*Brazilian Journal of Biosystems Engineering v. 10(2): 217-233, 2016*

# REFERENCE EVAPOTRANSPIRATION BY PENMAN–MONTEITH FAO 56 WITH MISSING DATA OF GLOBAL RADIATION

**A. P. de Souza[1*], A. A. Tanaka[1], A. C. da Silva[1], E. M. Uliana[1], F. T. de Almeida[1], A. W. A. Gomes[2], A. E. Klar[3]**

[1] *UFMT - Univ Federal de Mato Grosso, Instituto de Ciências Agrárias e Ambientas, Campus de Sinop, MT, Brasil*
[2] *UFRPE - Univ Federal Rural do Pernambuco, Unidade Acadêmica de Garanhuns, PE, Brasil*
[3] *UNESP - Univ Estadual Paulista, Faculdade de Ciências Agronômicas, Departamento de Engenharia Rural, Botucatu, SP, Brasil*

*Article history*: Received 19 May 2016; Received in revised form 20June 2016; Accepted 23 June 2016; Available online 30 July 2016.

## ABSTRACT

The aim of this study was to evaluate the errors generated on the reference evapotranspiration ($ET_0$) estimation by Penman-Monteith FAO 56 (PMF 56) when employed simplified models to estimate the global radiation ($H_G$) are based on the air temperature. We evaluated 28 automatic weather stations (EMA's) belonging to the National Institute of Meteorology (INMET) network, in different biomes of Mato Grosso state. Was evaluated fifteen simplified models of $H_G$ estimate calibrated regionally and five models without calibration. It was used as a reference ETo obtained by PMF 56, with $H_G$ measure. The statistical performance were employed mean bias error (MBE), root mean square error (RMSE), adjustmentindex (d) and the cumulative numerical order of the different models in each index. The regional calibration models $H_G$ estimation models improve the estimates of ETo. Can be used Bristow and Campbell (1984) and Goodin et al. (1999), De Jong and Stewart (1993) models to $H_G$estimates and then $ET_0$ to Amazon, Cerrado and Pantanal, respectively.

**Keywords**: Minimum data, solar radiation, air temperature, statistical indicative

# EVAPOTRANSPIRAÇÃO DE REFERÊNCIA POR PENMAN-MONTEITH FAO 56 COM AUSÊNCIA DE DADOS DE RADIAÇÃO GLOBAL

## RESUMO

Objetivou-se avaliar os erros gerados na estimativa da evapotranspiração de referência ($ET_0$) pelo método de Penman-Monteith FAO 56 (PMF 56) quando são empregados modelos simplificados de estimativa da radiação global ($H_G$) baseados na temperatura do ar. Foram avaliadas 28 estações meteorológicas automáticas (EMA's) pertencentes a rede do Instituto Nacional de Meteorologia (INMET), nos diferentes biomas do Estado de Mato Grosso. Foram avaliados quinze modelos simplificados de estimativa de $H_G$ calibrados regionalmente e cinco modelos sem calibração. Empregou-se como referência a ETo obtida por PMF 56, com $H_G$ medida. Na avaliação do desempenho estatístico foram empregados os indicativos estatísticos de erro relativo médio (MBE), raiz quadrática do erro médio (RMSE), índice de ajustamento

---

[*] pachecoufmt@gmail.com

(d) e o ordenamento numérico acumulado dos diferentes modelos em cada índice. A calibração regional de modelos de modelos de estimativa de $H_G$ melhoram as estimativas da ETo. Podem ser empregados os modelos de Bristow e Campbell (1984), Goodin et al. (1999) e De Jong e Stewart (1993) para estimativas de $H_G$ e posteriormente de ETo, para Amazônia, Cerrado e Pantanal, respectivamente.

**Palavras-Chave**: Dados mínimos, radiação solar, temperatura do ar, indicativos estatísticos

## INTRODUCTION

Solar radiation can be considered as the primary source of renewable and natural energy to the environment, which are important in many physical, chemical, biological and biophysical processes that occur on Earth's surface, with applications in areas such as agronomy, ecology, solar energy systems, environment, oceanography, architecture, among others (DAUT et al., 2011; CARVALHO et al., 2011; SOUZA & ESCOBEDO, 2013). Specifically in agricultural systems, solar radiation is essential in photosynthetic processes and the availability of energy for heating air and / or ground, as well as changes of water physical state by evaporation, transpiration and / or evaporation, which together define the water culture needs.

According to Carvalho et al. (2015) the evapotranspiration (ET) is the most active variable of the hydrological cycle and the main component of the water balance in agricultural ecosystems. Therefore, it is an important parameter for the planning and management of water resources (RAZIEI&PEREIRA, 2013; FALAMARZI et al., 2014; MANCOSU et al., 2014).

In general, the conceptual developments of potential evapotranspiration refers to the maximum loss of water from a vegetated surface, low size, in full development and without water deficit, in order to reduce the effect of local advective energy. In this context, evapotranspiration can be directly proportional to the availability of solar energy and radiation balance (CHANG, 1968; PEREIRA et al., 1997; ALLEN et al., 1998; ALLEN et al., 2011).

Direct measurements and/or estimates of solar radiation, specifically global radiation ($H_G$) are important in many evapotranspiration estimation models, therefore, reliability in recording and/or data estimates predict accurately models for hydroagricultural purpose (EL SEBAII & TRABEA, 2003). The lack of $H_G$ measures a generalized manner, it can be considered as a major research limiting and applications for growth simulation models, development and crops yield (HOOK & MCCLENDON, 1992).

According to Souza & Escobedo (2013) routine monitoring of solar radiation was, during a long time, difficult and expensive, because of the high costs limit the acquisition of pyranometers, restricting its use to research centers. And yet, in Brazil, as in many countries, there are several problems in recording weather information for establishment of monitoring networks. Specifically HG, many stations have no pyranometers and/or data acquisition systems, thus making in inconsistent databases with a large number of faults and/or long periods of measurements absence (data loss failures equipment, calibration errors, water accumulation and dirt on the sensor, etc.), which in turn, do not allow seasonality assessments of solar radiation components and/or atmospheric attenuation (WU et al., 2007; ABRAHA & SAVAGE, 2008; ALMOROX et al., 2011).

Therefore, many statistical and/or $H_G$ estimated parametric models were developed based on meteorological parameters (with higher routine measures and/or database), geographic, atmospheric and astronomical. Stand out models based on variables such as sunshine (ANGSTROM, 1924), air temperature (HARGREAVES, 1981; BRISTOW & CAMPBELL, 1984; HUNT et al., 1998;LIU & SCOTT, 2001; ABRAHA & SAVAGE, 2008), using data from nearby stations to the study local (HUNT et al., 1998; TRNKA et al., 2005; RIVINGTON et al., 2006), linear interpolation (SOLTANI et al., 2004), interpolation of neural networks (ELIZONDO et al., 1994; REDDY & RANJAN, 2003), and satellite-based methods (PINKER et al., 1995), generation from time stochastic models (RICHARDSON & WRIGHT, 1984;HANSEN, 1999).

According to the International Commission on Irrigation and Drainage (ICID) and the United Nations of Food and Agriculture Organization (FAO), when evapotranspiration and solar radiation are not monitored, estimates can be employed by mathematical models. However, it is emphasized that the select method to be used depends on factors such as weather conditions, accessibility to necessary meteorological data, complexity of the method, grouping the considered data and costs (CARVALHO et al., 2007;ZANETTI et al., 2008). Thus, it is recommended that the different estimation models are evaluated and / or calibrated to the local climate.

The Penman-Monteith FAO 56 (PMF) is recognized as the standard methodology for estimating reference evapotranspiration by combining energy and aerodynamic components (SMITH, 1991; ALLEN et al., 1998). However, this method requires a greater number of input variables such as solar radiation, air temperature, relative humidity and wind speed. Knowing the difficulty of using the standard method PMF 56 in many regions due to lack of climate data, suggested procedures for estimating missing variables such as vapor pressure deficit and wind speed (CARVALHO et al., 2015) and solar radiation (GAVILÁN et al., 2007; YIN et al., 2008; SENTELHAS et al., 2010). Such procedures have required the assessment in different weather conditions to test their viability (DORNELAS et al., 2006; CUNHA et al., 2008; CARVALHO et al., 2011; TODOROVIC et al., 2013; ALENCAR et al., 2015).

The evaluated equations are based on air temperature, air humidity and precipitation, these variables are monitored in all EMAs above, and these data are available on climate normal on conventional weather stations (EMC's) from INMET network in the Mato Grosso state (12 stations distributed in different regions). Therefore, this assessment allows applications to obtain the global radiation and evapotranspiration in the historical series of EMC's more reliably.Given the above, and the importance of solar radiation in obtaining evapotranspiration, this work aimed to evaluate the estimate of global radiation influence in obtaining the daily reference evapotranspiration by Penman - Monteith FAO 56, for Mato Grosso State.

## MATERIAL AND METHODS

The meteorological data collected by 28 automatic weather stations (EMA's) installed in the Mato Grosso state (Table 1) were obtained from the National Institute of Meteorology (INMET). The EMA's network in Mato Grosso consists of 35 stations; however some had flaws and lack of data, characterized by equipment failure and/or calibration, maintenance periods or disabled, being disregarded in this study. The data period refers to operational time of this weather station.

The Mato Grosso state is located in the Midwest region of Brazil, between the coordinates 06 ° 00' S and 19 ° 45' S and 50 ° 06' W and 62 ° 45'W, totaling area of 903,357,908 km$^2$ (Figure 1). In general, Mato Grosso state has two seasons well defined: rainy season (October to April) and dry (May to September). The average annual temperatures ranged between 23.00 and 26.84 ° C and the total annual rainfall vary from 1200 to 2000 mm, with higher levels in the North and East, Northern State and the areas with altitudes close to 800m. The Köppen climate classification, occur climate types Aw (Climate Tropical Savannah) and Cwa (altitude tropical climate) (SOUZA et al., 2013).

**Table 1.** Automatic Weather Stations of INMET network evaluated in Mato Grosso State

| Region | Code | Station name | Latitude | Longitude | Altitude (m) | Data Period | Number of data | Effective data | Losses (%) |
|---|---|---|---|---|---|---|---|---|---|
| Amazon and transitions | A-924 | 1. Alta Floresta | -10.0672 | -56.7522 | 294 | 09/2011-01/2013 | 519 | 422 | 18.69 |
| | A-910 | 2. Apiacás | -9.5639 | -57.3936 | 220 | 10/2006-01/2013 | 2315 | 1364 | 41.08 |
| | A-926 | 3. Carlinda | -9.9703 | -55.8272 | 300 | 04/2008-01/2013 | 1768 | 1517 | 14.2 |
| | A-906 | 4. Guarantã do Norte | -9.9500 | -54.8833 | 320 | 05/2007-01/2013 | 2102 | 1338 | 36.35 |
| | A-919 | 5. Cotriguaçu | -9.9061 | -58.5719 | 261 | 01/2008-01/2013 | 1858 | 1564 | 15.82 |
| | A-914 | 6. Juara | -11.2803 | -57.5267 | 260 | 11/2006-02/2012 | 1947 | 1265 | 35.03 |
| | A-920 | 7. Juína | -11.3750 | -58.775 | 374 | 10/2007-01/2013 | 1949 | 1259 | 35.4 |
| | A-928 | 8. Nova Maringá | -13.0386 | -57.0922 | 353 | 04/2008-01/2013 | 1768 | 975 | 44.85 |
| | A-917 | 9. Sinop | -11.9822 | -55.5658 | 371 | 11/2006-06/2012 | 2284 | 930 | 59.28 |
| | A-904 | 10. Sorriso | -12.5452 | -55.7113 | 380 | 01/2009-01/2013 | 1493 | 958 | 35.83 |
| | A-917 | 11. Pontes de Lacerda | -15.2511 | -59.3467 | 256 | 01/2008-01/2013 | 1858 | 1301 | 29.98 |
| | A-935 | 12. Porto Estrela | -15.3247 | -57.2264 | 145 | 02/2008-01/2013 | 1827 | 767 | 58.02 |
| | A-936 | 13. Salto do Céu | -15.1247 | -58.1275 | 303 | 01/2008-01/2013 | 1858 | 1462 | 21.31 |
| | A-922 | 14. Vila Bela S. Trindade | -15.0628 | -59.8729 | 222 | 01/2008-01/2013 | 1858 | 1404 | 24.43 |
| Cerrado and transitions | A-929 | 15. Nova Ubiratã | -13.4111 | -54.7522 | 518 | 04/2008-01/2013 | 1768 | 1168 | 33.94 |
| | A-912 | 16. Campo Verde | -15.3139 | -55.0808 | 749 | 01/2008-01/2013 | 1858 | 898 | 51.67 |
| | A-907 | 17. Rondonópolis | -16.4500 | -54.5666 | 284 | 01/2008-01/2013 | 1858 | 1377 | 25.89 |
| | A-932 | 18. Guiratinga | -16.3417 | -53.7661 | 526 | 01/2008-01/2013 | 1858 | 1201 | 35.36 |
| | A-933 | 19. Itiquira | -17.1750 | -54.5014 | 585 | 08/2008-01/2013 | 1646 | 981 | 40.4 |
| | A-913 | 20. Comodoro | -13.4231 | -59.4546 | 591 | 01/2008-01/2013 | 1858 | 1511 | 18.68 |
| | A-927 | 21. Novo Mundo | -12.5219 | -58.2314 | 431 | 03/2008-01/2013 | 1798 | 1373 | 23.64 |
| | A-905 | 22. Campo Novo Parecis | -13.7833 | -57.8333 | 570 | 06/2010-01/2013 | 976 | 505 | 48.26 |
| | A-931 | 23. Santo Ant. do Leste | -14.9278 | -53.8836 | 648 | 08/2008-01/2013 | 1646 | 1238 | 24.79 |
| | A-930 | 24. Gaúcha do Norte | -13.1847 | -53.2575 | 379 | 08/2008-01/2013 | 1646 | 1376 | 16.4 |
| | A-908 | 25. Água Boa | -14.0161 | -52.2122 | 432 | 01/2008-01/2013 | 1858 | 1631 | 12.22 |
| | A-918 | 26. Confresa | -10.6539 | -51.5668 | 237 | 06/2008-01/2013 | 1707 | 1278 | 25.13 |
| | A-921 | 27. S. Felix do Araguaia | -11.6189 | -50.7278 | 218 | 08/2011-01/2013 | 550 | 456 | 17.09 |
| Pantanal | A-901 | 28. Cuiabá | -15.5594 | -56.0628 | 240 | 05/2011-01/2013 | 642 | 463 | 27.88 |

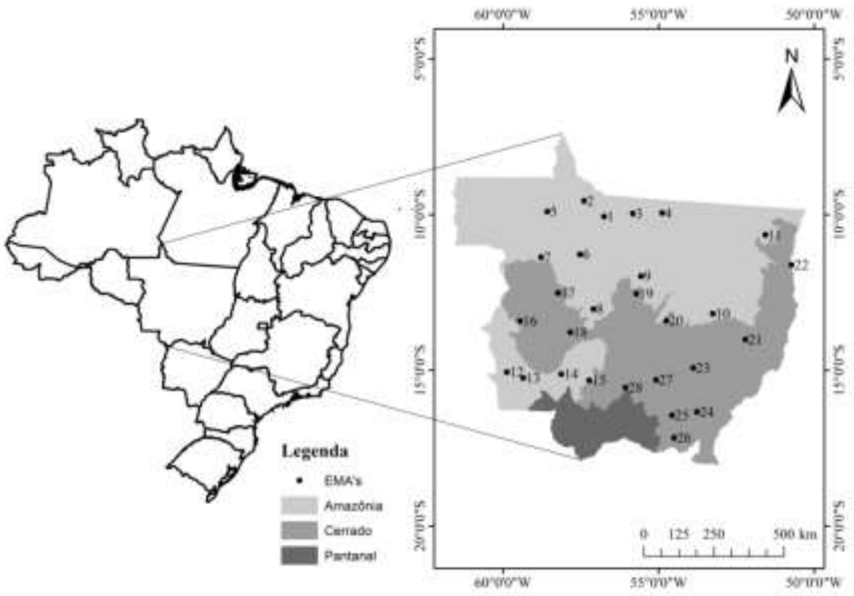

**Figure 1.** Automatic Weather Station Location (evaluated EMA's and biomes of Mato Grosso state. (Numerical identification according to Table 1)

The incident radiation on the atmosphere top ($H_0$) was obtained as a function of latitude and time of year, according to Iqbal (1983). The evaluated estimation models of solar radiation and their source are shown in Table 2. For estimating the solar radiation were used equations with calibrated coefficients for each regional station (Models 1 to 15), whereas the models 16 to 20 have been used the coefficients proposed by the each model authors.

**Table 2.** Estimating equation of solar radiation, parameters and references

| Estimating model | Equation | Parameters | Reference |
|---|---|---|---|
| 1 - ABS | $H_G=0.75\left(1-\exp\left(-b\frac{\Delta T^2}{\Delta Tmed}\right)\right)H_0$ | b | Abraha and Savage (2008) |
| 2 - ASW | $H_G=0.75\ [1-\exp\left(-b\ f(T_{med})\Delta T^2 f(T_{min})\right)]\ H_0$<br>$f(T_{med})=0.017\exp[\exp(-0.053\ T_{médio})]$<br>$f(T_{min})=\exp\left(\frac{T_{min}}{tnc}\right)$ | b, tnc | Abraha and Savage (2008); Weiss et al. (2001) |
| 3 - ALM | $H_G=a\Delta T^b\left[1-\exp\left(-c\left(\frac{e_{smin}}{e_{smax}}\right)^d\right)\right]H_0$ | a, b, c, d | Almorox et al. (2011) |
| 4 - ANN | $H_G=a(1+2.7.10^{-5}Alt)\sqrt{\Delta T}H_0$ | a | Annandele et al .(2002) |
| 5 - BRC | $H_G=a[1-\exp(-b\Delta T^c)]H_0$ | a, b, c | Bristow and Campbell (1984) |
| 6 - CHE | $H_G=(a\sqrt{\Delta T}+b)H_0$ | a, b | Chen et al (2004) |
| 7 - DJS | $H_G=a\Delta T^b(1+cP+dP^2)H_0$ | a, b, c, d | De Jong and Stewart (1993) |
| 8 - DOC | $H_G=a(1-\exp\left(-b\frac{\Delta T^c}{\Delta Tmed}\right))H_0$ | a, b, c | Donatelli and Campbell (1998) |
| 9 - GOO | $H_G=a(1-\exp\left(-b\frac{\Delta T^c}{H_0}\right))H_0$ | a, b, c | Goodin et al (1999) |
| 10 - HAR | $H_G=a(T_{max}-T_{min})^{0.5}H_0$ | a | Hargreaves (1981) |
| 11 - HU1 | $H_G=a\sqrt{\Delta T}\ H_0+b$ | a, b | Hunt et al (1998) |
| 12 – HU2 | $H_G=a\sqrt{\Delta T}H_0+bT_{max}+cP+dP^2+e$ | a, b, c, d, e | Hunt et al (1998) |
| 13 - MAH | $H_G=a\ \Delta T^{0.69}H_0^{0.91}$ | a | Mahmood and Hubbard (2002) |
| 14 - MEV | $H_G=0.75(1-\exp\left(-b\Delta T^2\right))H_0$ | b | Meza and Varas (2000) |
| 15 - THR | $H_G=H_0[1-0.9\exp\left(-b\Delta T^{1.5}\right)]$ | b | Thorton and Running (1999) |
| 16 – KR1 | $H_G=a(T_{max}-T_{min})^{0.5}H_0$ | a, kr1=0,16 | Hargreaves and Samani (1982) |
| 17 – KR2 | $H_G=a(T_{max}-T_{min})^{0.5}H_0$<br>$a=a_i\left(\frac{P_{atm}}{P_o}\right)^{0.5}$ | a<br>kr2=0,17 | Hargreaves and Samani (1982) Allen (1995) |
| 18 – KR3 | $H_G=a(T_{max}-T_{min})^{0.5}H_0$<br>$a=0.00185(T_{max}-T_{min})^2-0.0433(T_{max}-T_{min})+0.4023$ | a<br>kr3 | Hargreaves and Samani (1982) Samani (2000) |
| 19 - BCA | $H_G=a\ [\exp(-b\ \Delta T^c)]H_0$<br>$b=0.036\exp(-0.154\ \overline{\Delta T})$ | a, b, c<br>a=0,7; c=2,4 | Bristow and Campbell (1984) |
| 20 - WEI | $H_G=0.75\left(1-\exp\left(-b\frac{\Delta T^2}{H_o}\right)\right)H_0$ | b | Weiss et al. (2001) |

*$\Delta T$ – daily temperature range, obtained by the difference in Tmax and Tmin ; $\overline{\Delta T}$ – averagethermal range; $T_{med}$ – average air temperature; $T_{min}$ –minimum air temperature; $T_{max}$ – maximum temperature; $es_{min}$ – minimum vapor pressure saturation, using $T_{min}$; $es_{max}$ – maximum saturation pressure, using $T_{max}$; Alt – local altitude; P – precipitation; tnc – temperature factor of summer night; $P_{atm}$ – local atmospheric pressure (kPa); $P_0$ – average atmospheric pressure on sea level (101.33 kPa); the saturation pressure $e_s$

Was evaluated the influence of estimated $H_G$ in obtaining daily evapotranspiration ($ET_0$) by Penman-Monteith FAO method (Allen et al., 1998) (eq. 21), with standard measured Hg. This assessment was based on the influence that the net radiation (Rn) presents on ETo estimation, and also that Rn estimate can be simplified by the radiation balance on shortwave (ROC) and longwave (ROL). Therefore, ROC can be defined as the difference between the incident radiation ($H_G$) and reflected radiation (albedo lawns parameterized 23%) (ALLEN et al., 1998).

$$ET_0 = \frac{0.408\,\Delta\,(H - G) + \gamma\,\frac{900}{T + 278}\,U_2\,(es - ea)}{\Delta + \gamma\,(1 + 0.34\,U_2)}$$

Where: $ET_0$–reference evapotranspiration (mm $day^{-1}$);Rn–radiation balance(MJ $m^2$ $d^{-1}$); G –heat flow in soil, (MJ $m^2$ $d^{-1}$) (adopted G = 0.03 Rn); T –daily average air temperature at 2 m height (°C); $u_2$ – wind speed at 2 m height (m $s^{-1}$); $e_s$–vapor saturation pressure (kPa); $e_a$–current vapor pressure(kPa);Δ–curve inclination of vapor pressure*versus* temperature (kPa $°C^{-1}$); γ - psychrometric constant (kPa $°C^{-1}$); 0,408 stands for$\frac{1}{\lambda}$, λthe vaporization latent heat of water equal 2.45 MJ $Kg^{-1}$, 900 is a coefficient to unit conversion.These variables were estimated according to the recommendations of Pereira et al. (1997) and Allen et al. (1998).The daily values of the radiation balance in long-wave (ROL) was given in equation 22.

$$ROL = -\left(0.9\frac{n}{N} + 0.1\right)\left(0.56 - 0.25\sqrt{e_a}\right)\sigma\left[\left(T_{kn}^4 + T_{kn}^4\right)/2\right]$$

where:$\sigma$ - Stefan-Boltzmann constant (4.903 $10^{-9}$ MJ $m^{-2}$ $K^{-4}$ $day^{-1}$); $T_{kx}$–daily maximum temperature (K); $T_{kn}$–daily minimum temperature (K).

In performance assessing the equations of daily estimates on inclined surfaces as the horizontal were employed statistical indicative: determination coefficient (R²), percentage relative error, MBE (Mean Bias Error), RMSE (Root Mean Square Error) and adjustment index "d" Willmott, as recommended by Souza & Escobedo (2013) and Badescu (2013).

$$MBE = \frac{\sum_{i=1}^{N}(P_i - O_i)}{N - 1}$$

$$RMSE = \left[\frac{\sum_{i=1}^{N}(P_i - O_i)^2}{N}\right]^{0.5}$$

$$d = \left[\frac{\sum_{i=1}^{N}(P_i - O_i)^2}{\sum\left(|Pi - O| + |Oi - O|\right)^2}\right]$$

where: Pi –estimated values by simplified models (mm $day^{-1}$); Oi –estimated values by PMF (mm $day^{-1}$); O –average estimated values by PMF (mm $day^{-1}$); N –number of values.

It used weighted values (Vp) of statistical indications to classify the best method for estimating ETo. To obtain the Vp value assigned to weights from 1 to "n" for each statistical indicator, "n" being the number of models tested, in which case, given the weight 1 to the best model and the weight "n" to worse, and consequently, the best model is the one with the lowest sum of the assigned weights ie lower amount of accumulated Vp (TANAKA et al., 2016).

## RESULTS AND DISCUSSION

The annual variation in ETo values estimated by the PMF 56 method for meteorological stations located at different latitudes and biomes of the Mato Grosso state, presented behavior similar of global radiation seasonality throughout the year, with higher values in summer and lower in winter (Figure 2). This behavior was influenced by the temporal variation in average air temperature, which was similar for all locations under study, with the highest average temperatures occurring from September to April (rainy season) and the lowest between the months of May and August (dry season).

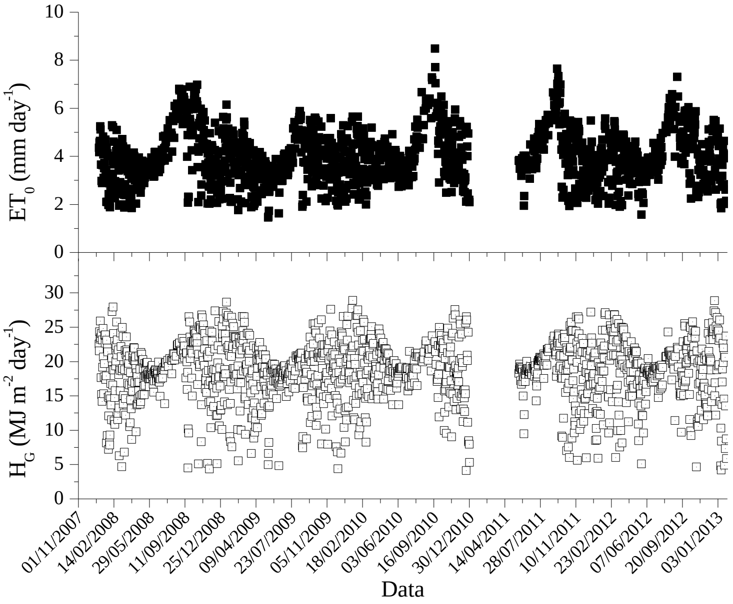

**Figure 2.** Seasonality of global radiation and reference evapotranspiration for the Água Boa station (A908) belonging to INMET network, from 01/2008 to 01/2013

According to Carvalho et al. (2015), if there is no water restriction, evapotranspiration is proportional to the availability of solar energy and radiation balance, setting thus the scenarios to evaluate the influence of $H_G$ estimates in ETo (CARVALHO et al., 2011; SOUZA et al., 2011).

The average daily $ET_0$ for the Amazon biome, the Cerrado and Pantanal (considering its transitions) were 3.57; 3.76 mm and 3.31 day$^{-1}$, respectively. These results corroborate with Souza et al. (2013), which analyzed 13 normal climate in the Mato Grosso state, found average daily $ET_0$ of 4.41 and 4.73 mm for Cáceres and Cuiabá (Pantanal), 3.59 and 3.64 for Matupá and Vera (Amazon) and 3.85 and 3.90 mm for Rondonópolis and Canarana (Cerrado).

The seasonality is dependent on the solar radiation and the amount of water vapor in the local atmosphere which, in turn, is related to cloud cover and directly affect the radiation balance; therefore, the estimates for the same model range from humid regions, semi humid or arid. According to Souza et al. (2011), this behavior can be observed for daily averages of $ET_0$ obtained by $H_G$ evaluated models estimation (Table 3).

For models not regionally calibrated (KR1, KR2, KR3, BCA and WEI) were observed average values of $ET_0$ higher than those obtained with measured $H_G$, independently of evaluated station.

Marti et al. (2010) and Carvalho et al. (2015) find it convenient to use the relative error (ER) to infer onperformance quality of $ET_0$ estimates different models, however, indicate that model as satisfactory ER $\leq$ 20% and its cumulative frequency distributions. Relative error analysis showed that occurs errors probability up to 20% ranged from 25.2 to 34.7% for $H_G$ with $ET_0$ estimates obtained by GOO calibrated models and ABS, respectively (Table 4). For uncalibrated models, the probability of ER maximum of 20% ranged from 39 to 64.5%. In general, there was a 50% probability of occurrence ER between 10 and 14% for $H_G$ calibrated estimation models.

According to Souza et al. (2011), the statistical indicative MBE, RMSE and d Willmott adjustment index used together is a proper assessment of the statistical performance estimation models with simultaneous analysis of deviations from the mean, to identify the occurrence of under or overestimation and as for the model scattering and the adjustment in relation to the measured values. The indicative MBE is the deviation from the medium and provides information on the model of long-term performance; negative values indicate an underestimation and positive values overestimation. As smaller MBE absolute value, better the performance of the tested model, however, an overestimation cancels an underestimation.

In this sense, the locally calibrated models showed lower MBE amplitudes when compared with non-calibrated models (with the exception of ABS and CHE) (Figure 3). To 27 and 28 EMA's (São Félix do Araguaia and Cuiabá), all calibrated models showed trends to underestimate $ET_0$ (up to -0.19 mm day$^{-1}$).

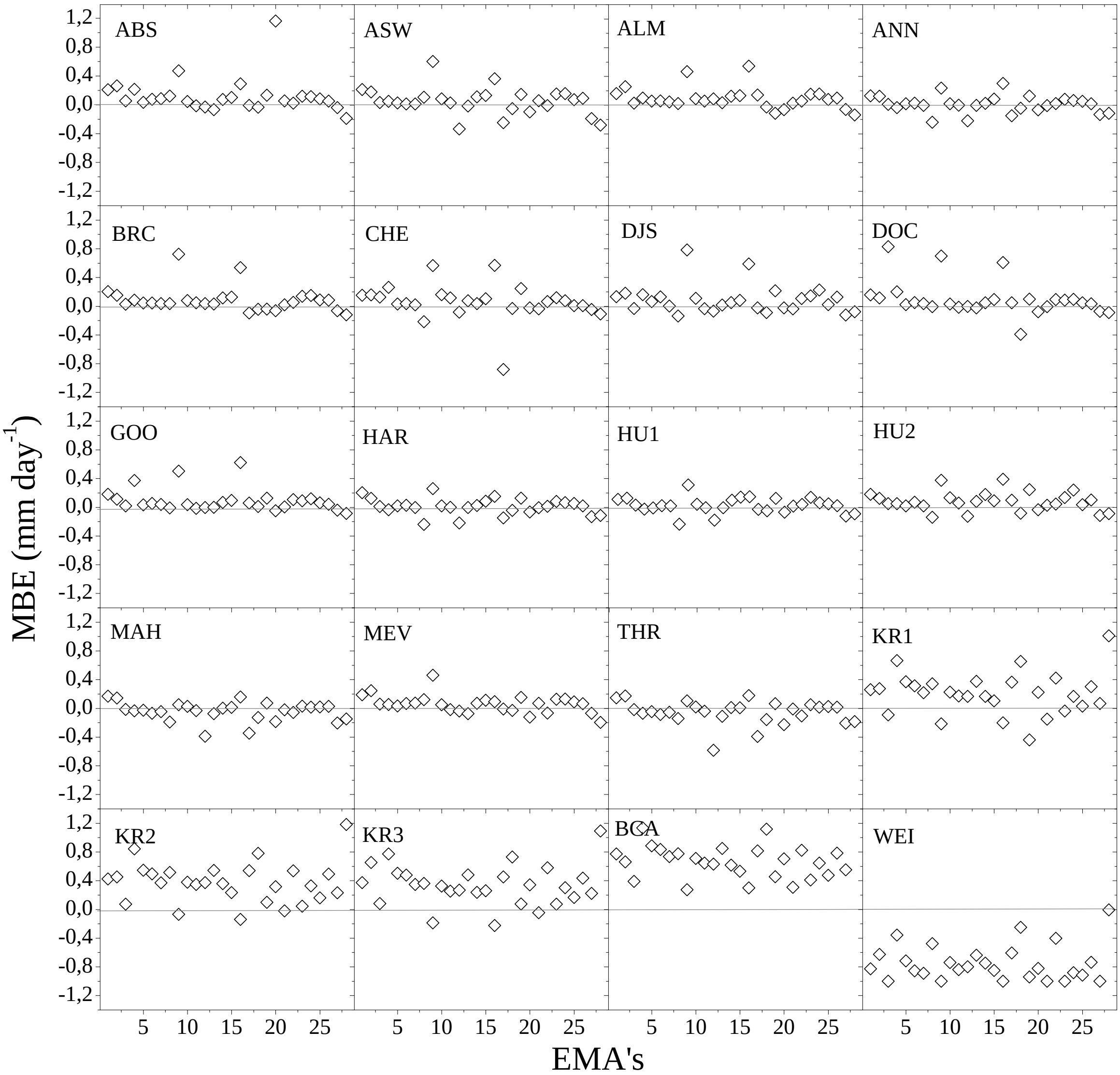

**Figure 3.** MBE values to $ET_0$ estimated by PMF 56 method with different $H_G$ estimating models use, to 28 EMA’s in Mato Grosso State, Brazil

The WEI model allowed underestimation of $ET_0$ regardless of evaluated EMA. Among the locally calibrated models, the major sub and overestimation occurred for ABS (-0.19 and 1.16 mm on day$^{-1}$ on Cuiabá and Comodoro EMA's respectively). These results indicate the importance of simplified models regional calibration to estimates from other meteorological variables for use in the PMF 56 model. According to Carvalho et al. (2015) the use of simplified measures and parameterization variables like vapor pressure (ea) and solar radiation ($H_G$) can provide low deviations of mean values of $ET_0$ by PMF 56 for tropical regions.

As for scattering, the calibrated models presented the RMSE ranging from 0.11 to 1.58 mm day$^{-1}$ (Figure 4), whereas uncalibrated models presented dispersion from 0.10 to 1.70 mm day$^{-1}$. The ANN, HAR and HU1 models behaved similarly as the scattering, with differences of 1.70 mm day$^{-1}$ between maximum and minimum values of RMSE (0.53 to 0.76 mm day$^{-1}$). This statistical indicator informs about the actual value of the error produced by the model and indicates the values range for the dependent variable ($ET_0$ PMF with $H_G$ measure) considering a given value of the independent variable ($ET_0$ PMF with estimated $H_G$). As lower the RMSE obtained values, better is the models performance.

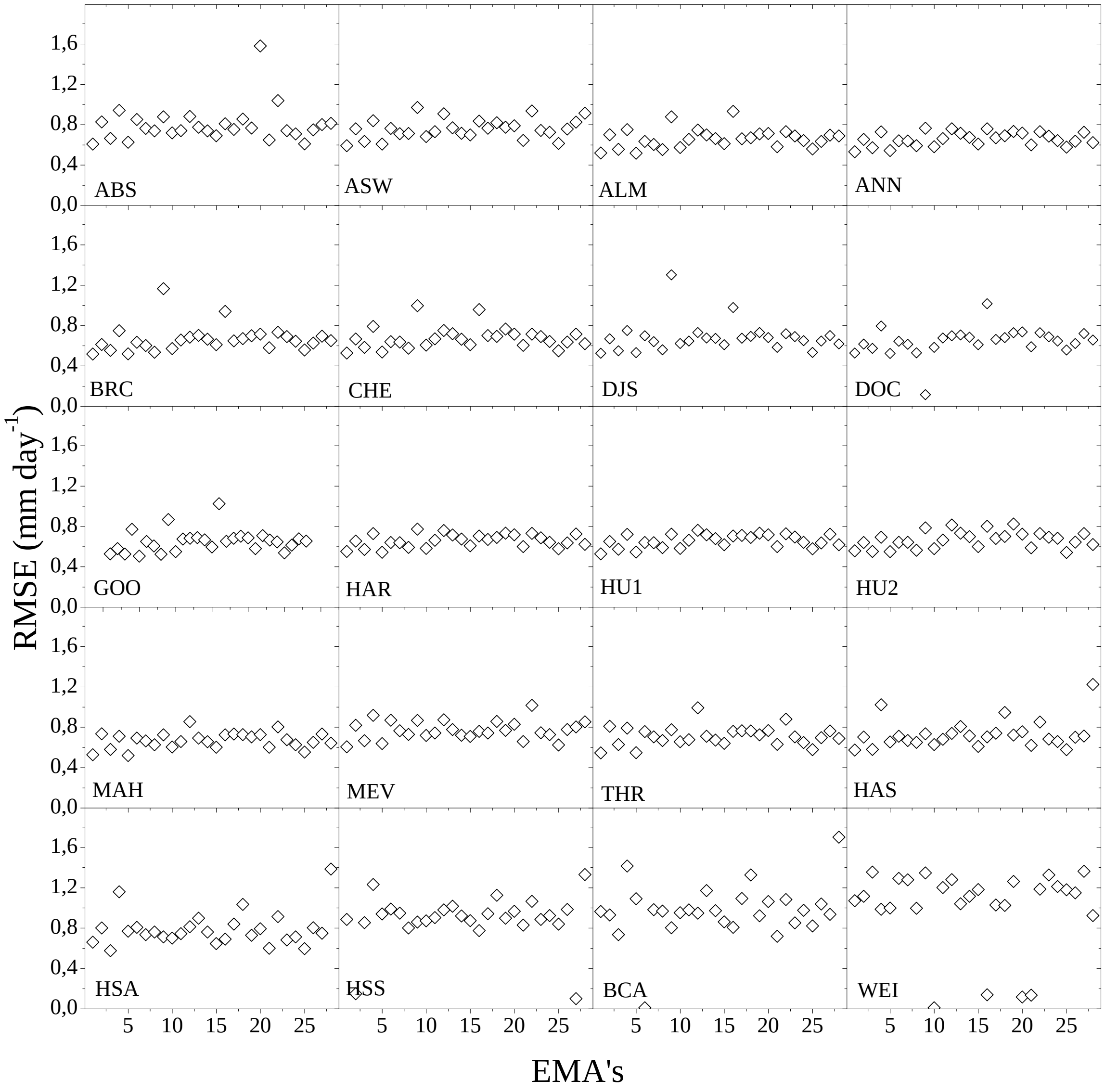

**Figure 4.** RMSE values to $ET_0$ estimated by PMF 56 method with different $H_G$ estimating models use, to 28 EMA’s in Mato Grosso State, Brazil

**Table 3.** Daily average of reference evapotranspiration (mm day$^{-1}$) by Penman-Monteith FAO 56 model with different global radiation estimate methods, to different automatic weather stations in Mato Grosso state.

| Region | Station | Measured $H_G$ | ABS | ASW | ALM | ANN | BRC | CHE | DJS | DOC | GOO | HAR | HU1 | HU2 | MAH | MEV | THR | KR1 | KR2 | KR3 | BCA | WEI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Amazon and transitions | 1. Alta Floresta | 3.96 | 4.04 | 4.03 | 4.04 | 4.01 | 4.04 | 3.97 | 3.98 | 4.01 | 4.02 | 4.01 | 4.00 | 3.99 | 3.98 | 4.05 | 3.98 | 3.99 | 4.12 | 4.12 | 4.43 | 3.04 |
| | 2. Apiacás | 3.44 | 3.70 | 3.62 | 3.69 | 3.56 | 3.59 | 3.59 | 3.62 | 3.55 | 3.55 | 3.56 | 3.56 | 3.56 | 3.58 | 3.68 | 3.61 | 3.71 | 3.89 | 4.09 | 4.10 | 2.81 |
| | 3. Carlinda | 3.68 | 3.73 | 3.72 | 3.71 | 3.69 | 3.71 | 3.81 | 3.65 | 3.68 | 3.70 | 3.69 | 3.71 | 3.73 | 3.66 | 3.74 | 3.66 | 3.59 | 3.75 | 3.76 | 4.07 | 2.56 |
| | 4. Guarantã do Norte | 3.31 | 3.51 | 3.35 | 3.40 | 3.27 | 3.38 | 3.56 | 3.46 | 3.50 | 3.68 | 3.27 | 3.27 | 3.35 | 3.27 | 3.35 | 3.23 | 3.96 | 4.14 | 4.07 | 4.43 | 2.96 |
| | 5. Cotriguaçu | 3.26 | 3.29 | 3.29 | 3.32 | 3.28 | 3.30 | 3.29 | 3.32 | 3.28 | 3.29 | 3.28 | 3.25 | 3.28 | 3.23 | 3.29 | 3.22 | 3.63 | 3.81 | 3.76 | 4.14 | 2.54 |
| | 6. Juara | 3.61 | 3.68 | 3.62 | 3.66 | 3.63 | 3.65 | 3.64 | 3.74 | 3.66 | 3.66 | 3.63 | 3.63 | 3.68 | 3.54 | 3.67 | 3.52 | 3.92 | 4.10 | 4.09 | 4.44 | 2.75 |
| | 7. Juína | 3.45 | 3.54 | 3.47 | 3.50 | 3.45 | 3.49 | 3.48 | 3.46 | 3.49 | 3.49 | 3.45 | 3.47 | 3.47 | 3.41 | 3.53 | 3.45 | 3.67 | 3.83 | 3.80 | 4.19 | 2.56 |
| | 8. Nova Maringá | 3.77 | 3.89 | 3.88 | 3.79 | 3.53 | 3.80 | 3.55 | 3.63 | 3.76 | 3.76 | 3.53 | 3.53 | 3.63 | 3.58 | 3.89 | 3.62 | 4.11 | 4.28 | 4.13 | 4.54 | 3.29 |
| | 9. Sinop | 3.56 | 3.93 | 4.06 | 3.99 | 3.78 | 4.34 | 4.15 | 4.42 | 4.31 | 4.10 | 3.80 | 3.92 | 3.99 | 3.59 | 3.91 | 3.61 | 3.35 | 3.49 | 3.47 | 3.80 | 2.51 |
| | 10. Sorriso | 3.67 | 3.72 | 3.76 | 3.76 | 3.69 | 3.75 | 3.83 | 3.78 | 3.71 | 3.71 | 3.69 | 3.71 | 3.81 | 3.70 | 3.72 | 3.69 | 3.90 | 4.05 | 4.00 | 4.38 | 2.94 |
| | 11. Pontes de Lacerda | 3.72 | 3.70 | 3.75 | 3.77 | 3.72 | 3.76 | 3.83 | 3.68 | 3.70 | 3.70 | 3.72 | 3.71 | 3.78 | 3.68 | 3.70 | 3.68 | 3.89 | 4.07 | 3.97 | 4.36 | 2.88 |
| | 12. Porto Estrela | 3.63 | 3.60 | 3.30 | 3.72 | 3.41 | 3.67 | 3.55 | 3.56 | 3.63 | 3.63 | 3.41 | 3.45 | 3.51 | 3.24 | 3.59 | 3.05 | 3.80 | 4.00 | 3.90 | 4.26 | 2.83 |
| | 13. Salto do Céu | 3.42 | 3.35 | 3.41 | 3.45 | 3.42 | 3.45 | 3.50 | 3.44 | 3.40 | 3.42 | 3.42 | 3.41 | 3.50 | 3.35 | 3.35 | 3.31 | 3.80 | 3.96 | 3.90 | 4.27 | 2.78 |
| | 14. Vila Bela S. Trindade | 3.50 | 3.57 | 3.61 | 3.62 | 3.52 | 3.61 | 3.53 | 3.55 | 3.55 | 3.56 | 3.52 | 3.60 | 3.67 | 3.50 | 3.57 | 3.51 | 3.66 | 3.86 | 3.73 | 4.11 | 2.75 |
| Cerrado and transitions | 15. Nova Ubiratã | 3.92 | 4.02 | 4.05 | 4.05 | 4.01 | 4.05 | 4.02 | 4.00 | 4.01 | 4.02 | 4.01 | 4.06 | 4.01 | 3.93 | 4.03 | 3.93 | 4.03 | 4.15 | 4.18 | 4.45 | 3.07 |
| | 16. Campo Verde | 3.95 | 4.24 | 4.32 | 4.49 | 4.25 | 4.49 | 4.52 | 4.54 | 4.56 | 4.57 | 4.10 | 4.10 | 4.34 | 4.11 | 4.05 | 4.13 | 3.75 | 3.81 | 3.73 | 4.25 | 2.85 |
| | 17. Rondonópolis | 3.71 | 3.70 | 3.46 | 3.85 | 3.56 | 3.61 | 3.71 | 3.68 | 3.75 | 3.77 | 3.56 | 3.68 | 3.80 | 3.36 | 3.70 | 3.31 | 4.07 | 4.25 | 4.16 | 4.52 | 3.10 |
| | 18. Guiratinga | 3.21 | 3.17 | 3.16 | 3.18 | 3.16 | 3.16 | 3.18 | 3.12 | 3.21 | 3.22 | 3.16 | 3.16 | 3.12 | 3.08 | 3.18 | 3.05 | 3.86 | 3.99 | 3.94 | 4.32 | 2.96 |
| | 19. Itiquira | 4.15 | 4.28 | 4.30 | 4.04 | 4.28 | 4.11 | 4.40 | 4.36 | 4.25 | 4.28 | 4.28 | 4.28 | 4.40 | 4.22 | 4.30 | 4.22 | 4.15 | 4.25 | 4.23 | 4.61 | 3.21 |
| | 20. Comodoro | 3.24 | 4.40 | 3.15 | 3.18 | 3.18 | 3.18 | 3.22 | 3.22 | 3.17 | 3.19 | 3.18 | 3.18 | 3.21 | 3.06 | 3.12 | 3.02 | 3.46 | 3.56 | 3.59 | 3.95 | 2.42 |
| | 21. Novo Mundo | 3.84 | 3.89 | 3.90 | 3.87 | 3.84 | 3.86 | 3.80 | 3.80 | 3.83 | 3.84 | 3.84 | 3.86 | 3.87 | 3.82 | 3.91 | 3.83 | 3.69 | 3.82 | 3.79 | 4.15 | 2.77 |
| | 22. Campo Novo Parecis | 3.68 | 3.70 | 3.67 | 3.74 | 3.70 | 3.73 | 3.75 | 3.79 | 3.77 | 3.79 | 3.69 | 3.72 | 3.72 | 3.62 | 3.61 | 3.57 | 4.10 | 4.22 | 4.26 | 4.50 | 3.28 |
| | 23. Santo Antonio do | 4.08 | 4.20 | 4.24 | 4.23 | 4.16 | 4.22 | 4.20 | 4.22 | 4.17 | 4.17 | 4.16 | 4.22 | 4.22 | 4.11 | 4.21 | 4.13 | 4.04 | 4.12 | 4.15 | 4.49 | 3.07 |
| | 24.Gaúcha do Norte | 3.69 | 3.80 | 3.85 | 3.84 | 3.75 | 3.84 | 3.76 | 3.92 | 3.78 | 3.81 | 3.75 | 3.75 | 3.93 | 3.71 | 3.82 | 3.71 | 3.86 | 4.02 | 3.99 | 4.33 | 2.81 |
| | 25. Água Boa | 3.96 | 4.04 | 4.03 | 4.04 | 4.01 | 4.04 | 3.97 | 3.98 | 4.01 | 4.02 | 4.01 | 4.00 | 3.99 | 3.98 | 4.05 | 3.98 | 3.99 | 4.12 | 4.12 | 4.43 | 3.04 |
| | 26. Confresa | 3.73 | 3.78 | 3.83 | 3.83 | 3.75 | 3.82 | 3.74 | 3.86 | 3.76 | 3.77 | 3.75 | 3.75 | 3.83 | 3.76 | 3.80 | 3.75 | 4.03 | 4.22 | 4.17 | 4.52 | 2.99 |
| | 27. S. Felix do Araguaia | 3.75 | 3.71 | 3.56 | 3.69 | 3.62 | 3.69 | 3.70 | 3.63 | 3.68 | 3.71 | 3.62 | 3.63 | 3.63 | 3.55 | 3.68 | 3.54 | 3.82 | 3.98 | 3.97 | 4.30 | 2.68 |
| Pantanal | 28. Cuiabá | 3.31 | 3.12 | 3.03 | 3.17 | 3.19 | 3.19 | 3.20 | 3.23 | 3.22 | 3.22 | 3.19 | 3.22 | 3.22 | 3.16 | 3.11 | 3.12 | 4.32 | 4.49 | 4.40 | 4.40 | 3.30 |

**Table 4.** Cumulative frequency of relative percentage error occurrence of $ET_0$ estimate with HG estimate by empirical models to PMF 56 method in Mato Grosso state.

| | Relative Error (%) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $H_G$ Estimating model | 2 | 4 | 6 | 8 | 10 | 20 | 30 | 40 | 50 | 100 |
| ABS | 91.7 | 83.8 | 75.9 | 68.5 | 61.5 | 34.7 | 19.0 | 10.9 | 6.2 | 0.6 |
| ASW | 90.9 | 82.2 | 73.7 | 66.0 | 58.6 | 31.5 | 16.6 | 9.3 | 4.9 | 0.2 |
| ALM | 89.8 | 80.2 | 70.7 | 61.9 | 53.9 | 25.7 | 12.9 | 7.0 | 3.7 | 0.1 |
| ANN | 91.5 | 82.7 | 73.8 | 65.8 | 57.8 | 27.5 | 12.8 | 6.6 | 3.4 | 0.1 |
| BRC | 89.5 | 79.5 | 70.0 | 61.1 | 53.4 | 25.4 | 13.4 | 7.6 | 4.4 | 0.4 |
| CHE | 90.7 | 81.9 | 73.2 | 64.9 | 57.2 | 28.0 | 14.2 | 8.1 | 4.4 | 0.2 |
| DJS | 90.5 | 81.4 | 72.5 | 64.4 | 56.5 | 27.0 | 13.5 | 7.5 | 4.3 | 0.4 |
| DOC | 90.1 | 80.3 | 70.8 | 61.8 | 54.0 | 26.2 | 14.0 | 8.2 | 4.9 | 0.4 |
| GOO | 89.4 | 79.2 | 69.4 | 60.6 | 52.2 | 25.2 | 13.2 | 7.5 | 4.4 | 0.2 |
| HAR | 91.4 | 82.6 | 73.7 | 65.8 | 57.8 | 27.5 | 12.8 | 6.6 | 3.4 | 0.1 |
| HU1 | 91.3 | 82.3 | 73.5 | 65.2 | 57.7 | 27.2 | 13.0 | 7.0 | 3.7 | 0.1 |
| HU2 | 90.8 | 81.3 | 72.7 | 64.3 | 56.3 | 27.2 | 13.7 | 7.6 | 4.1 | 0.2 |
| MAH | 90.7 | 81.9 | 73.3 | 65.0 | 57.3 | 26.4 | 11.0 | 4.9 | 2.3 | 0.1 |
| MEV | 91.5 | 83.2 | 75.1 | 67.4 | 60.4 | 33.2 | 17.6 | 9.4 | 5.1 | 0.2 |
| THR | 91.3 | 83.0 | 74.7 | 66.8 | 59.1 | 28.8 | 12.2 | 5.4 | 2.6 | 0.1 |
| KR1 | 91.4 | 82.6 | 74.4 | 66.5 | 59.1 | 31.9 | 18.0 | 10.7 | 6.0 | 0.2 |
| KR2 | 91.1 | 82.7 | 74.6 | 67.3 | 60.6 | 35.5 | 21.8 | 13.6 | 8.3 | 0.3 |
| KR3 | 93.8 | 87.1 | 80.4 | 74.1 | 67.8 | 41.4 | 25.7 | 18.4 | 13.9 | 2.2 |
| BCA | 92.7 | 85.4 | 78.2 | 71.6 | 66.0 | 45.9 | 32.5 | 22.2 | 15.0 | 1.5 |
| WEI | 95.7 | 91.4 | 87.0 | 82.9 | 78.9 | 61.0 | 43.5 | 26.0 | 12.1 | 0.1 |

The scattering obtained in this study corroborate with others that aimed to seek simplification in obtaining $H_G$ as input variable to PMF 56 model. Todorovic et al. (2013) evaluated 577 stations in 16 Mediterranean countries and suggested empirical coefficients local corrections of $H_G$ estimating equations and obtained scattering around 0.59 - 0.65; 0.47 - 0.82; 0.41 - 0.47; and 0.36 - 0.55 mm day$^{-1}$ for arid, semi-arid, sub-humid and humid, respectively. Raziei & Pereira (2013) evaluated 40 EMC's in Iran and observed changes in RMSE between 0.27 and 2.86; and from 0.18 to 52 mm day$^{-1}$ in arid and humid regions, respectively. Sentelhas et al. (2010) obtained for stations in Canada RMSE values of 0.79 to 1.12 mm day$^{-1}$ with $H_G$ estimated models by maximum and minimum temperatures of the air. Already Carvalho et al. (2015) evaluated 46 EMC's in the Brazilian Southeast obtained RMSE range of 0.05 to 0.85 mm day$^{-1}$, with higher values for stations up - country. Specifically for Minas Gerais state, Alencar et al. (2015) found for 20 EMC's analyzed scatterings ranging from 0.49 to 0.83 mm day$^{-1}$ when $ET_0$ was estimated by PMF 56 with the $H_G$ data absence.

The adjustment index d of Willmott is dimensionless (ranging from 0 to 1) and shows how the estimated values (dependent variable) fit to the measured values (independent variable), or indicates the removal of estimated data of the observed mean (CARVALHO et al., 2015). The minor adjustments were obtained by the models KR3 and WEI (Figure 5).

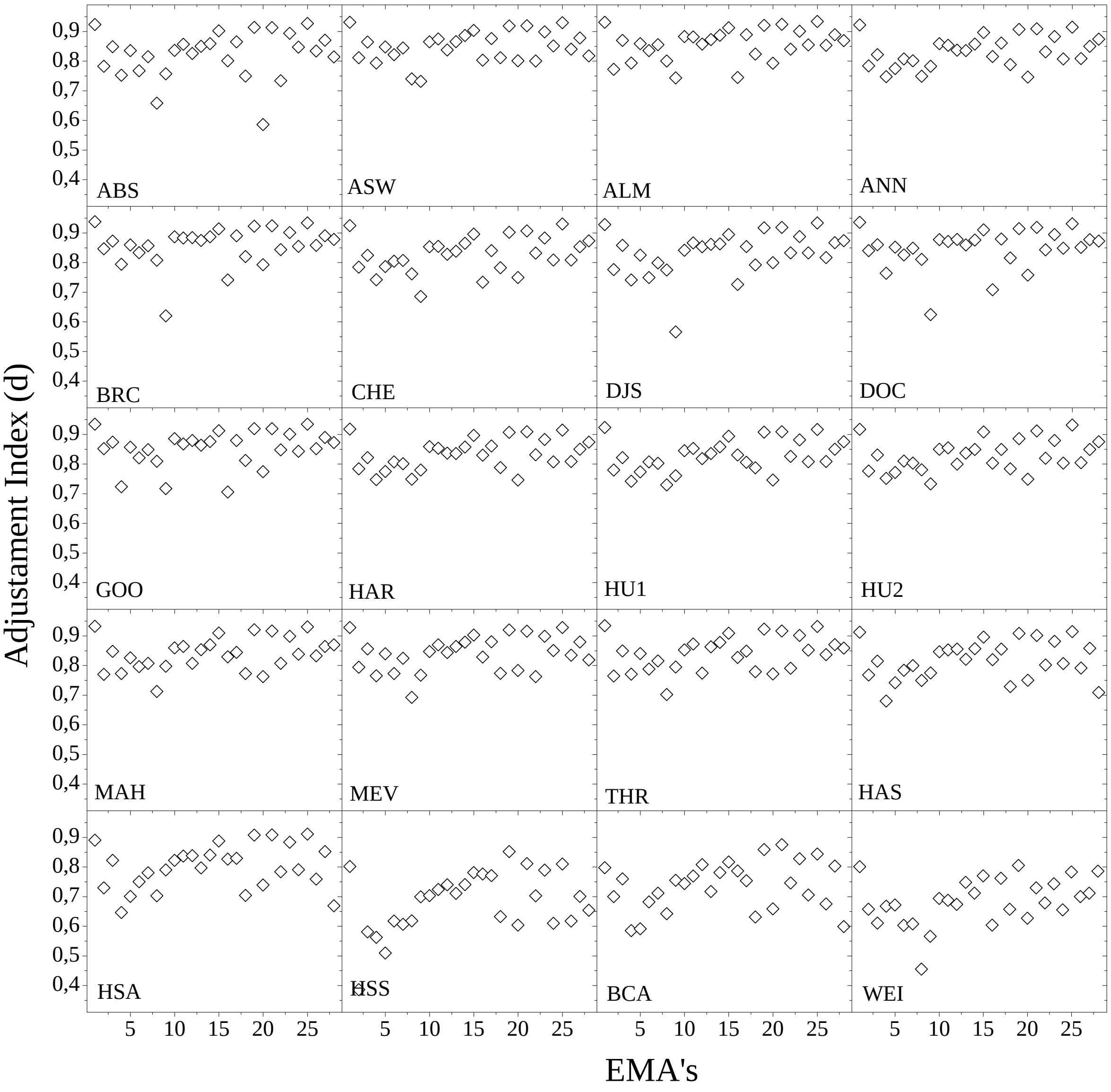

**Figure 5.** Adjustment index values (d) to $ET_0$ estimating by PMF 56 method with different $H_G$ estimating models use, to 28 EMA’s in Mato Grosso State, Brazil.

For the calibrated model, "d" values ranging from 0.56 to 0.94, being smaller than the difference between maximum and minimum were 0.75 to 0.92 (17% variation in adjustment) for HAR and ANN models. The worst adjustments were observed in EMA's A906 (Guarantã do Norte), A917 (Sinop) and A928 (Nova Maringá), both in the State of the Amazon region, resulting from the high percentage of data losses (Table 1).

In Table 5 are the cumulative values (Vp) for statistical indicative considered in performance evaluation estimate of $ET_0$ with different obtaining HG models. The GOO, BRC, MAH, DOC, HU1 and DJS models were framed with smaller total of Vp to 28.6; 21.4; 21.4; 14.3; 10.7 and 3.6% of EMA's, respectively. The best estimates of $ET_0$ to the Amazon and Cerrado regions, with their transitions were found when applied BRC and GOO models, respectively. The uncalibrated models showed the highest accumulated Vp values indicating the worst statistical indicative regardless of the season, and demonstrating that the local calibration of solar radiation estimation models is essential for obtaining good evapotranspiration estimates.

**Table 5.** Classification of global solar radiation estimating models on reference evapotranspiration estimate according to performance indicators ordering MBE, RMSE and d.

| Region | Station | ABS | ASW | ALM | ANN | BRC | CHE | DJS | DOC | GOO | HAR | HU1 | HU2 | MAH | MEV | THR | KR1 | KR2 | KR3 | BCA | WEI | Best |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Amazon and transitions | 1. Alta Floresta | 41 | 38 | 20 | 27 | 28 | 20 | 15 | 14 | 22 | 37 | 17 | 36 | 20 | 34 | 17 | 45 | 52 | 53 | 58 | 59 | DOC |
| | 2. Apiacás | 41 | 30 | 29 | 19 | 11 | 23 | 31 | 8 | 3 | 19 | 21 | 21 | 33 | 34 | 41 | 42 | 48 | 59 | 56 | 56 | GOO |
| | 3. Carlinda | 39 | 28 | 25 | 24 | 24 | 43 | 18 | 15 | 7 | 23 | 30 | 26 | 25 | 37 | 28 | 46 | 41 | 55 | 55 | 59 | GOO |
| | 4. Guarantã do Norte | 37 | 25 | 16 | 19 | 12 | 38 | 34 | 32 | 40 | 19 | 18 | 17 | 8 | 27 | 24 | 51 | 55 | 57 | 59 | 50 | MAH |
| | 5. Cotriguaçu | 32 | 28 | 21 | 23 | 16 | 25 | 32 | 14 | 15 | 23 | 25 | 31 | 19 | 31 | 30 | 48 | 52 | 55 | 59 | 56 | DOC |
| | 6. Juara | 44 | 21 | 14 | 25 | 9 | 18 | 39 | 19 | 23 | 16 | 13 | 25 | 34 | 41 | 39 | 41 | 49 | 54 | 56 | 60 | BRC |
| | 7. Juína | 39 | 23 | 15 | 23 | 11 | 23 | 26 | 16 | 16 | 22 | 23 | 26 | 32 | 37 | 33 | 43 | 50 | 55 | 56 | 59 | BRC |
| | 8. Nova Maringá | 38 | 30 | 9 | 30 | 8 | 25 | 19 | 4 | 5 | 33 | 32 | 20 | 34 | 38 | 34 | 37 | 49 | 53 | 56 | 57 | DOC |
| | 9. Sinop | 36 | 46 | 26 | 20 | 38 | 48 | 58 | 52 | 41 | 19 | 19 | 30 | 5 | 30 | 12 | 14 | 6 | 30 | 27 | 59 | MAH |
| | 10. Sorriso | 40 | 32 | 30 | 14 | 21 | 34 | 39 | 17 | 9 | 17 | 26 | 29 | 19 | 38 | 24 | 41 | 50 | 54 | 56 | 60 | GOO |
| | 11. Pontes de Lacerda | 29 | 26 | 18 | 25 | 14 | 35 | 19 | 22 | 22 | 20 | 25 | 34 | 22 | 29 | 28 | 44 | 52 | 54 | 56 | 60 | BRC |
| | 12. Porto Estrela | 31 | 37 | 13 | 28 | 8 | 27 | 16 | 7 | 5 | 30 | 38 | 37 | 46 | 26 | 55 | 20 | 39 | 51 | 51 | 60 | GOO |
| | 13. Salto do Céu | 34 | 23 | 14 | 23 | 10 | 35 | 14 | 21 | 7 | 24 | 27 | 38 | 23 | 32 | 28 | 48 | 52 | 55 | 59 | 56 | GOO |
| | 14. Vila B. S. Trindade | 40 | 29 | 19 | 28 | 16 | 18 | 24 | 23 | 19 | 24 | 33 | 38 | 10 | 27 | 13 | 43 | 51 | 53 | 55 | 59 | MAH |
| | Total | 521 | 416 | 269 | 328 | 226 | 412 | 384 | 264 | 234 | 326 | 347 | 408 | 330 | 461 | 406 | 563 | 646 | 738 | 759 | 810 | BRC |
| Cerrado and transitions | 15. Nova Ubiratã | 34 | 36 | 20 | 25 | 34 | 34 | 27 | 17 | 11 | 19 | 44 | 15 | 10 | 38 | 20 | 32 | 48 | 56 | 55 | 60 | MAH |
| | 16. Campo Verde | 32 | 37 | 36 | 29 | 39 | 48 | 51 | 54 | 57 | 10 | 6 | 32 | 13 | 13 | 17 | 17 | 9 | 30 | 33 | 60 | HU1 |
| | 17. Rondonópolis | 23 | 35 | 18 | 29 | 11 | 25 | 22 | 14 | 14 | 24 | 32 | 29 | 39 | 19 | 45 | 37 | 51 | 53 | 60 | 57 | BRC |
| | 18. Guiratinga | 35 | 30 | 12 | 21 | 18 | 25 | 27 | 7 | 10 | 19 | 27 | 32 | 39 | 32 | 39 | 49 | 54 | 56 | 60 | 51 | DOC |
| | 19. Itiquira | 37 | 34 | 12 | 31 | 5 | 46 | 33 | 23 | 20 | 36 | 32 | 52 | 11 | 35 | 11 | 17 | 26 | 42 | 56 | 60 | BRC |
| | 20. Comodoro | 60 | 27 | 15 | 27 | 12 | 18 | 4 | 30 | 12 | 28 | 32 | 24 | 31 | 33 | 35 | 36 | 47 | 53 | 53 | 56 | DJS |
| | 21. Novo Mundo | 42 | 37 | 23 | 22 | 15 | 42 | 23 | 15 | 6 | 25 | 26 | 28 | 26 | 44 | 27 | 43 | 36 | 53 | 48 | 60 | GOO |
| | 22. Campo Novo Parecis | 39 | 27 | 23 | 16 | 11 | 18 | 22 | 20 | 15 | 18 | 18 | 22 | 30 | 43 | 42 | 41 | 47 | 57 | 56 | 55 | BRC |
| | 23. S. Antonio do Leste | 34 | 36 | 24 | 30 | 21 | 32 | 37 | 23 | 14 | 25 | 44 | 42 | 10 | 35 | 19 | 19 | 17 | 45 | 55 | 60 | MAH |
| | 24. Gaúcha do Norte | 30 | 33 | 26 | 23 | 22 | 25 | 38 | 24 | 28 | 22 | 23 | 46 | 13 | 33 | 14 | 42 | 50 | 55 | 56 | 59 | MAH |
| | 25. Água Boa | 41 | 22 | 17 | 25 | 17 | 13 | 7 | 21 | 14 | 36 | 30 | 15 | 16 | 44 | 18 | 27 | 50 | 55 | 54 | 59 | DJS |
| | 26. Confresa | 32 | 32 | 19 | 24 | 17 | 17 | 35 | 14 | 13 | 23 | 28 | 26 | 27 | 34 | 21 | 45 | 52 | 55 | 58 | 57 | GOO |
| | 27. S. Felix do Araguaia | 25 | 36 | 15 | 33 | 16 | 25 | 24 | 20 | 4 | 36 | 31 | 37 | 37 | 27 | 37 | 22 | 43 | 56 | 55 | 59 | GOO |
| | Total | 464 | 422 | 260 | 335 | 238 | 368 | 350 | 282 | 218 | 321 | 373 | 400 | 302 | 430 | 345 | 427 | 530 | 666 | 699 | 753 | GOO |
| Pantanal | 28. Cuiabá | 43 | 43 | 24 | 22 | 14 | 17 | 9 | 23 | 20 | 17 | 10 | 12 | 29 | 42 | 36 | 51 | 56 | 55 | 60 | 33 | DJS |
| | Total | 1028 | 881 | 553 | 685 | 478 | 797 | 743 | 569 | 472 | 664 | 730 | 820 | 661 | 933 | 787 | 1041 | 1232 | 1459 | 1518 | 1596 | GOO; BRC |

## CONCLUSIONS

The local calibration of simplified models coefficients to estimate the solar radiation has positively influence on daily estimate of reference evapotranspiration.

In the absence of solar radiation data, reference evapotranspiration estimates by Penman-Monteith FAO 56 to the Amazon, the Cerrado and Pantanal region in Mato Grosso State should consider Bristow and Campbell (1984), Goodin et al. (1999) and De Jong and Stewart (1993) methods, with regional calibration of parametric coefficients for each model.

## REFERENCES

ABRAHA, M. G.; SAVAGE, M. J. Comparison of estimates of daily solar radiation from air temperature range for application in crop simulations. **Agricultural and Forest Meteorology** 148: 401-416, 2008.

ALENCAR, L. P.; SEDIYAMA, G. C.; MANTOVANI, E. C.Estimativa da evapotranspiração de referência (ETo padrão FAO), para Minas Gerais, na ausência de alguns dados climáticos. **Engenharia Agrícola** 35(1): 39-50, 2015.

ALLEN, R.G., PEREIRA, L.S., HOWELL, T.A., JENSEN, M.E. Evapotranspiration information reporting: I. Factors governing measurement accuracy. Agricultural Water Management v.98, p.899–920, 2011.

ALLEN, R. G.; PEREIRA, L. S.; RAES, D. **Crop evapotranspiration**. Rome: FAO, 297p (FAO Irrigation and Drainage Paper, 56). 1998.

ALLEN, R. G. **Evaluation of procedures for estimating mean monthly solar radiation from air temperature**. Rep. United Nations Food and Agriculture Organization (FAO). Rome, Italy. 1995.

ALMOROX, J.; HONTORIA, C.; BENITO, M. Models for obtaining daily global solar radiation with measured air temperature data in Madrid (Spain). **Applied Energy** 88: 1703-1709, 2011.

ANNANDALE, J.G.; JOVANIC, N. Z.; BENADE, N.; ALLEN, R. G. Software for missing data error analysis of Penman-Monteith reference evapotranspiration. **Irrigation Science** 21: 57-67, 2002.

ANGSTROM, A. Solar and terrestrial radiation. **Quarterly Journal of the Royal Meteorological Society** 50(4): 121-126, 1924.

BADESCU, V. Assessing the performance of solar radiation computing models and model selection procedures. **Journal of Atmospheric and Solar-Terrestrial Physics** 105-106: 119-134, 2013.

BRISTOW, K.L.; CAMPBELL, G.S. On the relationship between incoming solar radiation and daily minimum and maximum temperature. **Agricultural and Forest Meteorology** 31: 159-166, 1984.

CARVALHO, D. F.; ROCHA, H. S.; BONOMO, R.; SOUZA, A. P. Estimativa da evapotranspiração de referência a partir de dados meteorológicos limitados. **Pesquisa Agropecuária Brasileira** 50(1): 1-11, 2015.

CARVALHO, D. F.; SILVA, D. G.; SOUZA, A. P.; GOMES, D. P.; ROCHA, H. S. Coeficientes da equação de Angstrom-Prescott e sua influência na evapotranspiração de referência em Seropédica, RJ. **Revista Brasileira de Engenharia Agrícola e Ambiental** 15(8): 838-844, 2011.

CARVALHO, D. F.; SILVA, L. D. B.; GUERRA, J. G. M.; CRUZ, F. A. Instalação, calibração e funcionamento de um lisímetro de pesagem. **Engenharia Agrícola** 27: 363-372, 2007.

CHANG, J. Climate and Agriculture: an ecological survey. **Aldine Publication** Cap. 13 Evapotranspiration**,** Chicago, p.129-143. 1968.

CHEN, R. S.; ERSI, K.; YANG, J. P.; LU, S. H.; ZHAO, W. Z. Validation of five global radiation models with measured daily data in China. **Energy Conversion and Management** 45: 1759-1769, 2004.

CUNHA, A. R.; VOLPE, C. A.; ESCOBEDO, J. F. Estimativa da evapotranspiração de referência pelo método de Penman-Monteith (FAO-56) com saldo de radiação medido por diferentes sensores. **Agronomía Tropical** 58(1): 74-84, 2008.

DAUT, I.; IRWANTO, M.; IRWAN, Y. M.; GOMESH, N.; AHMAD, N. S. Combination of Hargreaves method and linear regression as a new method to estimate solar radiation in Perlis, Northern Malaysia. **Solar Energy** 85: 2871-2880, 2011.

DE JONG, R.; STEWART, D. W. Estimating global solar radiation from common meteorological observations in western Canada. **Journal Plant Science** 73: 509-518, 1993.

DONATELLI, M.; CAMPBELL, G. S. A simple model to estimate global solar radiation. In: **Proceedings** of Fifth ESA Congress, vol. 2, Nitra, Slovak Republic, 28 June–2 July 1998, The Slovak Agriculture University, Nitra, Slovak Republic, p. 133-134. 1998.

DORNELAS, K. D. S.; SILVA, C. L.; OLIVEIRA, C. A. S. Coeficientes médios da equação de Angström-Prescott, radiação solar e evapotranspiração de referência em Brasília. **Pesquisa Agropecuária Brasileira** 41(8): 1213-1219, 2006.

ELIZONDO, D.; HOOGENBOOM, G.; McCLENDON, R. W. Development of a neural network to predict daily solar radiation. **Agricultural and Forest Meteorology** 71(1-2): 115-132, 1994. DOI:

EL-SEBAII, A. A.; TRABEA, A. A. Estimation of horizontal diffuse solar radiation in Egypt. **Energy Conversion and Management** 44(15): 2471-82, 2003.

FALAMARZI, Y.; PALIZDAN, N.; HUANG, Y. F.; LEE, T. S. Estimating evapotranspiration from temperature and wind speed data using artificial and wavelet neural networks (WNNs). **Agricultural Water Management** 140(10): 26-36, 2014.

GAVILÁN, P.; BERENGENA, J.; ALLEN, R. G. Measuring versus estimating net radiation and soil heat flux: impact on Penman-Monteith reference ET estimates in semiarid regions. **Agricultural Water Management** 89(3): 275-286, 2007.

GOODIN, D. G.; HUTCHINSON, J. M. S.; VANDERLIP, R. L.; KNAPP, M. C. Estimating solar irradiance for crop modelling using daily air temperature data. **Agronomy Journal** 91: 845-851, 1999.

HANSEN, J. W. Stochastic daily solar irradiance for biological modelling applications**. Agricultural and Forest Meteorology** 94(1): 53-63, 1999.

HARGREAVES, G. H. **Responding to tropical climates**. In: The 1980–81 Food and Climate Review, The Food and Climate Forum, Aspen Institute for Humanistic Studies, Boulder, Colo, p. 29–32. 1981.

HARGREAVES, G. H.; SAMANI, Z. A. Estimating potential evapotranspiration. **Journal of Irrigation and Drainage**. **ASCE**, 108: 225-30, 1982.

HOOK, J. E.; McCLENDON, R. W. Estimation of solar radiation data from long-term meteorological records. **Agronomy Journal** 84(4): 739-42, 1992.

HUNT, L. A.; KUCHAR, L.; SWANTON, C. J. Estimation of solar radiation for use in crop modelling. **Agricultural and Forest Meteorology** 91: 293-300, 1998.

IQBAL, M. **An introduction to solar radiation**. Canadá: Academic Press, 1983. 390p.

LIU, D. L.; SCOTT, B. J. Estimation of solar radiation in Australia from rainfall and temperature observations. **Agricultural and Forest Meteorology** 106(1): 41-59, 2001.

MAHMOOD, R.; HUBBARD, K. G. Effect of time of temperature and estimation of daily solar radiation for the Northern Great Plains, USA. **Agronomy Journal** 94: 723-733, 2002.

MANCOSU, N.; SNYDER, R. L.; SPANO, D. Procedures to develop a standardized reference evapotranspiration zone map. **Journal of Irrigation and Drainage Engineering** 140(9): 1-11, 2014.

MARTÍ, P.; ROYUELA, A.; MANZANO, J.; PALAU‐SALVADOR, G. Generalization of ETo ANN models through data supplanting. **Journal of Irrigation and Drainage Engineering** 136: 161‐174, 2010.

MEZA, F.; VARAS, E. Estimation of mean monthly solar global radiation as a function of temperature. **Agricultural and Forest Meteorology** 100(2-3): 231-241, 2000.

PEREIRA, A. R.; VILLA NOVA, N. A.; SEDIYAMA, G. C. **Evapo(transpi)ração**. Piracicaba: FEALQ, 183p. 1997.

PINKER, R. T.; FROUIN, R.; LI, Z. A review of satellite methods to derive surface shortwave irradiance. **Remote Sensing Environment** 51(1): 108-124, 1995.

RAZIEI, T.; PEREIRA, L. S. Estimation of ETo with Hargreaves–Samani and FAO-PM temperature methods for a wide range of climates in Iran. **Agricultural Water Management** 121(6): 1-18, 2013.

REDDY, K.S.; RANJAN, M. Solar resource estimation using artificial neural networks and comparison with other correlation models. **Energy Conversion and Management** 44(15): 2519-2530, 2003.

RICHARDSON, C. W.; WRIGHT, D. A. WGEN: A Model for generating Daily Weather Variables. USDA, **Agricultural Research Service ARS-8**, USA. 1984.

RIVINGTON, M.; MATTHEWS, K. B.; BELLOCCHI, G.; BUCHAN, K. Evaluating uncertainty introduced to process-based simulation model estimates by alternative sources of meteorological data. **Agricultural Systems** 88(2-3): 451-471, 2006.

SAMANI, Z. Estimating solar radiation and evapotranspiration using minimum climatological data. **Journal Irrigation Drainage Engeneering** 126(4): 265-267, 2000.

SENTELHAS, P. C.; GILLESPIE,T. J.; SANTOS, E. A. Evaluation of FAO Penman-Monteith and alternative methods for estimating reference evapotranspiration with missing data in Southern Ontario, Canadá. **Agricultural Water Management** 97(5): 635-644, 2010.

SMITH, M. **Report on the expert consultation on procedures for revision of FAO guidelines for prediction of crop water requirements**: Rome: FAO, 54p. 1991.

SOLTANI, A.; MEINKE, H.; DE VOIL, P. Assessing linear interpolation to generate daily radiation and temperature data for use in crop simulations. **European Journal Agrononomy** 21: 133-148, 2004.

SOUZA, A. P.; ESCOBEDO, J. F. Estimativas da radiação global incidente em superfíciesinclinadas com base na razão de insolação. **Revista Brasileira de Ciências Agrárias** 8(3): 483-491, 2013.

SOUZA, A. P.; MOTA, L. L.; ZAMADEI, T.; MARTIM, C. C.; ALMEIDA, F. T.; PAULINO, J. Classificação climática e balanço hídrico climatológico no estado de Mato Grosso. **Nativa** 1(1): 34-43, 2013.

SOUZA, A. P.; CARVALHO, D. F.; SILVA, L. D. B.; ALMEIDA, F. T.; ROCHA, H. S. Estimativas da evapotranspiração de referência em diferentes condições de nebulosidade. **Pesquisa Agropecuária Brasileira** 46(3): 219-228, 2011.

TANAKA, A. A.; SOUZA, A. P.; KLAR, A. E.; SILVA, A. C.; GOMES, A. W. A. Estimativas da evapotranspiração de referência para o Estado de Mato Grosso por métodos simplificados. **Pesquisa Agropecuária Brasileira** 51(2): 91-104, 2016.

THORNTON, P. E.; RUNNING, S. W. An improved algorithm for estimating incident solar radiation from measurements of temperature, humidity and precipitation. **Agricultural and Forest Meteorology** 93: 211–228, 1999.

TODOROVIC, M.; KARIC, B.; PEREIRA, L. S. Reference evapotranspiration estimate with limited weather data across a range of Mediterranean climates. **Journal of Hydrology** 481(1): 166-176, 2013.

TRNKA, M.; ZALUD, Z.; EITZINGER, J.; DUBROVSKÝ, M. Global solar radiation in Central European lowlands estimated by various empirical formulae. **Agricultural and Forest Meteorology** 131: 54-76, 2005.

ZANETTI, S. S.; SOUZA, E. F; CARVALHO, D. F. de; BERNARDO, S. Estimação da evapotranspiração de referência no Estado do Rio de Janeiro usando redes neurais artificiais. **Revista Brasileira de Engenharia Agrícola e Ambiental** 12(2): 174-180, 2008.

WEISS, A.; HAYS, C. J.; HU, Q.; EASTERLING, W. E. Incorporating bias error in calculating solar irradiance: implications for crop yield simulations. **Agronomy Journal** 93: 1321–1326, 2001.

WU, G., LIN, Y., WANG, T. Method and strategy for modeling daily global solar radiation with measured meteorological data- a case study in Nanchang station, China. **Energy Conversion and Management** 48(9): 2447–2452, 2007.

YIN, Y.; WU, S.; ZHENG, D.; YANG, Q. Radiation calibration of FAO56 Penman-Monteith model to estimate reference crop evapotranspiration in China. **Agricultural Water Management** 95(1): 77-84, 2008.