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Delineation of air temperature based models for estimation of global solar radiation*

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ABSTRACT

Data on global solar radiation is an essential input variable to many crop models from the process oriented crop models at field scale, to the land surface based ecological models at regional scale and the global circulation models. Here an attempt has been made to delineate four temperature based relations proposed by Bristow and Campbell (1984), Hargreaves (1985), Richardson (1985) and Goodin *et al.,* (1999) for their relevance to the actually measured. Daily data on measured solar radiation, maximum and minimum air temperatures at Patancheru location is collected for the period 1st Jan 2009 to 1st April 2011. Models performance has been evaluated using mean bias error, mean absolute percentage error, root mean square error and D-index of agreement. The comparative analysis revealed that among the four models Bristow-Campbell model estimated solar radiation comparatively with less errors and the estimated radiation values were most close to the measured values.

Key words: Bristow-Campbell, Hargreaves, Richardson, Goodin et al., Extra terrestrial radiation

Many models have been proposed by various researchers for estimating solar radiation in relation with different atmospheric parameters such as relative humidity, air temperature, rain fall, cloud cover etc. Though direct measurement of solar radiaiotn can be done using a variety of instruments, adroitness is important to operate them and even during odd weather days many errors could be confronted. By using appropriate relations one can successfully estimate those missing days data of solar radiation. Since measurement of air temperature is always most accurate and easy, here air temperature based relations are examined for their accuracy. Relations proposed by Bristow-Campbell (1984), Hargreaves (1985), Richardson (1985) and Goodin *et. al.*,(1999) are coped here.

MATERIALS AND METHODS

Daily data on global solar radiation (MJ m^{-2} day^{-1}), maximum air temperature (°C), minimum air temperature (°C), were collected from Agrometeorological Observatory situated at the International Crop Research Institute for Semi Arid Tropics (ICRISAT), Patancheru (17.54° N, 78.26° E), Hyderabad covering the period from 1st January 2009 to 1st April 2011.

In the absence of measured solar radiation data it is possible to estimate radiation using empirical relations between solar radiation and commonly measured meteorological parameters. Four different models, based on maximum and minimum temperature, were used to estimate solar radiation and were compared for their applicability in the location on the basis of accuracy with least error. The details of each model is given below.

Bristow and Campbell model (1984)

The Bristow-Campbell model described R_s as an exponential asymptotic function of daily temperature range which calculates R_s by estimating the daily transmissivity coefficient (T_t), defined as

$$T_t = \frac{R_s}{R_a} \qquad \text{(Eq. 1)}$$

T_t is estimated from the daily air temperature range (DT) using an exponential equation:

$$T_t = a\left[1 - \exp\left(-b\,(\Delta T^c)\right)\right] \qquad \text{(Eq. 2)}$$

where a, b and c are empirical coefficients. The coefficient a reprsents the maximum value of atmospheric transmission

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coefficient and depends on pollution content of the air and elevation. The coefficients b and c determine the effect of increments in the DT on the maximum value of atmospheric transmission.

Hargreaves model (1985)

Hargreaves estimate the solar radiation (R_s) by relating the daily temperature range (difference between maximum and minimum temperature) to extra terrestrial radiation (R_a) which is given by the relation

$$\frac{R_s}{R_a} = a\sqrt{T_{max} - T_{min}} + b \qquad \text{(Eq. 3)}$$

where, a and b are the coefficients, T_{max} and T_{min} are the daily maximum and minimum temperature respectively.

Richardson model (1985)

A relationship between daily temperature and solar radiation was developed by Richardson (1985) using the days when actual radiation data were available. The equation that was developed is

$$\frac{R_s}{R_a} = a(T_{max} - T_{min})^b \qquad \text{(Eq. 4)}$$

where a and b are the coefficients.

Goodin et al., (1999) model

Goodin *et al.*, (1999) refined the Bristow-Campbell model by adding extra terrestrial radiation (R_a) meant to act as a scaling factor allowing DT to accomodate a greater range of R_s values. The equation is given by

$$\frac{R_s}{R_a} = a\,[1 - \exp(-b(\frac{\Delta T^c}{R_a})] \qquad \text{(Eq. 5)}$$

Extra terrestrial radiation (R_a)

All the four models uses extra terrestrial radiation (R_a) as a common parameter in estimating the solar radiation at a given location which is computed after Duffie and Beckman (1991) as

$$R_s = \frac{24 * 60}{\pi} GS_c\left[dr[W_s \,Sin(LAT) Sin(d) + Cos(LAT) Cos(d) Sin(W_s)]\right] \qquad \text{(Eq. 6)}$$

where GS_c is the solar constant (0.82 M J $m^{-2} min^{-1}$), dr is the relative distance of the Earth from the Sun, d is the solar declination in radiance. The distance from the Earth to Sun is calculated as

$$dr = 1 + 0.033\, Cos\left(\frac{2\pi * i}{365}\right) \qquad \text{(Eq. 7)}$$

where i is the Julian day. Solar declination (d) is computed as

$$d = 0.4093\, Sin\,[2\pi\left(\frac{284 + i}{365}\right)] \qquad \text{(Eq. 8)}$$

The sunset hour angle, W_s, in radians is calculated as

$$c\ W_s = arc\,Cos\,(-Tan\,(LAT)\,Tan(d)) \qquad \text{(Eq. 9)}$$

The maximum possible hours of sunshine (N) is simulated using the following function

$$N = \left(\frac{2}{15}\right) Cos^{-1}\,(-Tan\,(LAT)\,Tan(d)) \qquad \text{(Eq. 10)}$$

where

$$d = 23.45\, Sin\left[360\left(\frac{284 + i}{365}\right)\right] \qquad \text{(Eq. 11)}$$

where LAt is latitude of the station.

Evaluation of models performance

The estimated global solar radiation with four temperature based relations were compared with observed data using Mean Bias Error (MBE), Mean Absolute Error (MAE), Root Mean Square Error (RMSE) and D-index (Ahuja *et al.*, 2002). D-index is a measure of the deviation between model prediction and observed in relationship to the scattering of the observed data. It has a value ranging from 0 to 1, where if the value is equal to 1 means perfect simulation. MBE, MAE, RMSE and D-index are given by the following relations,

$$MBE = \frac{\sum_{i=1}^{N}(P_i - O_i)}{N} \qquad \text{(Eq. 12)}$$

$$MAE = \frac{\sum_{i=1}^{N}|P_i - O_i|}{N} \qquad \text{(Eq. 13)}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(P_i - O_i)^2}{N}} \qquad \text{(Eq. 14)}$$

$$D = 1 - \frac{\sum_{i=1}^{N}(P_i - O_i)^2}{\sum_{i=1}^{N}(|P_i - O_{avg}| + |O_i - O_{avg}|)^2} \qquad \text{(Eq. 15)}$$

RESULTS AND DISCUSSION

Four relations proposed by Bristow and Campbell (1984), Hargreaves (1985), Richardson (1985), and Goodin et.al (1999) were considered for the analysis which estimate global solar radiation in relation with maximum and minimum air temperature. The coefficient values for each relations which varies with location were estimated using Okadales DataFit 9.0. by regressing and presented in Table 1.

Statistical evaluation of model performance

The accuracy of each temperature based relation in estimating global solar radiation has been assessed using statistical measures like MBE, MAE, RMSE and D-index. The results of the analysis for different relations are presented in the Table 2.

The analysis indicated that Hargreaves relations under estimated the radiation to a larger extent (-0.21) followed by Bristow-Campbell (-0.18). Whilst the relation of Goodin over estimated the radiation (0.16). The errors associated with the estimation of radiation are generally large (2.19) with Goodin followed by Hargreaves (1.86) and Richardson (1.79). Least error of 1.76 was noticed with Bristow-Campbell model. Further the estimated values were

Table 1: Coefficients generated using different empirical models

Sl. No.	Empirical Models	Coefficients	R^2
1.	Bristow-Campbell	a = 0.63 b = 0.08 c = 1.25	0.67
2.	Hargreaves	a = 0.14 b = 0.54	0.64
3.	Richardson	a = 0.15 b = 0.49	0.64
4.	Goodin	a = 0.62 b = 2.35 c = 1.39	0.48

Table 2 : Statistical results for different models

Sl. No.	Empirical Model	MBE	MAE	RMSE	D-index
1.	Bristow-Campbell	-0.18	1.76	2.40	0.90
2.	Hargreaves	-0.21	1.86	2.53	0.88
3.	Richardson	-0.01	1.79	2.52	0.88
4.	Goodin	0.16	2.19	2.44	0.90

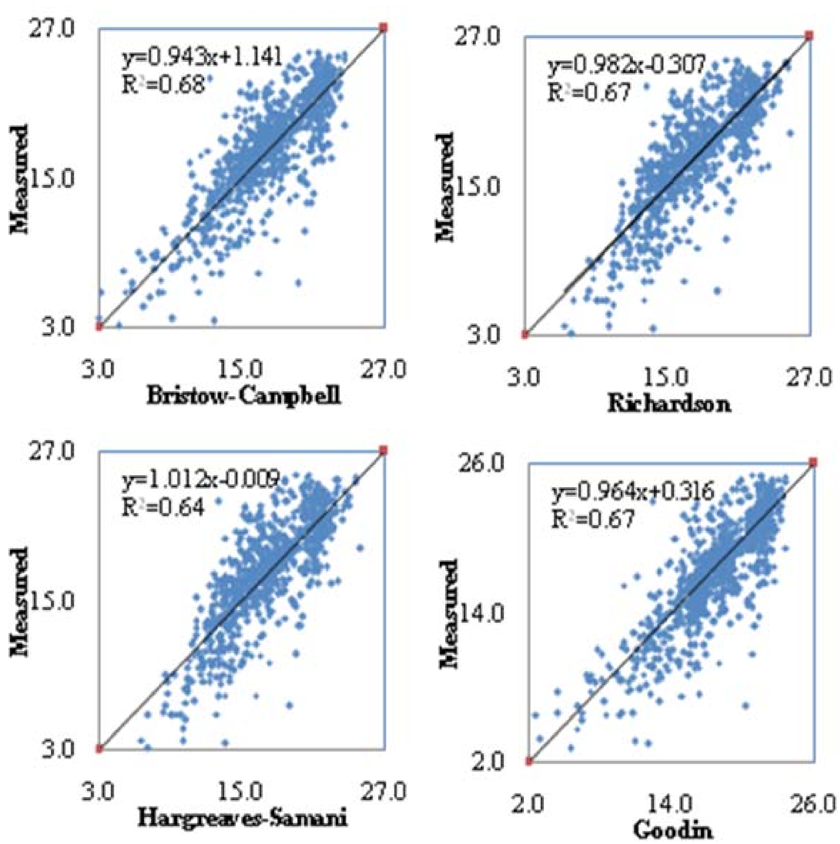

Fig. 1: Measured vs estimated solar radiation using different models

subjected to index of agreement (D-index) which is a comparatively better statistical tool to assess the accuracy of estimation. It is observed from the Table 2 that, the D-index of Bristow-Campbell model is closer to unity with the lowest RMSE of 2.40 MJ m^{-2} day^{-1} compared to the other three models. It can be inferred from the present investigation that Bristow-Campbell model can be used for the estimation of global solar radiation for Hyderabad conditions with minimal errors.

Measured Vs estimated global solar radiation

The estimated global solar radiation using different relations were plotted against measured and presented in Fig. 1 a to d. It is evident from the figure that the estimated values are more closer to the measured with B-C model compared to all other models. The R^2 values, a measure for the close agreement between the two variables are presented in table 10. They are also in the conformity of the observation on the B-C model as highest R^2 value of 0.67 was noticed.

CONCLUSION

Four models (Bristow-Campbell, Hargreaves, Richardson, and Goodin) which estimate global solar radiation in relation with air temperature were tested for Patancheru location. A comparison is made between the measured and estimated global solar radiation using statistical measures like MBE, MAE, RMSE and D-Index. Bristow-Campbell model was found to be more practiable for estimating the global solar radiation as the model possess high D-index value of 0.90 with the lowest RMSE of 2.40 MJ m^{-2} day^{-1} compared to the other three models.

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