated by the energy balance equation showed large variation during the dry season, ranging from 0.88 to 1.00, which is the maximum value. For Brutsaert and Brunt methods, emissivity values during the dry season varied from 0.80 to 0.91, and from 0.76 to 0.98, respectively, showing that those models estimate atmospheric emissivity within range of energy balance (Figure 2). That also happened during the wet season (Figure 3). The emissivity values by energy balance equation ranged from 0.85 to values higher than 1.00. Using the Bignami and Idso models, the values varied from 0.78 to 0.87, and 0.84 to 1.00, respectively. The average, minimum and maximum monthly values of atmospheric emissivity are shown in Table 2.

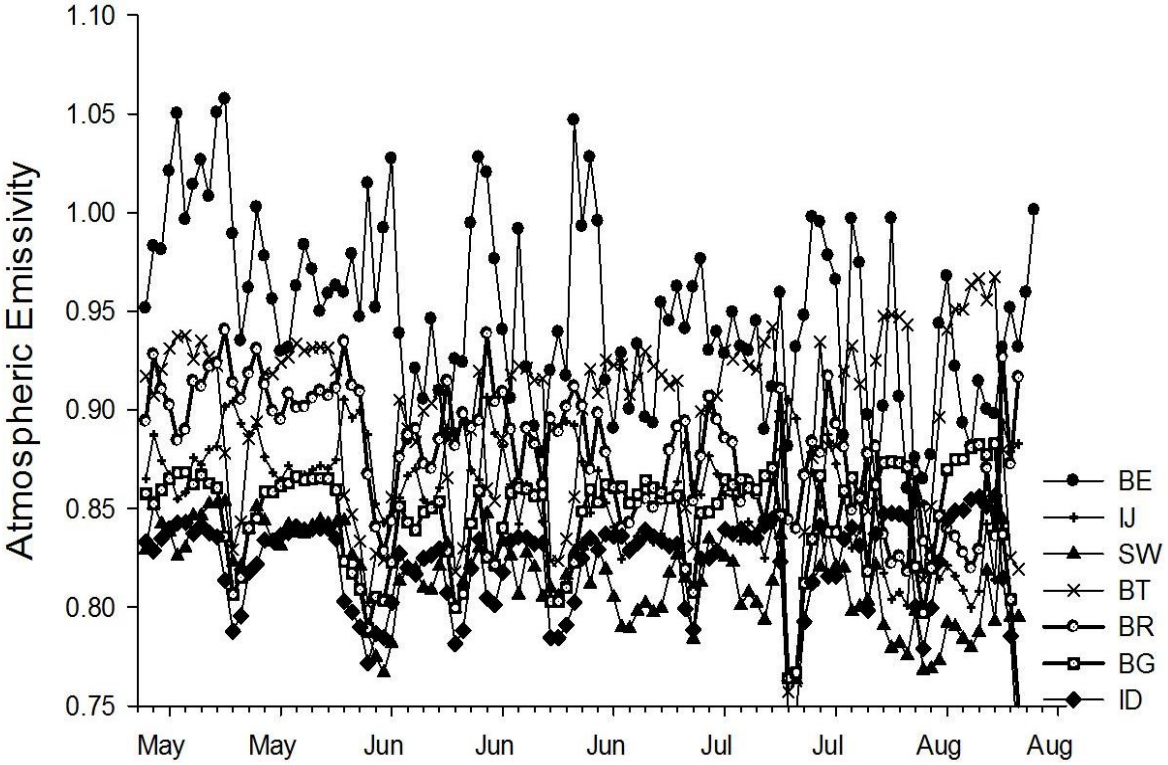

Figure 2. Mean daily atmospheric emissivity for the dry season computed by energy balance (BE), Brutsaert (BT), Bignami (BG), Brunt (BR), Idso (ID), Idso and Jackson (IJ), and Swinbank (SW) equations under *campo sujo* Cerrado at the Fazenda Miranda.

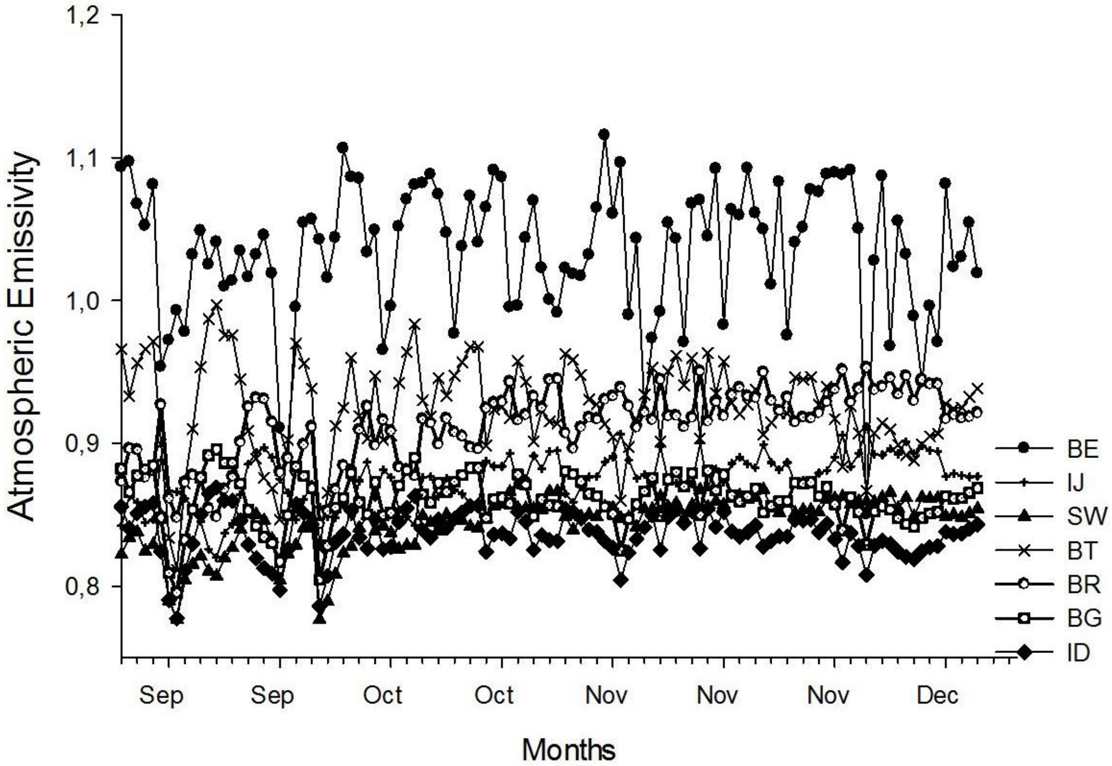

Figure 3. Mean daily atmospheric emissivity for the wet season computed by energy balance (BE), Brutsaert (BT), Bignami (BG), Brunt (BR), Idso (ID), Idso and Jackson (IJ), and Swinbank (SW) equations under *campo sujo* Cerrado at the Fazenda Miranda.

3.3. Atmospheric emissivity models performance

To evaluate the performance of the equations proposed by Brunt, Swinbank, Idso and Jackson, Brutsaert, Idso, and Bignami to estimate atmospheric emissivity (ε), mean ε daily values from May to August were used, covering a dry season and a part of the wet season, from September to December.

After estimations, the ε values were divided by periods and Mean Absolute Deviation (MAD), Mean Squared Error (MSE), and coefficient of determination (R^2) were calculated using linear regression without interception. Willmott's index of agreement (d), the Pearson correlation coefficient (r), and the confidence coefficient or Camargo and Sentelhas performance (c) were calculated as well, as shown in Table 3.

Low error values for the wet season (September to December) showed that the models adjust to the study area, where the variation ranges of MAD (-0.07 to -0.13), MSE (0.19 to 0.22), and R^2 (0.93 to 0.95) were lower than the values for the dry season. For the dry season, MAD ranged from -0.09 to -0.12, MSE ranged from 0.18 to 0.27, and R^2 varied from 0.89 to 0.96.

Negative MAD values indicate underestimation, while positive values indicate overestimation. We noted that the six models tend to underestimate atmospheric emissivity values. Due to lack of studies about atmospheric emissivity in literature, the performance of our estimates were compared to Von Randow and Alvalá (2006) and Aguiar *et al*. (2011). Those studies estimated ORL using the same models. This underestimation tendency was also found by to Von Randow and Alvalá (2006) and Aguiar *et al.* (2011), which indicated that the problems could be related to the coefficients used on the equations, which are adjusted to other regions.

It is possible to observe in Table 3 that the Pearson correlation coefficient (r) values for dry period are above 0.3, which are characterized as intermediate and high correlations, indicating good precision when compared to monthly average. Idso and Jackson method obtained the lowest value for dry season, while Brutsaert, Bignami, and Idso models showed the best coefficient with a value of 0.59 each one.

For the wet season, the r values were very low and considered as low and very low. Idso and Jackson equation indicated the best effectiveness, with an r value of 0.31. The other methods obtained r values lower than 0.30 and were interpreted as low correlation.

About the confidence coefficient or Camargo and Sentelhas performance (c), for wet season, very poor performance were found for every method used. For dry season, the best results were found for Brutsaert, and Idso models, which indicated poor performance, and the other methods were determined as very poor.

Table 3. Statistical analyses of observed (computed by energy balance equation) and estimated atmospheric emissivity values.

Method	MAD	MSE	R^2	d	r	Classification	c	Performance
				Dry season				
Idso and Jackson	-0.07	0.22	0.93	0.32	0.33	Intermediate	0.11	Very Poor
Swinbank	-0.09	0.22	0.93	0.38	0.41	Intermediate	0.15	Very Poor
Brutsaert	-0.09	0.20	0.94	0.72	0.59	High	0.42	Poor
Brunt	-0.05	0.20	0.95	0.71	0.55	High	0.39	Very Poor
Bignami	-0.13	0.22	0.93	0.68	0.59	High	0.40	Very Poor
Idso	-0.07	0.19	0.95	0.73	0.59	High	0.43	Poor
				Wet season				
Method	**MAD**	**MSE**	**R^2**	**d**	**r**	**Classification**	**c**	**Performance**
Idso and Jackson	-0.09	0.18	0.96	0.31	0.31	Intermediate	0.09	Very Poor
Swinbank	-0.12	0.27	0.89	0.18	-0.12	Low	-0.02	Very Poor
Brutsaert	-0.10	0.24	0.92	0.16	-0.17	Low	-0.03	Very Poor
Brunt	-0.10	0.24	0.92	0.16	-0.17	Low	-0.03	Very Poor
Bignami	-0.10	0.20	0.94	0.26	-0.07	Very Low	-0.02	Very Poor
Idso	-0.08	0.22	0.94	0.16	-0.16	Low	-0.02	Very Poor

Idso equation obtained the highest R^2 value for the dry season, a high R^2 value of 0.94 for wet season, evidencing low error values compared to observed data, and the best r and c values for dry season, which represent the errors in comparison with regression equation.

For the wet season, the model with best performance was the Idso and Jackson equation, being the only method used with positive c and the highest R^2 value, 0.96.

The Brutsaert, Brunt, and Bignami equations had similar results. On the other hand, the Swinbank and Idso and Jackson methods results were very much alike too, and both models consider *Tar* only.

Figures 2 and 3 show values of daily average cycle of atmospheric emissivity, and it is possible to observe again that the values in the wet season are higher than in the dry season, and that the modelled values underestimate the emissivity found by energy balance equation.

For the dry season, Idso and Brutsaert equations showed the best model performances. On the other hand, the equation developed by Idso and Jackson results were more efficient for the wet season, where thermal amplitude is low, showing a sensitivity of this equation to the air temperature variation, since water vapor practically does not vary throughout the day.

Regarding the energy available to the environment, since atmospheric emissivity varied seasonally, with higher values observed during the wet season, the average energy of longwave radiation (ORL) that comes from the available atmosphere also varied from one period to another. Considering the higher emissivity during the wet season, during this period there was a higher availability of energy to the environment (Curado et al., 2011).

4. CONCLUSIONS

The equations evaluated in this study showed poor performance during the studied year, and only during the dry season was their performance acceptable. Those results were expected, since high cloudiness conditions negatively affected the models' performance for the wet season.

For dry season, the methods that consider water vapor pressure and air temperature show better performance than models that consider air temperature only, as with the Swinbank (1963) and Idso and Jackson (1969) equations. However, for the wet season, the Idso and Jackson (1969) model is more efficient, indicating a sensitivity associated to the air temperature.

The Idso (1981) and Brutsaert (1975) equations show better performance for the study area, obtaining higher indexes of agreement. Therefore, these models are the most suitable methods to estimate atmospheric emissivity for *campo sujo* Cerrado.

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