Estimation of solar radiation using two step method in West Bengal

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ABSTRACT. Solar radiation is the main source of energy for many physical, chemical and biological processes. Estimation of solar radiation from other measured meteorological variables offers an important alternative in the absence of availability of measured solar radiation data. In this paper, we validate and assess five commonly used air temperature based models. The weather data of Dumdum (a station in Gangetic West Bengal) has been taken to observe whether the same works for this region or not. We have also validated and assessed a Local power-2 model (polynomial with degree two) with the same station, i.e., Dumdum (22.39° N, 88.27° E) and found it to give a more good result than Local model (linear in nature) so far developed. However the two step method to estimate solar radiation from the commonly measured air temperature in two steps gives more accurate estimation of solar radiation of a place. The model performance is evaluated using different law of error. Results show that the two step method gives good performance and significantly outperforms the temperature based models as claimed by our predecessors. The parameters of S/S0 equation were calculated by multiple regression model and was used in the two step method for calculating the solar radiation. It is found that the two step method using the parameters determined by the proposed equations gives good performance. Therefore the two step method with the parameters determined by the proposed equations could also be used to estimate solar radiation in West Bengal and also at different places in India having similar topography. It is believed to be useful for the site where no measured solar radiation and sunshine duration data is available, whereas the air temperature are commonly measured.

Key words – Solar radiation, Air temperature, Multiple regression model, Local power-2 model.

1. Introduction

Sun’s energy is the main source of energy for many physical, chemical and biological processes, such as crop growth, plant photosynthesis. It is also essential and important variable to many simulation models studies, such as agriculture, environment, hydrology, meteorology and ecology. Hence, accurate records of solar radiation are of vital importance. However it is not widely available due to excessive cost and difficulties in maintenance and calibration of the measurement equipment (Hunt et al., 1998). Only small percent of the meteorological
stations of the countries are measuring this parameter. For example, in USA, less than 1% of meteorological stations are recording solar radiation (NCDC, 1995; Thorton and Running, 1999). In China, only 98 stations are recording solar radiation (Chen et al., 2004). Thus accurate methods have to be developed if possible space-wise for estimation of solar radiation so that relatively correct estimation of the solar radiation can be found out for use in input in different simulation model studies carried out in the neighbourhood of the station that is being studied.

India has about 300 clear, sunny days in a year, it’s theoretically calculated solar energy incidence on it’s land area alone is about 18000 trillion mega joules (MJ) per year, so to use this huge renewable source in all fields, it is doing an extensive study by setting up a large network of 45 radiation observatories to record the different components of solar radiation but the not recorded solar radiation data between stations can be filled by estimation of solar radiation by two step method.

A number of methods, including satellite - derived (Frulla et al., 1988; Pinker et al., 1995; Olseth and Skartveit, 2001), Stochastic algorithm (Richardson, 1981; Hansen, 1999; Wilks and Wilby, 1999) and Empirical relationships (Angstrom, 1924; Prescott, 1940), interpolation - based (Hay and Suckling, 1979; Rivington et al., 2006) Learning machine method (Tymvios et al., 2005; Lam et al., 2008; Chen et al., 2011) have been developed for this purpose. Among them, the empirical relationship method is attractive for its simplicity, efficiency and much lower data requirement. Angstrom (1924) first proposed a linear relationship between the ratio of average daily solar radiation to the corresponding value on a clear sky and the ratio of average daily sunshine duration to the maximum possible sunshine duration. Prescott (1940) modified this method by replacing the clear sky radiation with the extraterrestrial radiation. Based on the daily data of Pune, Das and Pujari (1993) developed a relationship between solar irradiance and the daily range of temperature and tested it for Hyderabad and Kolkata to get encouraging results. Subsequently, the well known sunshine based Angstrom-Prescott (A-P) model was developed. Despite its good performance even for West Bengal, as proved through the works of Lala (Roy) et al., 2013, it is often limited by the lack of sufficient sunshine duration records. To circumvent this difficulty, lots of air temperature based models have been developed and widely used (Hargreaves and Samani, 1982; Bristow and Campbell, 1984; Hargreaves et al., 1985; Chen et al., 2004). These models allow widespread applications because air temperatures are routinely measured at most meteorological stations. However, a number of studies have shown that the sunshine based A-P model significantly outperformed the temperature based models (Iziomon and Mayer, 2002; Podesta et al., 2004; Trnka et al., 2005) Therefore, more accurate solar radiation estimation using air temperature is of vital importance and significance.

The much better performance of the sunshine based A-P model over the temperature based model seems to indicate that if the sunshine duration could be estimated from air temperature, then the estimated sunshine duration could be used as inputs for A-P model to estimate solar radiation and the conversion in this way may be able to improve the estimation accuracy over the temperature-based models. This method was named by Chen et al. (2015), as two-step estimation method, this method estimates the sunshine duration using air temperature firstly, and then estimate solar radiation by A-P model using the estimated sunshine duration.

In the present work, five widely used air temperature-based models and a local regression model are studied. The main objectives of this study are to (1) calibrate and validate the temperature based models from data (2) investigate and evaluate the two step method.

2. Data and methodology

2.1. Site and data set

The current study focuses on the site of Dum dum, where solar radiation measurements are taken and it lies in the alluvial plain of river Ganga and experiences tropical type of climate, this region is characterized by abundant water resource and thus plays significant role in water supply for agricultural production. Average annual rainfall for this region ranges from 1089.4 mm to 2446.8 mm and average annual bright sunshine hours for this region ranges from 1804.4 hrs to 2617.8 hrs. The mean daily solar radiation (MJ m⁻²), sunshine duration (h), air temperature (°C), including mean maximum temperature and minimum temperature are used in this study. The data were obtained from NDC, Pune.

2.2. Temperature based solar radiation estimation models

2.2.1. H-S model

Hargreaves and Samani (1982) suggested a solar radiation estimation model that is a function of extraterrestrial radiation, maximum and minimum temperature as follows:

\[ \frac{R_s}{R_e} = a(T_{\text{max}} - T_{\text{min}})^{0.5} \]  

(1)
TABLE 1
The empirical parameters of the temperature-based models

| Station | H-S model | H-Sm model | BC model | Chen model |
|---------|-----------|------------|----------|------------|
|         | Avg. a R² | a b R²     | a Avg. b c | a b R²     |
| Dumdum  | 0.153 0.71 | 0.14 0.039 0.71 0.7 0.009 2.4 0.69 | 0.17 -0.009 0.73 |

| Station | Local model | Local power -2 model |
|---------|-------------|----------------------|
|         | a b R²      | a b c R²             |
| Dumdum  | 0.022 0.253 0.684 | -0.005 0.125 -0.027 0.798 |

TABLE 2
The empirical parameters of A-P model and local S model from SPSS

| Station | A-P model | Local S model (from SPSS) |
|---------|-----------|---------------------------|
|         | a b R²    | a b c R²                  |
| Dumdum  | 0.4247 0.2579 0.9359 | 0.0754 -0.0612 -0.5413 0.746 |

where, $R_s$ is monthly mean daily actual global radiation (MJ m⁻²), $T_{max}$ and $T_{min}$ are maximum and minimum temperature, respectively. $R_a$ is mean daily extraterrestrial solar radiation (MJ m⁻²), which is a function of latitude and day of the year. The detailed procedure for calculation of extraterrestrial radiation can be found in Allen et al. (1998), here ‘a’ is empirical parameter, which was recommended to be 0.16 for interior regions and 0.19 for coastal regions. This parameter has been verified by this author for the region under study in Lala (Roy) et al. (2013) and has been computed equal to 0.153 for this region.

2.2.2. H-Sm model

Hargreaves et al. (1985) further modified the H-S model by adding an empirical correction parameter and obtained the following equation:

$$R_s/R_a = a(T_{max} - T_{min})^{0.5} + b$$

(2)

where, $a$ and $b$ are empirical parameters.

2.2.3. B-C model

Bristow & Campbell (1984) studied the relationship between solar radiation and maximum, minimum temperature and developed the equation given below:

$$R_s = a R_a \left\{ 1 - \exp \left[ -b(\Delta T_i)^{1} \right] \right\}$$

(3)

$a$, $b$ and $c$ are parameters, values widely used for these coefficients are 0.7 for $a$, 2.4 for $c$ and the value of $b$ can be calculated from the equation:

$$b = 0.036 \exp \left( -0.154 \Delta T_i \right)$$

(4)

where, $\Delta T_i$ is the monthly average of the $\Delta T_i$ daily values, $T_{max,i}$ is the air temperature difference calculated by subtracting the average $T_{min,i}$ of the current and the next day from $T_{max,i}$ of the current day:

$$\Delta T_i = T_{max,i} - T_{min,i} - T_{min,i+1} + T_{max,i+1}$$

(5)

where, $T_{max,i}$, $T_{min,i}$, $T_{min,i+1}$ are $T_{max}$, $T_{min}$, in $i^{th}$ day, $T_{min}$ in (i+1)$^{th}$ day, respectively.

2.2.4. Chen model

Chen et al. (2004) presented a new model as follows:

$$R_s/R_a = a \ln(T_{max} - T_{min}) + b$$

(6)

where, $a$ and $b$ are empirical parameters.

2.2.5. Local model

In addition to these well known models, Chen proposed the following equation based on his
TABLE 3

Root mean square error (RMSE in MJ m\(^{-2}\)) , Relative root mean square error (RRMSE), Mean absolute bias error (MABE in MJ m\(^{-2}\)) and mean absolute percentage error (MAPE) of the temperature based models

| Station: Dum Dum (Kolkata Airport) | H-S Model | | H-Sm Model | |
|---|---|---|---|---|
| Year | RMSE | RRMSE | MABE | MAPE | RMSE | RRMSE | MABE | MAPE |
| 2007 | 3.466088 | 22.97715 | 2.546046 | 28.93079 | 3.749019 | 24.85274 | 2.874582 | 31.820886 |
| 2008 | 4.147926 | 28.18477 | 2.945165 | 35.77673 | 4.30001 | 29.21817 | 3.109136 | 37.82267 |
| 2009 | 3.925267 | 27.11447 | 2.976165 | 28.23522 | 3.901909 | 26.95312 | 2.964177 | 29.22678 |
| 2010 | 3.827083 | 22.87831 | 2.633082 | 15.02331 | 4.264941 | 25.49582 | 3.098713 | 17.992606 |
| 2011 | 3.368293 | 19.53482 | 2.362109 | 14.05536 | 3.352263 | 19.44186 | 2.521674 | 14.987449 |
| Mean | 3.746931 | 24.1379 | 2.692513 | 24.40428 | 3.913628 | 25.19234 | 2.913656 | 26.37202 |
| Std. Dev. | 0.324524 | 3.512812 | 0.263838 | 9.481571 | 0.392134 | 3.62571 | 0.239889 | 9.604719 |

| Station: Dum Dum (Kolkata Airport) | B-C Model | Chen Model | |
|---|---|---|
| Year | RMSE | RRMSE | MABE | MAPE | RMSE | RRMSE | MABE | MAPE |
| 2007 | 5.963616 | 39.53359 | 4.843022 | 45.78977 | 4.817594 | 31.93646 | 4.0062 | 31.60256 |
| 2008 | 6.852554 | 46.56247 | 5.370144 | 56.97154 | 4.666284 | 31.70697 | 3.87975 | 33.89092 |
| 2009 | 6.978642 | 48.2062 | 5.936184 | 51.96764 | 3.975538 | 27.46173 | 3.189569 | 24.32826 |
| 2010 | 5.455692 | 32.61414 | 4.735609 | 29.96766 | 6.218966 | 37.17699 | 4.780566 | 25.8195 |
| 2011 | 4.76059 | 27.60962 | 3.882695 | 24.5471 | 5.897253 | 34.20183 | 5.21331 | 29.71076 |
| Mean | 6.002219 | 38.9052 | 4.953531 | 41.84874 | 5.115127 | 32.4968 | 4.213889 | 29.0704 |
| Std. Dev. | 0.937856 | 8.841731 | 0.765762 | 14.02792 | 0.924504 | 3.57425 | 0.794349 | 3.972265 |

| Station: Dum Dum (Kolkata Airport) | Local Model | Local Power Model | |
|---|---|---|
| Year | RMSE | RRMSE | MABE | MAPE | RMSE | RRMSE | MABE | MAPE |
| 2007 | 3.807178 | 25.23828 | 2.929542 | 33.10228 | 2.973662 | 20.34192 | 1.963815 | 24.32686 |
| 2008 | 4.361014 | 29.63269 | 3.158544 | 38.67852 | 3.161558 | 22.2774 | 1.99407 | 29.05156 |
| 2009 | 3.961175 | 27.36251 | 3.021083 | 29.97669 | 3.032898 | 21.85795 | 1.963557 | 22.20902 |
| 2010 | 4.264915 | 25.49567 | 3.100121 | 18.13266 | 3.483483 | 20.80227 | 2.23936 | 12.66026 |
| 2011 | 3.279753 | 19.02132 | 2.467563 | 14.60902 | 3.191594 | 18.30965 | 2.004419 | 12.15558 |
| Mean | 3.934807 | 25.35009 | 2.935371 | 26.89983 | 3.168639 | 20.71784 | 2.033044 | 20.08066 |
| Std. Dev. | 0.429157 | 3.952136 | 0.275306 | 10.18089 | 0.197576 | 1.555627 | 0.116754 | 7.43146 |

The values of all the parameters of the above temperature based models and the value of coefficient of regression (R\(^2\)) computed between \( \frac{R_s}{R_a} \) and difference of \( T_{\text{max}} - T_{\text{min}} \), has been given in Table 1.

2.3. Sunshine - based A-P model

A-P model was proposed by Angstrom (1924) and further modified by Prescott (1940). The original form of this model is:

\[
\frac{R_s}{R_a} = a \left( T_{\text{max}} - T_{\text{min}} \right) + b
\]  

where, \( a \) and \( b \) are empirical parameters.

2.2.6. Local power-2 model

Also, these authors proposed the following equation based on the investigation of relationship between \( \frac{R_s}{R_a} \) and maximum, minimum temperature in this local conditions (hereafter referred to local power-2 model).

\[
\frac{R_s}{R_a} = a \left( T_{\text{max}} - T_{\text{min}} \right)^2 + b \left( T_{\text{max}} - T_{\text{min}} \right) + c
\]  

where, \( a \), \( b \) and \( c \) are empirical parameters.
(h₁) which is calculated using the equations detailed by Allen et al. (1998).

2.4. Sunshine duration estimation model

The formula to estimate mean daily sunshine duration using maximum and minimum temperature was formulated by Chen et al. (2011) as follows:

\[
\frac{R}{R_o} = a T_{\text{max}} + b T_{\text{min}} + c
\]  

(10)

where, \(a\), \(b\) and \(c\) are empirical parameters and whose values have been computed by multiple regression of daily mean of 26 years (i.e., 1980 to 2006) of maximum temperature, minimum temperature and \(S/S_o\). The values of all the parameters and the value of coefficient of regression \((R^2)\) computed between \(R/R_o\) and \(S/S_o\) of the sunshine A-P model and the values of all the parameters and the value of coefficient of multiple regression \((R^2)\) computed between \(S/S_o\) and \(T_{\text{max}}\) and \(T_{\text{min}}\) of the sunshine duration estimation model, has been given in Table 2.

2.5. Performance criteria

To assess the performance of models, root mean square error (RMSE), relative root mean square error (RRMSE) (%), mean absolute bias error (MABE) and mean absolute percentage error (MAPE) (%) has been found. The four indicators are calculated by the following equations:

\[
\text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (y_i - \bar{y})^2}
\]  

(11)

\[
\text{RRMSE} = \frac{100}{\bar{y}} \sqrt{\frac{1}{n} \sum_{i=1}^{n} (y_i - \bar{y})^2}
\]  

(12)

\[
\text{MABE} = \frac{1}{n} \sum_{i=1}^{n} |y_i - \bar{y}_i|
\]

(13)

\[
\text{MAPE} = \frac{100}{\bar{y}} \sum_{i=1}^{n} \frac{|y_i - \bar{y}_i|}{|\bar{y}_i|}
\]

(14)

where, \(n\), \(y\), \(\bar{y}\) and \(\bar{y}_i\) represent the number of testing data, the observed value, the estimated value and the average value of the observation, respectively. Lower values of RMSE, RRMSE, MABE and MAPE indicate a better estimation accuracy of the model. The relative improvement of RMSE (RIrmse) and MABE (RImabe) were used to measure the improvement of the evaluated model accuracy over the reference model accuracy.

\[
\text{RIrmse} = \frac{\text{RMSE}_r - \text{RMSE}_e}{\text{RMSE}_r}
\]  

(15)

\[
\text{RImabe} = \frac{\text{MABE}_r - \text{MABE}_e}{\text{MABE}_r}
\]  

(16)

where, \(\text{RMSE}_r\) and \(\text{MABE}_r\) are the root mean square error and mean absolute bias error for the reference model, respectively. \(\text{RMSE}_e\) and \(\text{MABE}_e\) are the root mean square error and mean absolute bias error for the evaluated model, respectively. Higher values of R1rmse and R1mabe indicate a better improvement over the reference model.

3. Results and discussion

3.1. Performance of the temperature based models

The performances of the six temperature based models are presented in Table 3. The H-S model, H-Sm model, BC model, Chen model (2004), Local model and Local power-2 models for the station from the year 2007 to 2011 has values of RMSE (averaged 3.747, 3.914, 6.002, 5.115, 3.935 & 3.169 MJ m\(^{-2}\), respectively),
TABLE 4

Root mean square error (RMSE in MJ m\(^{-2}\) ), Relative root mean square error (RRMSE), Mean absolute bias error (MABE in MJ m\(^{-2}\)) and mean absolute percentage error (MAPE) of AP two step method

| Station: Dum Dum (Kolkata Airport) | AP two step method Model |
|-----------------------------------|--------------------------|
| Year                         |     |     |     |
| 2007                           | 2.464173 | 12.96446 | 1.661259 | 18.32252 |
| 2008                           | 2.32529 | 17.33904 | 1.46861 | 15.52661 |
| 2009                           | 2.549712 | 19.05863 | 1.742915 | 15.25118 |
| 2010                           | 2.89181 | 13.04524 | 1.309433 | 17.35703 |
| 2011                           | 2.44455 | 16.37406 | 1.101425 | 16.38325 |
| Mean                           | 2.535107 | 15.75629 | 1.456728 | 16.56812 |
| Std. Dev.                      | 0.214887 | 2.689623 | 0.260679 | 1.279996 |

RRMSE (averaged 24.138%, 25.192%, 38.905%, 32.497%, 25.35% & 20.718% respectively), MABE (averaged 2.693, 2.914, 4.954, 4.214, 2.935 & 2.033 MJ m\(^{-2}\) respectively) and MAPE (averaged 32.497%, 25.35% & 20.718% respectively). These six models have similar equation expressions, they differ in the form of the term \((T_{\max} - T_{\min})\), namely, the square root of \((T_{\max} - T_{\min})\) for Chen model, \((T_{\max} - T_{\min})\) for Local model and \((T_{\max} - T_{\min})\) for Local power-2 model. Out of these average values validated from the year 2007 to 2011 the performances was better for Local power-2 model according to the indicators of RMSE, RRMSE, MABE and MAPE, indicating that the newly formulated model (i.e., Local power-2 model) will give better performances over Chen’s local model in the temperature based model of evaluating \(R_s\), as can be seen from the Figs. 1&2.

3.2. Performance of the two step method

Despite the simplicity and significant performances of A-P model, it is often limited by the lack of available sunshine duration records. Therefore, in the present work, an attempt has been made to estimate sunshine duration by local S model [Eqn. (10)] using air temperature for the station. Consequently, the estimated sunshine duration is used as input for A-P model to estimate solar radiation, and the performance is presented in Table 4. This is a two step method as named by Chen et al. (2015). Such a method has not been studied before, for this region, which may be contributed to the lack of study on the relationship between the air temperature and the sunshine duration. Another reason may be that there are two estimation processes which may largely decrease the performance accuracy. However in the present work, the two step method gives good performances with the RMSE < 3 MJ m\(^{-2}\) for the validation year 2007 to 2011 (averaged 2.535 MJ m\(^{-2}\)), RRMSE < 20% (averaged 15.756%), MABE < 2 MJ m\(^{-2}\) (averaged 1.457 MJ m\(^{-2}\)), and MAPE < 20% (averaged 16.568%) as shown in Table 4. Therefore, it could be used to estimate solar radiation in the Gangetic West Bengal area.

3.3. Comparison of the two step method between temperature based models

Performance comparisons of the two step method and temperature based models given in Tables 3&4 shows that the two step method gives the averaged RMSE of 2.535 ± 0.215 MJ m\(^{-2}\), RRMSE of 15.756% ± 2.69%, MABE of 1.457 ± 0.261 MJ m\(^{-2}\) and MAPE of 16.568% ± 1.28% within the same station. The results of studies on relative improvement of the two step method over the temperature based models are presented in Table 5. Evidently, the two step method significantly out performs the temperature based models with the averaged R1rmse of five years (i.e., 2007-2011) -0.486, -0.549, -1.388, -1.017, -0.558 & -0.253; R1mabe of -0.880, -1.041, -2.424, -2.053, -1.051 & -0.439 for H-S, H-Sm, B-C, Chen, Local and Local power-2 model, respectively. These results further confirm that the two - step method can significantly improve the estimation accuracy over the temperature - based models which directly estimate solar radiation using air temperature only. Also it confirms that Local power-2 model for \(R_s\) gives better performance than Local model and the two step method is the best estimator of \(R_s\) compared to the six temperatures based models.

3.4. Determination of model parameters

The two step method has substantial potential for application in solar radiation estimation due to greater availability of air temperature data and the significant performance, but the equation for determining constants...
The relative improvement of Root mean square error (RIrmse) and mean absolute bias error (RImabe) of the two step method over the temperature based models

| Year | HS model | HS model | BC model | Chen model | Local model | Local power model |
|------|----------|----------|----------|------------|-------------|------------------|
|      | RIrmse   | RImabe   | RIrmse   | RImabe     | RIrmse      | RImabe           |
| 2007 | -0.407   | -0.533   | -0.521   | -0.730     | -1.420      | -1.915           |
| 2008 | -0.784   | -1.005   | -0.849   | -1.117     | -1.947      | -2.657           |
| 2009 | -0.539   | -0.708   | -0.530   | -0.701     | -1.737      | -2.406           |
| 2010 | -0.323   | -1.011   | -0.475   | -1.366     | -0.887      | -2.617           |
| 2011 | -0.378   | -1.145   | -0.371   | -1.289     | -0.947      | -2.525           |
| Mean | -0.486   | -0.880   | -0.549   | -1.041     | -1.388      | -2.424           |

of the equation of local S model as given by Chen was giving faulty values for this region so it was evaluated by the multiple regression method from the available long term data (26 years) of the station to suit to local conditions and subsequently it gave better results. Hence, here we have brought a little modification to the local S model as given by Chen et al. (2015) by changing the value of its parameters and showed this model equation will give better estimation of the solar radiation by using two step method for this region. We recommend to find the constant values of the local S model by running multiple regression method of the daily mean of maximum temperature, minimum temperature and $S/S_0$ for the year from the minimum 25 years previous station data to get better results by two step method.

3.5. Solar radiation estimation using the estimated parameters

The local S model with has been used to estimate $S/S_0$, which is later used as input to estimate solar radiation by A-P model using the parameter. Good performance of the two step method is found with the RMSE < 2.6 MJ m$^{-2}$ (averaged 2.54 MJm$^{-2}$) RRMSE < 20% (averaged 15.76 %), MABE < 1.5 MJ m$^{-2}$ (averaged 1.46 MJ m$^{-2}$), MAPE < 20 % (averaged 16.57%) and $R^2$ > 0.9 (averaged 0.936) and there is a substantially good agreement between the daily mean of $R_s/R_a$ with daily mean of $S/S_0$ as shown in Fig. 3 and the parameters generated from this relationship can be used to calculate the $R_s$ of this area by the two step method.

4. Conclusions

Solar radiation is an essential and important variable for use in many simulation models. Plant growth is a direct function of solar radiation. Many transpiration models in plant - water relationship require solar irradiance as an input. Estimation of solar radiation from other commonly measured meteorological variables is generally done when direct measurement are not readily available. In this work, we present the two step method to estimate solar radiation for this region from the commonly measured air temperature, namely, estimate sunshine duration by local S model, using air temperature firstly and then the estimated sunshine duration is used as inputs for A-P model to estimate solar radiation. The model performance indicators of RMSE, RRMSE, MABE and MAPE illustrate that the two step method gives good results. Further comparisons show that the two step method significantly outperforms the temperature based models. Therefore, it could be used to estimate solar radiation in Gangetic West Bengal and it can significantly improve the estimation accuracy over the temperature based models which directly estimate solar radiation using air temperature only.

As we have already mentioned that the two step method has substantial potential for direct application in solar radiation estimation due to greater availability of air temperature data and it significant improved performance over the temperature based models. The two step method using the estimated parameters was used to validate the value of $R_s$ from 2007-2011 and it is found that the estimated values agree well with the measured solar radiation. Therefore, the two step method with parameters determined by the equations as proposed in the paper could be used in Gangetic West Bengal and it is believed to be particularly useful for the sites where no solar radiation and sunshine duration data is available, whereas the air temperatures are commonly measured.

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