Original Article

MODELS TO ESTIMATE INCIDENT SOLAR RADIATION ON SEROPÉDICA, RIO DE JANEIRO

MODELOS DE ESTIMATIVA DA RADIAÇÃO SOLAR INCIDENTE EM SEROPÉDICA, RIO DE JANEIRO

Givanildo de GOIS[1]; Jessica Cristina Santos SOUZA[2]; José Francisco de OLIVEIRA-JÚNIOR[3]; Rafael Coll DELGADO[3]; Gustavo Bastos LYRA[3]; Paulo Eduardo TEODORO[4]

1. Aluno do Programa de Pós-graduação em Ciências Ambientais e Florestais - PPGCAF, Instituto de Florestas - UFRRJ, Seropédica, RJ, Brasil; 2. Estudante de Graduação, Instituto de Astronomia, Geofísica e Ciências Atmosféricas, Universidade de São Paulo, SP, Brazil; 3. Professor, Doutor, Instituto de Floresta, Universidade Federal Rural do Rio de Janeiro - UFRRJ, Seropédica, RJ, Brasil; Aluno do Programa de Pós-Graduação Stricto Sensu em Agronomia - área de concentração: Produção Vegetal da Universidade Estadual de Mato Grosso do Sul, Unidade Universitária de Aquidauana - UEMS/UUA, Aquidauana, MS, Brasil. eduteodoro@hotmail.com.

ABSTRACT: Incident solar radiation (R_s) is usually used as an input variable in growth simulation models and yield of agricultural crops, in the design of alternative energy systems, buildings desing, weather, irrigation projects and food preservation, among others. However, in Brazil, there are few studies that evaluated the performance of different models in estimating R_s. Therefore, the aim of the study is to evaluate the Hargreaves-Samani, Thornton-Running and Weiss models to estimate R_s in the municipality of Seropédica, Rio de Janeiro. We used hourly measurements of solar radiation (R_s, KJ m^{-2}) and maximum (t_x,°C) and minimum (t_n,°C) air temperature obtained from Ecologia Agrícola station (EA), between January/2008 to December/2013. Normality (Shapiro-Wilks and Jarque-Bera) and homogeneity of variance (Bartlett) tests were applied to the data set. The performance of the models was evaluated based on different statistical parameters (r^2 RMSE, d, ρ_s and Student's t-test). The results indicated the rejection of the variance normality hypothesis of the standardized residuals by Shapiro-Wilks and Jarque-Bera tests. Bartlett's test indicated the presence of heterogeneity of model estimates. Hargreaves-Samani and Thornton-Running models obtained high values forr^2 and low values for d. Hargreaves-Samani (coastal) model excelled in relation to other, being more suitable for estimating the R_s in the municipality of Seropédica, Rio de Janeiro.

KEYWORDS: Empirical models. Extreme air temperature. Baixada fluminense.

INTRODUCTION

Solar radiation is the main source of energy for many physical, chemical and biological processes occurring in the Earth system, and provide energy for atmospheric movements and, thus, determine weather and climate spatiotemporal patterns (CASTELLVÍ, 2008; JERSZURKI; SOUZA, 2013). It is directly responsible for air and soil heating (sensible heat flux), photosynthesis and evapotranspiration (latent heat flux), all direct impact on human activities (CARVALHO et al., 2011) and, currently, has been used as alternate energy source.

Incident solar radiation (R_s) is usually used as an input variable in growth simulation models and productivity of agricultural crops, design of alternative energy systems, buildings desing, weather, climate change scenarios, irrigation and food preservation projects, among others (ALMOROX et al., 2008; DANTAS et al., 2003; TOVAR-PESCADOR et al., 2006; DELGADO et al., 2014).

Knowledge of R_s is also essential in many reference evapotranspiration (ET) estimate models (Penman-Monteith e Priestley-Taylor) (ALLEN, 1996; FIETZ et al., 2009), important variable in agrometeorological applications. R_s varies according to the latitude, the apparent movement of the sun over the day and year and atmospheric conditions (cloudiness, concentration of aerosols, gases and pollutants) – (JERSZURKI; SOUZA, 2013). Therefore, it is indispensable understand its spatial and temporal variation (SILVA et al., 2012).

When not available series R_s, it can be estimated by other models that consider meteorological parameters, such as temperature, air humidity, rainfall and insolation (HARGREAVES; SAMANI, 1982; THORNTON; RUNNING, 1999; WEISS; HAYS, 2004), even using the output of climate and mesoscale models as, for example, the regional circulation model HadRM3 (DELGADO et al., 2014).

Castellví (2008) when evaluate three models (Bristow and Campbell; Hargreaves and Castellví) to estimate the daily R_s in dry climates depending on air temperature and rainfall data, verified that the

Received: 14/04/15
Accepted: 20/01/16

combinated use of Hargreaves and Castellví methods increases the accuracy in estimating the daily R_s. However, studies for estimate R_s in municipalities of the State of Rio de Janeiro have not been performed. Therefore, the objective of this study was to evaluate Hargreaves-Samani (HS), Thornton-Running (TR) and Weiss (WS) modelos for estimating the R_s in the municipality of Seropédica, Rio de Janeiro.

MATERIAL AND METHODS

The municipality of Seropédica, at 22° 44' 38'' S, 43° 42' 27" W and 26 m of altitude, located in the state of Rio de Janeiro and has an area of about 266.55 km². Although considered politically as a member of the Metropolitan Region of Rio de Janeiro (RMRJ), geographically is situated in an fluminense coastal plain area denominated Baixada de Sepetiba.

Limited to the south (S) by the Atlantic Ocean, this lowland has as internal limits the Serra do Mar to west (W) and northwest (NW), the massif of Pedra Branca to the east (E), Serra dos Órgãos to northest (NE), Serra da Mantiqueira to northwest (NW) and, to north (N) and northest (NE), a succession of low-lying hills, incorporating the call landscape Mar de Morros (GASPARINI et al., 2013).

According to Köppen classification, the climate of the region is 'Aw', with rainfall concentrated between November and March, average annual rainfall of 1,213 mm and average annual air temperature of 23.9°C (CARVALHO et al., 2011). The study was performed based on data initially schedules which have been integrated to determine the total daily incident solar radiation (R_s, MJ m^{-2} d^{-1}) and maximum (t_x,°C) and minimum air temperature (t_n,°C) corresponding to the period January 2008 to December 2013. Data were obtained from Estação Meteorológica Automática (EMA), called Ecologia Agrícola, belonging to the Instituto Nacional de Meteorologia (INMET).

Data were subjected to treatment quality and consistency, with the purpose of to eliminate possible inconsistencies. In these processes we used the criterion of elimination proposed by Liu et al. (2009): missing data t_x and t_n or $t_x \geq t_n$ and $R_s/R_a > 1$ (R_a is extraterrestrial radiation at the top of the atmosphere, MJ m^{-2} d^{-1}) were eliminated.

The models evaluated in this study used the daily temperature range as the input variable. Two of the models (Thornton-Running and Weiss) are modified versions of Bristow and Campbell model (1984). In all cases, were kept the constants of the models as originally proposed, ie, in this study was not aimed at the local calibration . Only we assessed HS, TR and WS models with t_x and t_n as input data.

Hagreaves and Samani (1982) were the precursors in the estimation of incident solar radiation based on air temperature, according to Equation 1. These authors adopted two patterns for k_t value for estimating the R_s; one for the interior regions, where weather patterns are dominated by large air masses; another to coastal regions, where weather patterns are dominated by the proximity to the coastal environment. In this study, we evaluated both k_t values because Seropédica is situated near a large body of water (Baía de Sepetiba, 18.5 km), following by Oceano Atlântico (25 km) and, therefore receives influence of both bodies of water.

$$R_s = k_t R_a \sqrt{t_x - t_n} \quad (1)$$

wherein: k_t is calibration coefficient equal to 0.16 (interior region) and 0.19 (costal region), dimensionless, t_x and t_n and R_a according to Borges et al. (2009).

Thornton and Running (1999) use daily and monthly temperature range to determine the overall transmissivity coefficient of the atmosphere, according to the Equations 2 and 3:

$$R_s = R_{so}\left[1 - 0{,}9\exp(-B(t_x - t_n)^{1{,}5}\right] \quad (2)$$

$$B = 0{,}031 + 0{,}201\exp(-0{,}185\Delta,_m) \quad (3)$$

wherein: B is empirical adjustment coefficient, dimensionless. The adjustment coefficient B is determined based on local climatological normal through the parameter, Δt_m is daily monthly temperature range (°C) and R_{so} is the solar radiation in day without cloudiness (MJ m^{-2} d^{-1}).

Weiss et al. model (2001) uses in addition to the air temperature range, uses the extraterrestrial radiation at the top of the atmosphere to estimate R_s, according to Equations 4 and 5:

$$R_s = 0{,}75\left[1 - \exp\left(-0{,}226\frac{(\Delta T)^2}{R_a}\right)\right]R_a \quad (4)$$

$$\Delta t = t_{x,i} - \left(\frac{t_{n(1)} + t_{n(i+1)}}{2}\right) \quad (5)$$

Parametric statistical tests were used to assess the normality (Shapiro-Wilks and Jarque-Bera) and homogeneity (Bartlett) in the data series, using the environment software R version 3.1.1.

Shapiro-Wilk's test (S-W) has been used in the literature to determine whether a random sample follows the normal distribution. Through the command *shapiro.test* applied in the environment R were obtained from the statistical values of W and p-value of standardized residues observed and estimated of R_s, being formulated the hypotheses nullity H_0 and alternative H_1, according to Equation 6.

$$W = \frac{\left(\sum_{i=1}^{n} a_{n-i+1}(x_{n-i+1} - x_1)\right)^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \qquad (6)$$

wherein: i = 1, 2,…n, are the sample size; x_i = ordered values of the sample; $\bar{x}$ = average sample value; a_{n-i+1} = constants generated from middle, variances and covariances of the statistical order of a sample size N and a normal distribution; W= statistical variable from S-W.

The conditions so that the observed data set R to be to a normal distribution at probability level α is defined by: (**i**) for $W_{cal} \leq W_{tab}$ is rejected H_0 for p-value $\alpha < 0.05$ and (**ii**) for $W_{cal} \geq W_{tab}$ is acept H_0 for p-value $\alpha > 0.05$.

Jarque-Bera's test (BERA; JARQUE, 1980), based on the difference between the coefficients of asymmetry and kurtosis of the sample data x_1, x_2, x_3, ..., x_n and the theoretical from normal distribution. The statistical JB shows asymptotic distribution χ^2 with ν = 2 degrees of freedom under the null hypothesis of normality, the test is defined according to Equations 7, 8 and 9:

$$JB = n\left[\frac{\left(\sqrt{b_1}\right)^2}{6} + \frac{(b_2 - 3)^2}{24}\right] \qquad (7)$$

$$\sqrt{b_1} = \frac{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^3}{\left[\sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2}\right]^3} \qquad (8)$$

$$b_2 = \frac{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^4}{\left[\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2\right]^2} \qquad (9)$$

wherein: i = 1, 2,…n, is the sample size; $\sqrt{b_1}$ and b_2 are the asymmetry and kurtosis coefficients; $\bar{x}$ = sample average; x_i= ordered sample values, $\chi^2_{\nu=2}$ = chi-squared distribution with two degrees of freedom.

The null and alternative hypothesis by the Jarque-Bera's test are defined as: (**i**) for JB ≥ $\chi^2_{(1-\alpha,\, \nu=2)}$ is rejected H_0 for p-value α < 0.05 and (**ii**) for JB ≤ $\chi^2_{(1-\alpha,\, \nu=2)}$ is accept H_0 for p-value α > 0.05.

Bartlett's test is used to verify the supposition that K samples from a population with equal variances (homogeneity). In the study we tested the homogeneity of variance of the observed and estimated data from R_s.

Bartlett's test statistic (B_0) was determined by Equations 10, 11, 12, 13, 14 and 15:

$$N = \sum_{j=1}^{n} n_j \qquad (10)$$

$$S_i^2 = \sum_{j=1}^{n_i}\frac{\left(y_{ij} - \overline{y_i}\right)^2}{n_i - 1} \qquad (11)$$

$$S_p^2 = \frac{1}{N-k}\sum_{i=1}^{k}(n_i - 1)S_i^2 \qquad (12)$$

$$q = (N-k)\ln S_p^2 - \sum_{i=1}^{k}\left[(n_i - 1)\ln S_i^2\right] \qquad (13)$$

$$c = 1 + \frac{1}{3(k-1)}\left(\sum_{i=1}^{n}\frac{1}{n_i - 1} - \frac{1}{N-k}\right) \qquad (14)$$

wherein, B_0 is defined as:

$$B_0 = \frac{q}{c} \qquad (15)$$

B_0 on the hypotesis $H_0 \approx \chi^2_{k-1}$

wherein, N= number of observations, n_i and k = number of observations whitin groups, S_i^2 = sample variance, S_p^2 = population variance, q= numerator coefficient, c= denominator coefficient, χ^2_{k-1} = chi-square distribution, a = significance level and B_0 = Bartlett's test statistic.

Wherein X is a feature of study, we formulated the hypotheses: (**i**) H_0: Incident solar radiation data R_s have homogeneous variances and (**ii**) H_1: Incident solar radiation data R_s have not homogeneous variances.

The conditions for the R_s dataset shows homogeneity or heterogeneity of variances at the level of probability α is: for B_0 ≥ $\chi^2_{(1-\alpha,\, k-1)}$ is rejected H_0 for p-value α < 0.05 and (ii) for B_0 ≤ $\chi^2_{(1-\alpha,\, k-1)}$ is accept H_0 for p-value α > 0.05.

Performance analysis of modelos HS, TR and WS models were performed by comparing R_s estimated and observed values based on the following statistical parameters: coefficient of determination (r^2), root-mean-square error (RMSE, MJ m^{-2} d^{-1}), Willmot's concordance index (d), Spearman's rank correlation coefficient (ρ_s) and t-test (Student).

Wherein, the expected values of r^2, d, ρ_s and t-test nearest 1 and ρ_s at 1 and -1 positive and negative correlation, RMSE values tending to 0 indicate good model performance (BORGES et al., 2009). The lower the value of t-test, better model performance, since the mean differences between the estimated and observed values will be small (SILVA et al., 2012).

RMSE provides information about the real value of the errors generated by the models. Great magnitudes errors may result in significant increases in the values provided by the RMSE, and not differentiate overestimates of underestimates. The r^2 indicates the accuracy of estimates, defined by Equation 16:

$$r^2 = 1 - \frac{\sum_{i=1}^{n}\left(E_i - \bar{O}\right)^2}{\sum_{i=1}^{n}\left(O_i - \bar{O}\right)^2} \quad (16)$$

The RQME is definited by Equation 17:

$$RQME = \sqrt{\frac{\sum_{i=1}^{n}\left(E_i - O_i\right)^2}{n}} \quad (17)$$

Willmott's index (d) (WILLMOT; MATSUURA, 2005) shows the correlation between the estimated values regarding to observed from R_s. It value ranges from 0 to 1, the agreement is greater when nearest to 1 and less precision when nearest to 0. Equation 18 is given by:

$$d = 1 - \left[\frac{\sum_{i=1}^{n}(E_i - O_i)^2}{\sum_{i=1}^{n}\left(\left|E_i - O_i\right| + \left|O_i - \bar{O}\right|\right)^2}\right] \quad (18)$$

Correlation between HS, TR and WS models was based in the t $\hat{\rho}_s$ coefficient, generated in the environment R. According to Lira and Neto (2006), ρ_s coefficient is known for variables measured on an ordinal level, also known as Spearman's rank correlation coefficient, estimated as Equation 19:

$$\hat{\rho}_s = \frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)}{\sqrt{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2 \sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2}} \quad (19)$$

Equation 20 can be rewritten, as the following Equation:

$$\hat{\rho}_s = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n(n^2 - 1)} \quad (20)$$

wherein: ρ_s = Spearman's rank correlation coefficient; d_i = difference between the ordinations; n= number of pairs of ordinations.

For samples greater than n $\geq$ 10, the Equation (21) has a *Student-t* distribution with n-2 degrees of freedom.

$$t = \hat{\rho}_s = \sqrt{\frac{n-2}{1 - \hat{\rho}_s^{\,2}}} \approx t_{n-2} \quad (21)$$

wherein: ρ_s = Spearman's rank correlation coefficient; n = number of pairs of ordinations. To verify the hypothesis that the R_s values estimated by the models differ significantly between the R_s observed values, it was used *Student-t*, accordint to Equação 22.

$$t = \sqrt{\frac{(n-1)EM^2}{RMSE^2 - EM^2}} \quad (22)$$

wherein, t critical value can be obtained from statistical table (t_{tab}, *t-Student*), with significance level α and (n - 1) degrees of freedom. A model was considered statistically significant when the null hypothesis H_0 presented the following (is accept, H_0: estimated data was equal to the observed) in the range (1-α), if t_{cal} be less than the critical value.

RESULTS AND DISCUSSION

The results obtained by Shapiro-Wilks (SW) and Jarque-Bera (JB) normality tests and Bartlett's variance homogeneit indicated the rejection of standardized residuals normality of variance hypothesis with p-value below level of significance at 5% probability in all models (Table 1).

It is possible to verify in Figure 1 the distance of waste from models used in the linear regression line, followed by high asymmetry coefficients for HS model for both cases (0.173), TR (0.179) a and WS (6.65) and kurtosis for HS model for both cases (-0.214), TR (-0.189) and WS (-103.39). Bartlett's test indicated the presence of heterocedasticity of variance for all the models tested (Table 1), with values of calculated chi-square distribution lower than Bartlett's values below the significance at 5% probability, with p-value equal to 2.48 x 10^{-7}.

Table 1. Parametric Tests of Normality (Shapiro-Wilks and Jarque Bera) and Homogeneity of Variance Test (Bartlett).

Models/Tests	Jarque-Bera		Shapiro-Wilks		Bartlett	
	χ^2	p-value	W	p-value	χ^2	p-value
HS (interior)	947.52	2.48×10^{-7}	0.939	2.48×10^{-7}	22847.63	2.48×10^{-7}
HS (coastal)	816.16	2.48×10^{-7}	0.950	2.48×10^{-7}	22558.94	2.48×10^{-7}
TR	1213.50	2.48×10^{-7}	0.907	2.48×10^{-7}	23492.31	2.48×10^{-7}
WS	1269.18	2.48×10^{-7}	0.889	2.48×10^{-7}	24189.94	2.48×10^{-7}

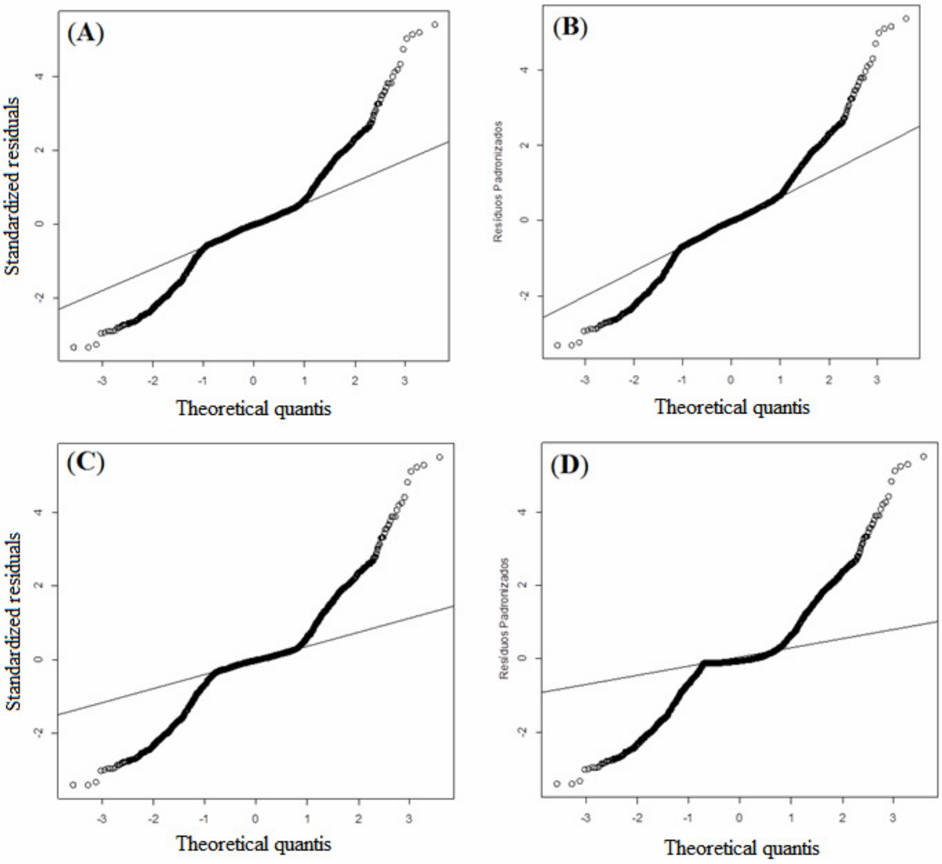

Figure 1. Standardized residuals *versus* Theoretical Quantis of Hargreaves-Samani (interior) (**A**), Hargreaves-Samani (coastal) (**B**), Thornton-Running (**C**) and Weiss (**D**) models.

We verified from Figure 2 that the tested models showed a linear growth trend of waste variance followed by underestimation of R_s estimated values, or values whose square root is greater than two. Moreover, there were no notable differences in the dispersion of waste (heterogeneity of variances) by combining levels of average factors and R_s estimated by the models, justifying the results obtained for the parametric tests of normality and homogeneity of variance.

Values around unity indicate high positive correlation of the observed and estimated v values. HS models, regardless of used k_t (interior – 0.93 and coastal – 0.93), and TR (0.92) obtained high values for r^2, which indicates possibility to obtain estimates of R_s with high precision (Table 2). Based on this parameter, the WS model has low positive correlation of observed and estimated R_s, suggesting inadequacy of this model to estimates of R_s. These results differ from those obtained by Borges et al. (2010), that when assessing different models for estimating the R_s in the municipality of Cruz das Almas (BA), verified superior performance of WS and RT models in relation to the HS, based on this parameter. Studies that assess the models adjusting for estimated R_s are scarce in Brazil and for the state of Rio de Janeiro, do not yet exist.

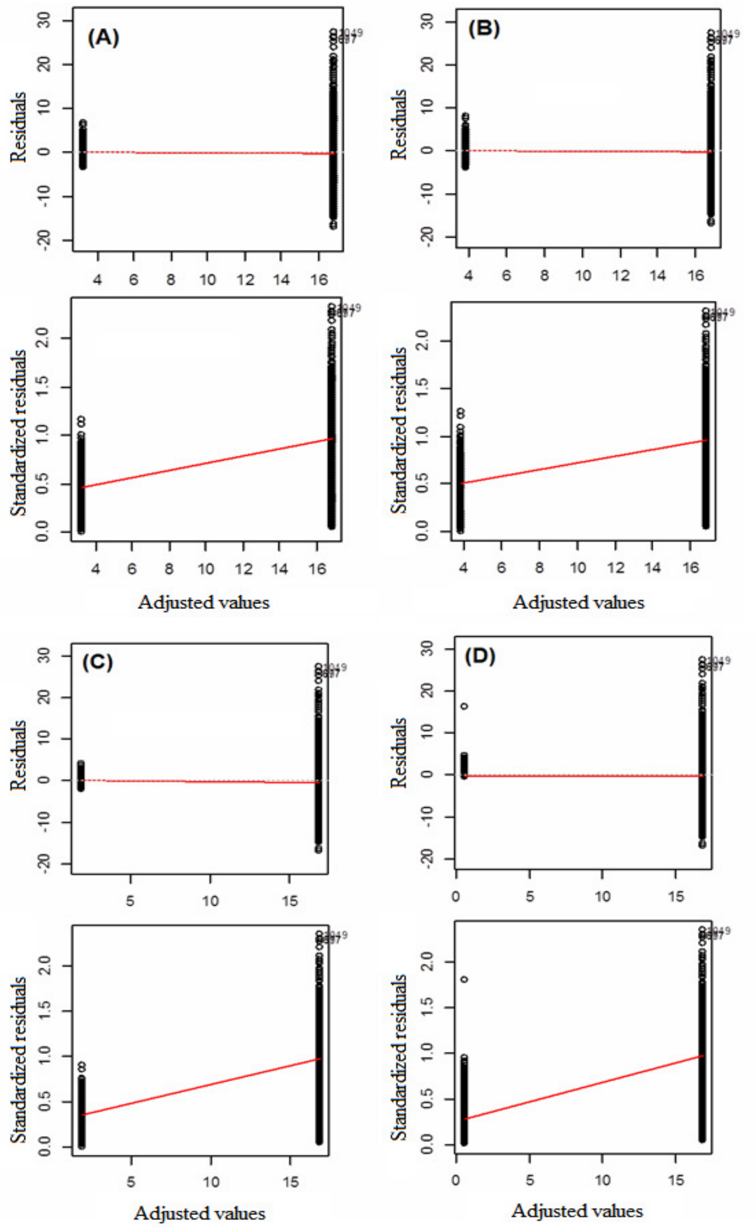

Figure 2. Residuals and standardized residuals *versus* Theoretical Quantis of Hargreaves-Samani (interior) (**A**), Hargreaves-Samani (coastal) (**B**), Thornton-Running (**C**) and Weiss (**D**) models.

Table 2. Parameters of Hargreaves-Samani (HS) interior and coastal model, Thornton-Running (TR) and Weiss (WS) models, determination coefficient (r^2), root-mean-square error (RMSE), Willmott's concordance index (d), Spearman's rank correlation coefficient (ρ_s) and t calculated.

Modelos	r^2	RMSE ($MJ.m^{-2}$ d^{-1})	d	$\hat{\rho}_s$	t calculated
HS (Interior)	0.93	14.60	0.44	0.964	71.93
HS (Coastal)	0.93	13.93	0.46	0.964	68.02
TR	0.92	16.07	0.40	0.958	80.29
WS	0.03	17.61	0.37	0.276	87.70

We verified low values of the rate *d* in both models evaluated, in the order of 0.4 Borges et al. (2010) and Jerszurki and Souza (2013) obtained d values in magnitude greater than this study in the evaluation of these models for estimating the R_s in the municipalities of Cruz das Almas (BA) and Telêmaco Borba (PR). RMSE values indicated that all models underestimated the R_s values.

T-test values obtained from the models indicated the rejection of the null hypothesis (Table 3). The estimated R_s values differ statistically, ie, the models are not significant at the α significance level, at 5% probability. Estimated and observed R_s values for $t_{cal} > t_{tab}$ were above the confidence interval of 1.96 at 5% probability.

TR model, with greater physical reasoning, it has the advantage of not producing estimates of R_s greater than R_a, in adittion to be able to estimate R_a values, given that for a specific ΔTm value the relation R_s/R_a converges to 1 in a broad spectrum of ΔT values. WS model has proved unsuitable to estimate R_s in Seropédica, RJ, with values of EAM and RMSE superior to other empirical models. It is important to mention that until this moment do not exist in literature local calibration for accomplished tests. Similar results were observed by Ball et al. (2004) and Borges et al. (2010), which verified the limitations of this model to estimate the R_s and emphasized the existing limitations to the transferability of this model to other regions without adequate local calibration, since it was calibrated with meteorological data from the locality of Mead, Nebraska (WEISS et al., 2001).

HS model, which showed better indices, regardless of used k_t, is a conservative model, where estimates rarely overestimated R_s for clear sky conditions (ALLEN, 1996). This is a desirable feature of the model, where R_s measured in absence of clouds is an upper limit for the R_s in a given locality.

CONCLUSIONS

Bartlett's test indicated the presence of heterogeneity of the estimates of the models.

The Hargreaves-Samani and Thornton-running models had high values of r² and low values of d.

Based on the statistical parameters, Hargreaves-Samani model is the most indicated to estimate incident solar radiation in Seropédica, Rio de Janeiro, but Thornton-Running can be used with lower precision, wile Wess model should not be used while. For future researches, it is necessary to fit the coefficients of the evaluated models for the climatic conditions from Seropédica, Rio de Janeiro.

ACKNOWLEDGEMENTS

To Instituto Nacional de Meteorologia by the availability of weather data from station Ecologia Agrícola, Seropédica – Rio de Janeiro.

RESUMO: A radiação solar incidente (R_s) é normalmente utilizada como variável de entrada em modelos de simulação de crescimento e produtividade de culturas agrícolas, no delineamento de sistemas alternativos de geração de energia, desing de edifícios, na climatologia, em projetos de irrigação e conservação de alimentos, entre outros. Entretanto, no Brasil, há excassez de pesquisas que avaliaram o desempenho de diferentes modelos na estimativa de R_s. Portanto, o objetivo do trabalho é avaliar os modelos Hargreaves-Samani, Thornton-Running e Weiss para estimativa da R_s no município de Seropédica, Rio de Janeiro. Utilizaram-se medidas horárias da radiação solar incidente (R_s, KJ m^{-2}) e da temperatura do ar máxima (t_x,°C) e mínima (t_n,°C) obtidas na estação Ecologia Agrícola (EA), entre janeiro/2008 a dezembro/2013. Testes de normalidade (Shapiro-Wilks e Jarque-Bera) e homogeneidade de variância (Bartlett) foram aplicados à série de dados. O desempenho dos modelos foi avaliado com base em diferentes parâmetros estatísticos (r^2 RMSE, d, ρ_s e teste-t de Student). Os resultados indicaram a rejeição da hipótese de normalidade de variância dos resíduos padronizados pelos testes de Shapiro-Wilks e Jarque-Bera. O teste de Bartlett indicou a presença de heterogeneidade das estimativas dos modelos. Os modelos Hargreaves-Samani e Thornton-Running tiveram altos valores de r^2 e baixos valores de d. O modelo de Hargreaves-Samani (costeiro) se sobressaiu em relação aos demais, sendo mais adequado para estimar a R_s no município de Seropédica, Rio de Janeiro.

PALAVRAS-CHAVE: Modelos empíricos. Extremos da temperatura do ar. Baixada fluminense.

REFERENCES

ALLEN, R. G. Assessing Intergrity of Weather Data For Reference Evapotranspiration Estimation. **Journal of Irrigation and Drainage Engineering**, Reston, v. 122, n. 2, p. 97-106, 1996. http://dx.doi.org/10.1061/(ASCE)0733-9437(1996)122:2(97)

ALMOROX, J.; BENITO, M.; HONTORIA, C. Estimation of global solar radiation in Venezuela. **Interciencia**, Caracas, v. 33, n. 4, p. 280-283, 2008.

BALL, R. A.; PURCELL, L. C.; CAREY, S. K. Evaluation of solar radiation prediction models in North America. **Agronomy Journal**, Madson, v. 96, n. 2, p. 391-397, 2004.

BERA, A.; JARQUE, C. Efficient test for normality, heterocedasticity and serial independence of regression residuals. **Econometrics Letters**, Ankara, v. 6, p. 255–259, 1980.

BORGES, V. P.; OLIVEIRA, A. S.; FILHO, M. A. C.; SILVA, T. S. M.; PAMPONET, B. M. Avaliação de modelos de estimativa da radiação solar incidente em Cruz das Almas, Bahia. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 14, n. 1, p. 74-80, 2010. http://dx.doi.org/10.1590/S1415-43662010000100010

BRISTOW, K. L.; CAMPBELL, G. S. On the relationship between incoming solar radiation and daily maximum and minimum temperature. **Agricultural And Forest Meteorology**, Connecticut, v. 31, n. 2, p. 150-166, 1984. http://dx.doi.org/10.1016/0168-1923(84)90017-0

CARVALHO, D. F.; SILVA, D. G.; SOUZA, A. P.; GOMES, D. P.; ROCHA, H. S. Coeficientes da equação de Angström-Prescott e sua influência na evapotranspiração de referência em Seropédica, RJ. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 15, n. 8, p. 108-116, 2011. http://dx.doi.org/10.1590/s1415-43662011000800011

CASTELLVÍ, F. Evaluation of three practical methods for estimating daily solar radiation in dry climates. **The Open Atmospheric Science Journal**, Beijing, v. 2, p. 185-191, 2008. http://dx.doi.org/10.2174/1874282300802010185

DANTAS, A. A.; CARVALHO, L. G.; FERREIRA, E. Estimativa da radiação solar global para a região de Lavras, MG. **Ciência e Agrotecnologia**, Lavras, v. 27, n. 6, p. 1260-1263, 2003.

DELGADO, R. C.; OLIVEIRA-JÚNIOR, J. F.; GOIS, G.; LYRA, G. B. Cenários climáticos da radiação solar global baseados no modelo regional HadRM3 para o Estado do Acre. **Floresta e Ambiente**, Seropédica, v. 21, n. 4, p. 417-428, 2014.

FIETZ, C. R.; FISCH, G. F. Avaliação de modelos de estimativa do saldo de radiação e do método de Priestley-Taylor para a região de Dourados, MS. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 13, n. 4, p. 449–453, 2009. http://dx.doi.org/10.1590/s1415-43662009000400012

GASPARINI, K. A. C.; LYRA, G. B.; FRANCELINO, M. R.; DELGADO, R. C.; OLIVEIRA-JÚNIOR, J. F.; FACCO, A. G. Técnicas de geoprocessamento e sensoriamento remoto aplicadas à identificação de conflitos do uso da terra em Seropédica. **Floresta e Ambiente**, Seropédica, v. 20, n. 3, p. 296-306, 2013.

HARGREAVES, G. H.; SAMANI, Z. A. Estimating potential evapotranspiration. **Journal of Irrigation and Drainage Engineering**, Reston, v. 108, n. 3, p. 223-230, 1982.

JERSZURKI, D.; SOUZA, J. L. M. Parametrização das equações de Hargreaves & Samani e Angströn-Prescott para estimativa da radiação solar na região de Telêmaco Borba, Estado do Paraná. **Ciência Rural**, Santa Maria, v. 43, n. 3, p. 383-389, 2013. http://dx.doi.org/10.1590/S0103-84782013005000004

LIRA, S. A.; NETO, C. A. Estatística não-paramétrica: para as ciências do comportamento, Uberlândia. **Revista Ciência & Engenharia**, Uberlândia, v. 15, n. 1/2, p. 45-53, 2006.

LIU, X.; MEI, X.; LI, Y.; WANG, Q.; JENSEN, R. J.; ZHANG, Y.; PORTER, J. R. Evaluation of temperature-based global solar radiation models in China. **Agricultural and Forest Meteorology**, Connecticut, v. 149, n. 9, p. 1433-1446, 2009. http://dx.doi.org/10.1016/j.agrformet.2009.03.012

OLIVEIRA-JÚNIOR, J. F.; DELGADO, R. C.; GOIS, G.; LANNES, A.; DIAS, F. O.; SOUZA, J. C. S.; SOUZA, M. Análise da precipitação e sua relação com sistemas meteorológicos em Seropédica, Rio de Janeiro. **Floresta e Ambiente**, Seropédica, v. 21, n. 2, p. 140-149, 2014.

OLIVEIRA-JÚNIOR, J. F.; SOUZA, J. C. S.; DIAS, F. O.;GOIS, G.; GONÇALVES, I. F. S.; SILVA, M. S. Caracterização do Regime de Vento no Município de Seropédica, Rio de Janeiro (2001-2010). **Floresta e Ambiente**, Seropédica, v. 20, n. 4, p. 447-459, 2013.

SILVA, C. R.; SILVA,V. J.; ALVES JÚNIOR, J.; CARVALHO, H. P. Radiação solar estimada com base na temperatura do ar para três regiões de Minas Gerais. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 16, n. 3, p. 281–288, 2012.

THORNTON, P. E.; RUNNING, S. W. An improved algorithm for estimating incident daily solar radiation from measurements of temperature, humidity and precipitation. **Agricultural and Forest Meteorology**, Connecticut, v. 93, p. 211-228, 1999. http://dx.doi.org/10.1016/S0168-1923(98)00126-9

TORMAN, V.; LEOTTI, B.; COSTER, R.; RIBOLDI, J. Normalidade de variáveis: métodos de verificação e comparação de alguns testes não-paramétricos por simulação, Porto Alegre. **Revista Hospital de Clínicas de Porto Alegre**, Porto Alegre, v. 32, n. 2, p. 227-234, 2012.

TOVAR-PESCADOR, J.; POZO-VÁZQUEZ, D.; RUIZ-ARIAS, J. A.; BATLLES, J.; LÓPEZ, G.; BOSCH, J. L. On the use of the digital elevation model to estimate the solar radiation in areas of complex topography. **Meteorological Applications**, Oklahoma, v. 13, n. 3, p. 279–287, 2006. http://dx.doi.org/10.1017/S1350482706002258

WEISS, A.; HAYS, C. J. Simulation of daily solar irradiance. **Agricultural and Forest Meteorology**, Connecticut, v. 123, n. 3-4, p. 187-199, 2004. http://dx.doi.org/10.1016/j.agrformet.2003.12.002

WEISS, A.; HAYS, C. J.; HU, Q.; EASTERLING, W. E. Incorporating bias error in calculating solar irradiance: implications for crop simulations. **Agronomy Journal**, Madson, v. 93, n. 6, p. 1321-1326, 2001. http://dx.doi.org/10.2134/agronj2001.1321

WILLMOT, C. J.; MATSUURA, K. Advantages of the mean absolute error (MAE) over the root mean square error (RMSE) in assessing average model performance. **Climate Research**, Oldendorf, v. 30, p. 79-82, 2005.