Prediction of maximum or minimum air temperature in a coastal location in West Bengal

SUKUMAR LALA (ROY), SANJIB BANDYOPADHYAY and SWETA DAS

Regional Meteorological Centre, Kolkata, India

(*Received 27 March 2012, Modified 25 March 2013*)

email: sukumarlala@gmail.com

सार – इस शोध पत्र का उद्देश्य भारतीय तटीय स्थान अर्थात् पश्चिमी बंगाल के अलीपुर (कोलकाता) में प्रेक्षित भूमंडलीय सौर विकिरण की मदद से हरग्रीब्स विकिरण फॉर्मूला से तारीखवार संशोधित K_{RS} पता करना है जिससे कि आगे यदि न्यूनतम तापमान (T_{min}) ज्ञात हो तो अधिकतम तापमान (T_{max}) का पूर्वानुमान देने में अथवा इसके विपरीत, उपयोग किया जा सके। भूमंडलीय सौर विकिरण के बीच सहसंबंध की गणना तारीखवार किए गए धूप के घंटावार आँकड़ों के औसत के उपयोग जिसमें आंग्स्ट्रोम प्रेसकॉट फार्मूला से प्राप्त नियतांक a_s = 0.25 और b_s = 0.5 है, से की गई है। इसमें प्रेक्षित किए गए भूमंडलीय सौर विकिरण आंकड़ों का अध्ययन किया गया है। यह निश्चित रूप से कहा जाता है कि आंग्स्ट्रोम प्रेसकॉट फार्मूला भूमंडलीय सौर विकिरण का सटीक आकलन करता है और यह सही पाया जाता है। इस शोध पत्र में हरग्रीब्स विकिरण फार्मूला (जिसमे K_{RS} = 0.19 लिया गया है) से तारीखवार प्राप्त किए गए अधिकतम तापमानों तथा न्यूनतम तापमानों के औसत (आंकड़े भारत मौसम विज्ञान विभाग के अलीपुर, कोलकाता जिला – 24 परगना के कार्यालय से प्राप्त) का उपयोग करके भूमंडलीय सौर विकिरण के बीच सहसंबंध की गणना की गई है और इसका अध्ययन प्रेक्षित भूमंडलीय सौर विकिरण के साथ भी किया गया है। तारीखवार संशोधित K_{RS} की गणना हरग्रीब्स विकिरण फार्मूला से की गई। इसमें भूमंडलीय सौर विकिरण के प्रेक्षित आंकड़ों, तारीखवार अधिकतम तापमानों और न्यूनतम तापमानों के औसत उपयोग में लिए गए हैं। इसे किसी स्टेशन के अधिकतम तापमानों और न्यूनतम तापमान आंकड़ों के तारीखवार K_{RS} के उपयोग के द्वारा आस पास के क्षेत्रों के वाष्पोत्सर्जन के लिए भूमंडलीय सौर विकिरण का आकलन करने के लिए भी उपयोग में लाया जा सकता है।

ABSTRACT. The objective of this study is to find the date wise corrected K_{RS} from the Hargreaves Radiation formula with the help of observed global solar radiation for the Indian coastal location namely Alipore (Kolkata) in West Bengal so that subsequently it can be used for predicting maximum temperature T_{max} if minimum temperature T_{min} is known or *vice-versa*. The correlation between the global solar radiation calculated by using date wise average sunshine hour data with constants a_s = 0.25 and b_s = 0.5, from Angstrom Prescott formula with the observed global solar radiation data was studied. The assertion that the Angstrom Prescott formula gives nearly accurate estimation of global solar radiation has been found to be correct. Correlation between the global solar radiation calculated by using date wise average of T_{max} and T_{min} (sourced from IMD located at Alipore, Kolkata, District - South 24 parganas) from Hargreaves Radiation formula (taking K_{RS} = 0.19) with the observed global solar radiation data was also studied. Date wise corrected K_{RS} by Hargreaves Radiation formula was computed using the observed data of global solar radiation, date wise average of maximum temperature T_{max} and minimum temperature T_{min}. The date wise corrected K_{RS} can be used for better prediction of T_{max} and T_{min}. Also it can be used for estimation of global solar radiation for reference evapo-transpiration of the neighbourhood areas by utilizing the date wise K_{RS} with the T_{max} and T_{min} of the station.

Key words – Global Solar Radiation, Hargreaves' radiation formula, Angstrom - Prescott formula, Adjustment co-efficient, Evapo-transpiration.

1. Introduction

It is well known that one of the major weather parameters is the global solar radiation received which affects to a large extent the evapo-transpiration. Knowledge of local global solar radiation is essential for many applications, especially in the fields of agriculture and irrigation engineering where it is a vital parameter to be reckoned. This parameter can be useful for conducting various field experiments with different crop varieties and can be conducive in estimating crop yield forecast for regions where there are no means for measuring global solar radiation. The accuracy with which global solar radiation can be found out will help in forecasting the crop yield better as global solar radiation is one of the prime factor that is playing for crop growth. Moreover, architectural design of buildings, design of green buildings, design of solar systems and study of cyclone

and other weather system also call for solar radiation data. Costs, maintenance and calibration of global solar radiation measuring instrument slacken the availability of this useful information. This paucity of global solar radiation data dictates the need to develop models to estimate on the basis of more readily available data, *i.e.*, maximum and minimum temperature (Al-Lawati *et al.*, 2003; Almorox and Hontoria, 2004).

2.   Background

Many empirical models are available for computation of global solar radiation using variables such as sunshine hours (Angstrom, 1924), air temperature (Hargreaves and Samani, 1982), precipitation (De jong and Stewart, 1993), relative humidity (Elagib *et al.*, 1998) and cloudiness (Black, 1956). Sunshine duration is the most commonly employed parameter for estimating global solar radiation. Most of the models available for estimating global solar radiation use the ratio (n/N) of actual duration of sunshine and maximum possible duration of bright sunshine (Al-Lawati *et al.*, 2003). The most widely used empirical method is that proposed by Angstrom (1924). He proposed a linear relationship between the ratio of average daily global solar radiation to the corresponding value on a completely clear day and the ratio of average daily sunshine duration to the maximum possible sunshine duration. The problem of determining clear sky global irradiance was by passed by Prescott, who suggested using extraterrestrial radiation intensity values instead (Almorox and Hontoria, 2004). Accurate estimation of evapo-transpiration demands accurate estimation of net radiation, R_n which is the difference between incoming solar radiation and outgoing radiation which consequently calls for accurate estimation of global solar radiation, (R_s). If measured data on actual duration of sunshine hours are available for the location under consideration, then R_s can be computed using Angstrom - Prescott formula given by Equation 1 (Allen *et al.*, 1998)

$$R_s = \left[a_s + b_s \left(n/N \right) \right] R_a \tag{1}$$

where R_s is the global solar or short-wave radiation in watt hour m^{-2}, n is the actual duration of sunshine in hours, N is the maximum possible duration of bright sunshine or daylight in hours. (n/N) is the relative sunshine duration, R_a is the extraterrestrial radiation in watt hour m^{-2} computed as a function of the latitude and the day of the year (Duffie and Beckman, 1991), a_s and b_s are the Angstrom constants. Depending on the atmospheric conditions (humidity & dust) and solar declination (latitude & month) the Angstrom values a_s and b_s will vary. Where no actual global solar radiation data are available and no calibration has been carried out for

improved a_s and b_s parameters, the values $a_s = 0.25$ and $b_s = 0.50$ are recommended (Allen *et al.*, 1998).

Now, the regions where measured data on daily sunshine hours (n) is absent, global solar radiation cannot be computed with the calculation procedures previously outlined and the other subsequent deductions cannot be elicited. In such situation global solar radiation could be derived from air temperature.

The difference between the maximum and minimum air temperature is related to the degree of cloud cover in a location and hence can be used as the indicator of the fraction of extra terrestrial radiation that reaches the earth's surface. This principle has been utilized by Hargreaves and Samani (1982) to develop estimates of reference evapo-transpiration using only air temperature data. The Hargreaves radiation formula, adjusted and validated at several weather stations in a variety of climate conditions is given by Equation 2.

$$R_s = K_{RS} \left(T_{\max} - T_{\min} \right)^{0.5} R_a \tag{2}$$

where R_a is extraterrestrial radiation in watt hour m^{-2}, $T_{\max}$ is the maximum air temperature in °C, $T_{\min}$ is the minimum air temperature in °C and K_{RS} is the adjustment coefficient.

The square root of the temperature difference is closely related to the daily global solar radiation in a given location. The adjustment coefficient K_{RS} is empirical and differs for 'interior' or 'coastal' regions. For 'interior' locations where land mass dominates and air masses are not strongly influenced by a large water body , $K_{RS} \approx 0.16$ and for 'coastal' locations, situated on or adjacent to the coast of a large land mass and where air masses are influenced by a nearby water body, $K_{RS} \approx 0.19$.

Method based on temperature difference can be used for locations where cloud coverage or global solar radiation data are not available. As the study location for this work is a coastal region, this method can be employed for estimation of surface solar radiation R_s in the absence of measurement of data on actual hours of daily sunshine, (n). Al-zoheiry *et al.* (2006) addressed the important need of model having a capacity to predict global solar radiation for locations with no or very few data. Hargreaves Radiation formula was used to estimate the daily K_{RS} value from average maximum air temperature and average minimum air temperature (daily normal values computed from 27 years data of the station, *i.e.*, Alipore) and then the value was used to validate the $T_{\max}$ and $T_{\min}$ data from 2008-2011 which method is different from the monthly computed K_{RS} that has been computed
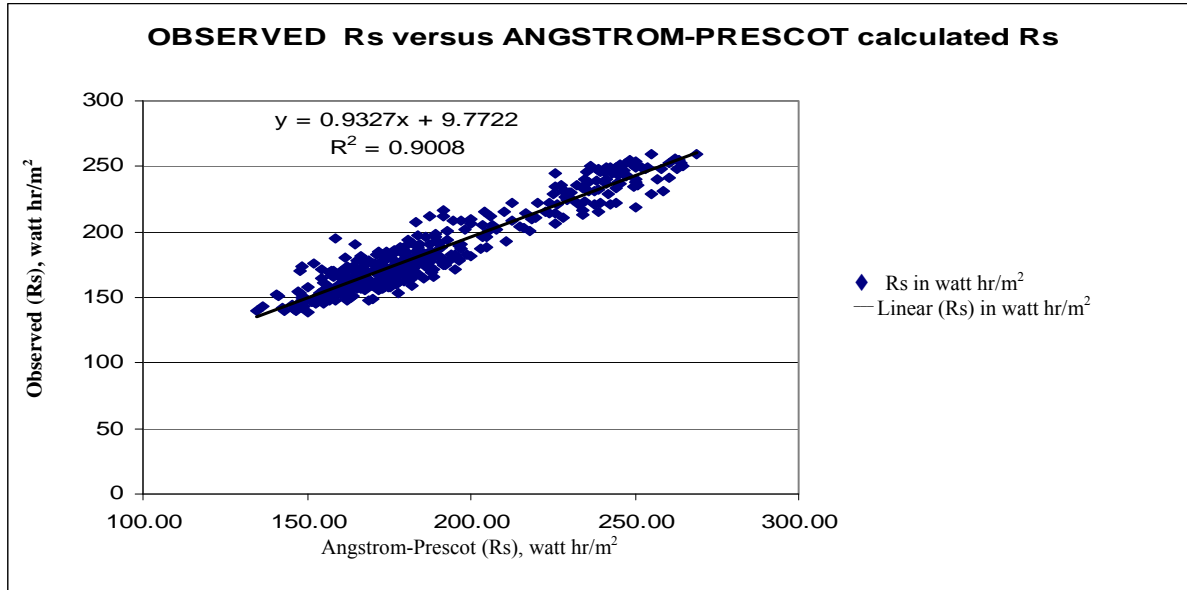
Fig. 1. Daily global solar radiation (1980-2007) with Angstrom – Prescott (a_s = 0.25 and bs = 0.50) *vs* observed data
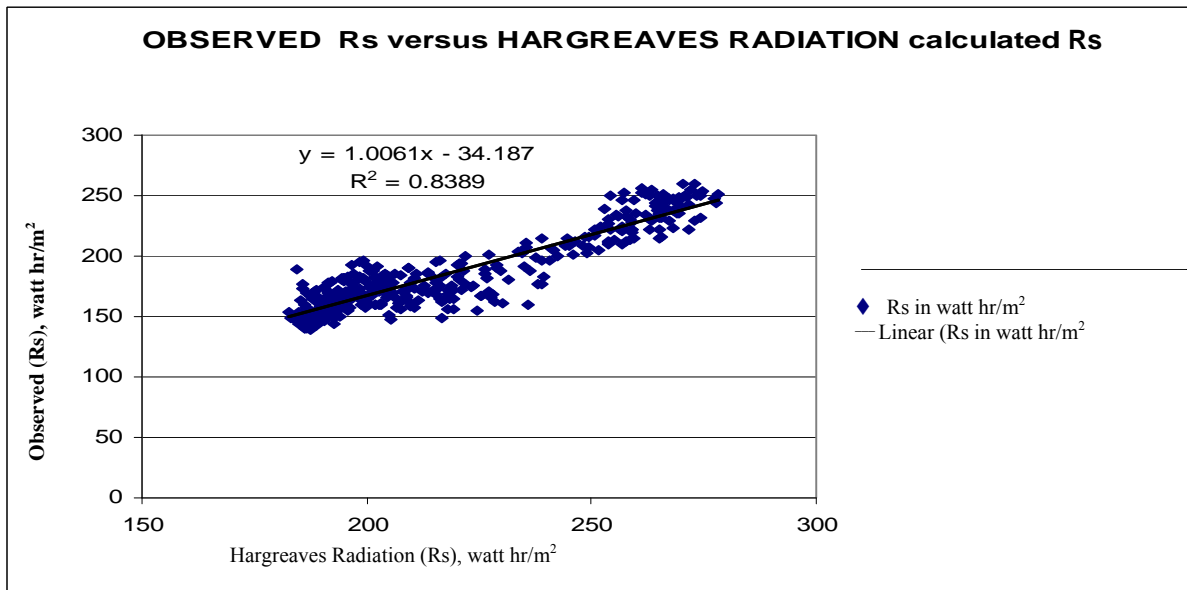

Fig. 2. Daily global solar radiation (1980-2007) with Hargreaves Radiation (K_{RS} = 0.19) *vs* observed data

by (Murugappan *et al.*, 2011) and hence can be used with precision to calculate other meteorological parameters.

3.   Data and methodology

The location taken for the study was Alipore (West Bengal) a site of old meteorological observatory. The Latitude and Longitude of Alipore is 22.57° N and 88.33° E. The date wise data on maximum temperature, minimum temperature and actual hours of sunshine for twenty seven years (1980 to 2007) were collected from IMD for the study. The R_s calculated from Angstrom - Prescott formula by using the ratio of date wise average daily sunshine hours to maximum sunshine hours, R_a which ranged from 285.58 to 474.46 watt hour m^{-2} and
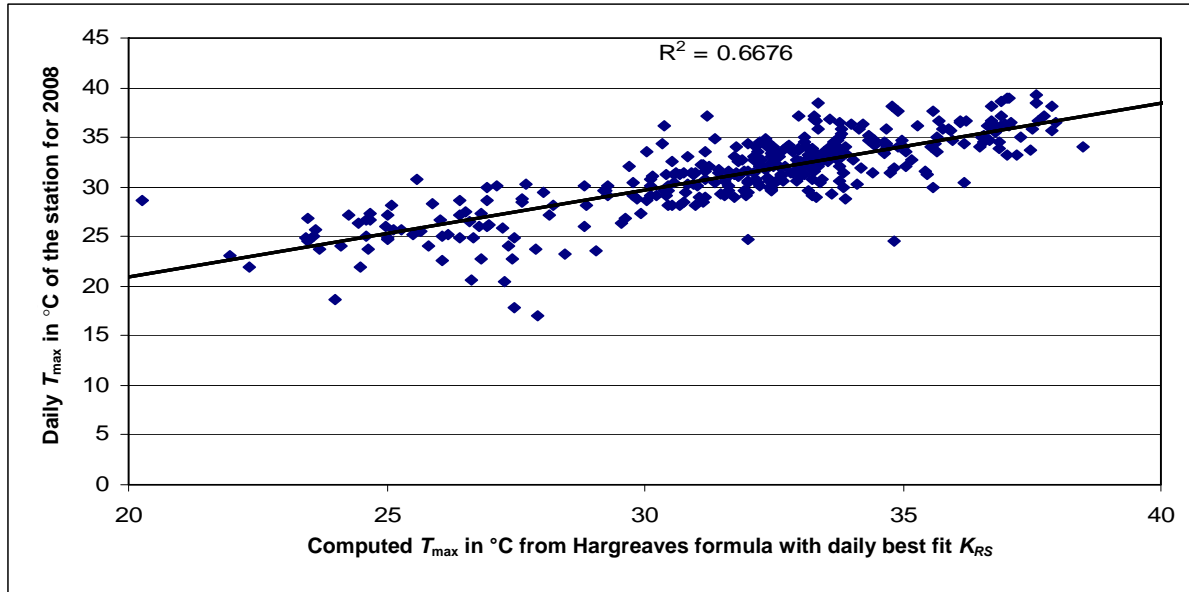
Fig. 3. Computed T_{max} in °C from Hargreaves formula with daily best fit K_{RS} *versus* Daily T_{max} in °C of the station for 2008 (Validation)
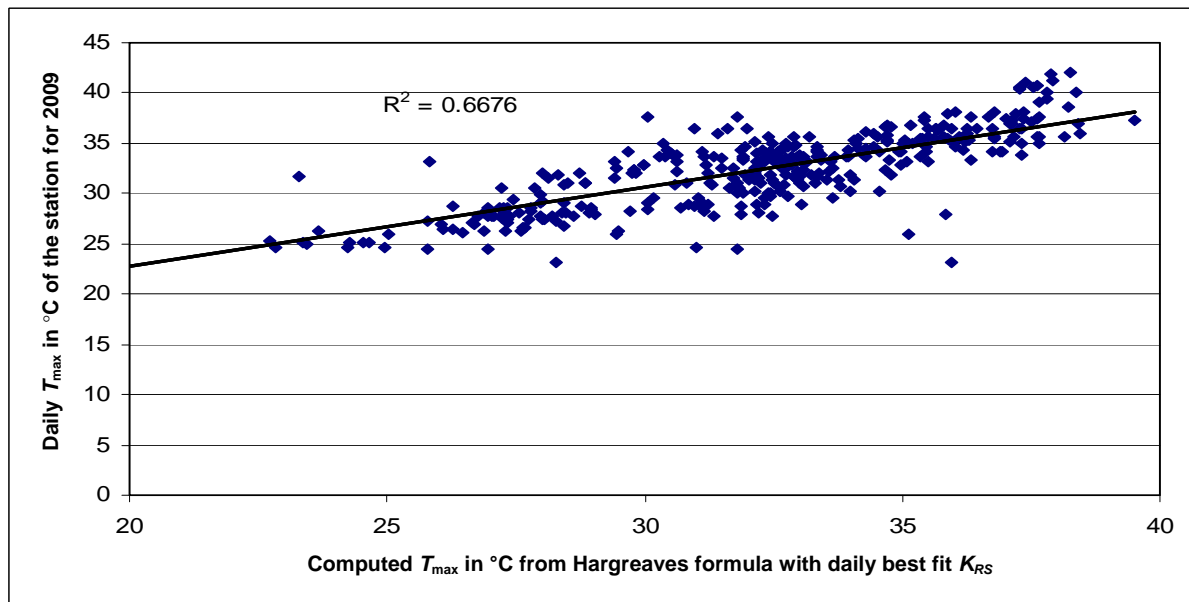
Fig. 4. Computed T_{max} in °C from Hargreaves formula with daily best fit K_{RS} *versus* Daily T_{max} in °C of the station for 2009 (Validation)

taking a_s = 0.25 and b_s = 0.50 was correlated with the observed R_s and a high correlation (0.95) was found out (Fig. 1) which ascertains the fact that the Angstrom–Prescott formula gave a good estimation of the global solar radiation from the sun shine hours. Also the R_s calculated from Hargreaves Radiation formula by using the date wise average daily T_{max} and T_{min}, R_a and taking

K_{RS} = 0.19 was correlated with the observed R_s and a correlation (0.91) was found out (Fig. 2). The Hargreaves and Samani model with adjustment co-efficient date wise (daily) K_{RS} that has been found out from the actual global solar radiation R_s, extraterrestrial solar radiation R_a and date wise average daily minimum and maximum temperature, was used to predict the T_{max} and T_{min} from
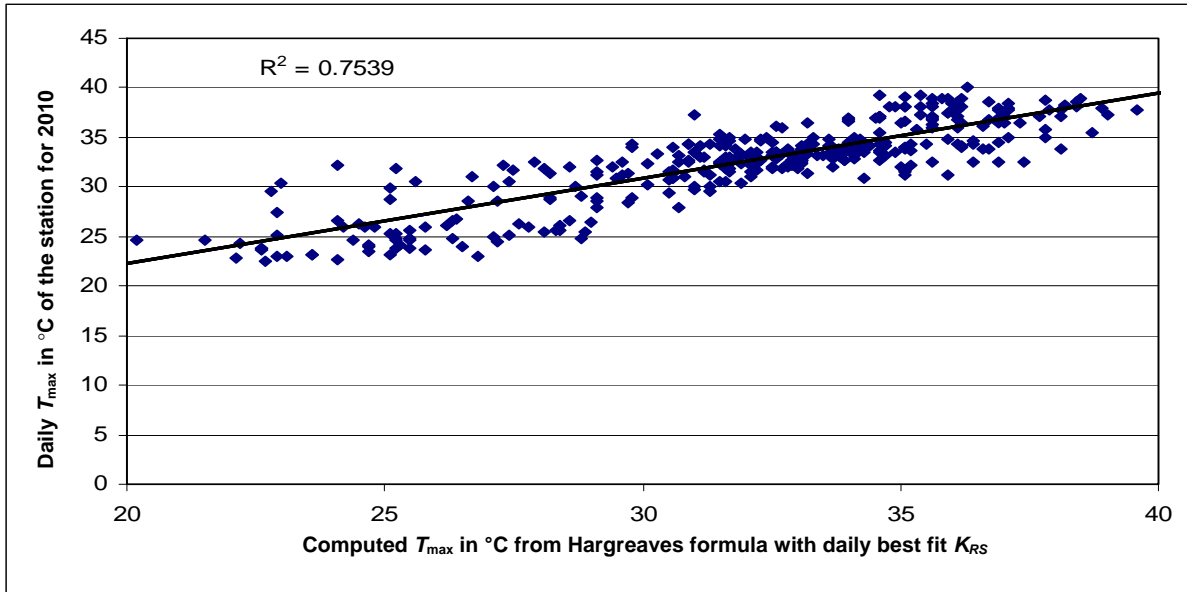
Fig. 5. Computed T_{max} in °C from Hargreaves formula with daily best fit K_{RS} *versus* Daily T_{max} in °C of the station for 2010 (Validation)
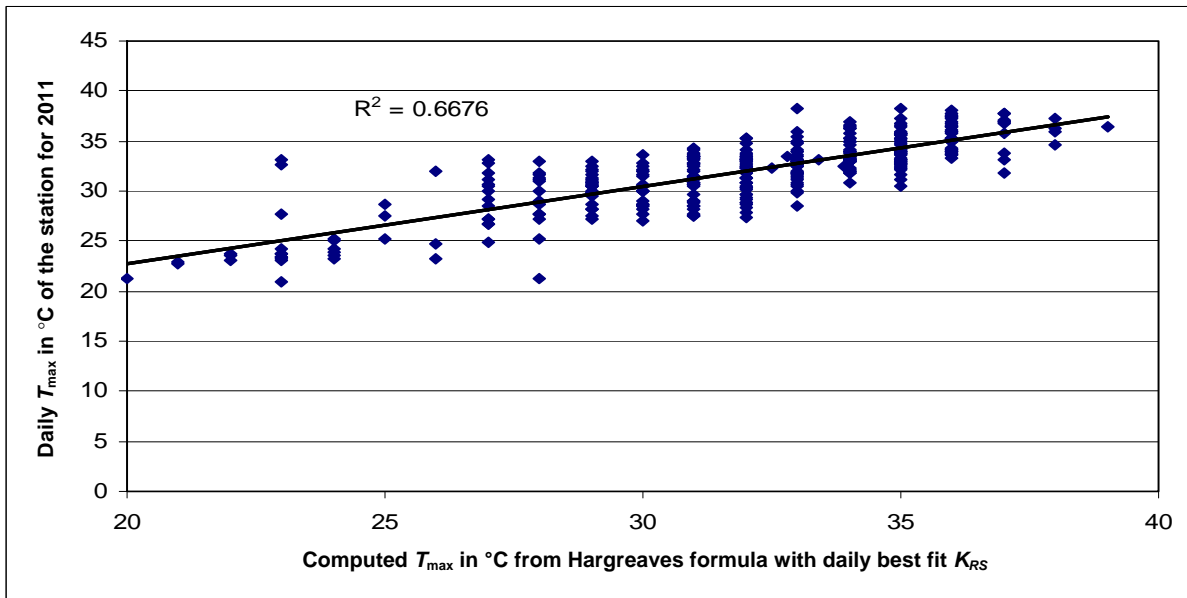
Fig. 6. Computed T_{max} in °C from Hargreaves formula with daily best fit K_{RS} *versus* Daily T_{max} in °C of the station for 2011 (Validation)

2008 to 2011 and then validate with the actual data. The previous method of taking K_{RS} = 0.19 was not adopted, instead date wise daily K_{RS} value was taken which ranged from 0.13 to 0.19.

This daily K_{RS} can be used for forecasting maximum air temperature or minimum air temperature if either one of the parameters is known, also this date wise daily K_{RS} values can be used for calculation of global solar radiation with precision, in and around the station if both maximum air temperature and minimum air temperature is known.

The Hargreaves radiation formula can be rewritten as

$$T_{max} = (R_s/R_a K_{RS})^2 + T_{min} \text{ to calculate } T_{max}$$

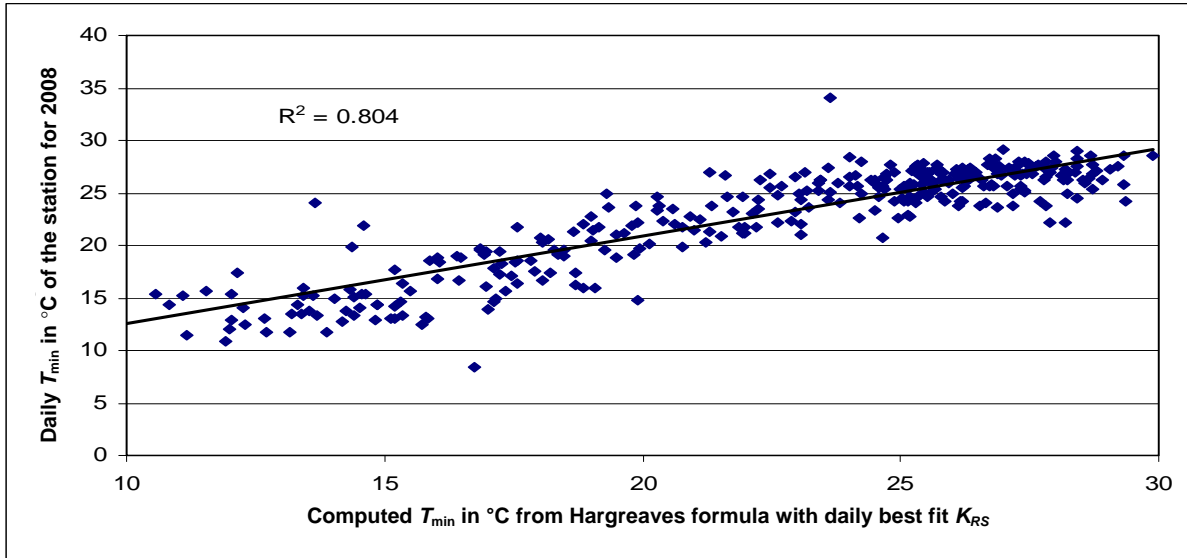and $T_{min} = T_{max} - (R_s/R_a K_{RS})^2$ to calculate T_{min}

Fig. 7. Computed T_{min} in °C from Hargreaves formula with daily best fit K_{RS} *versus* Daily T_{min} in °C of the station for 2008 (Validation)
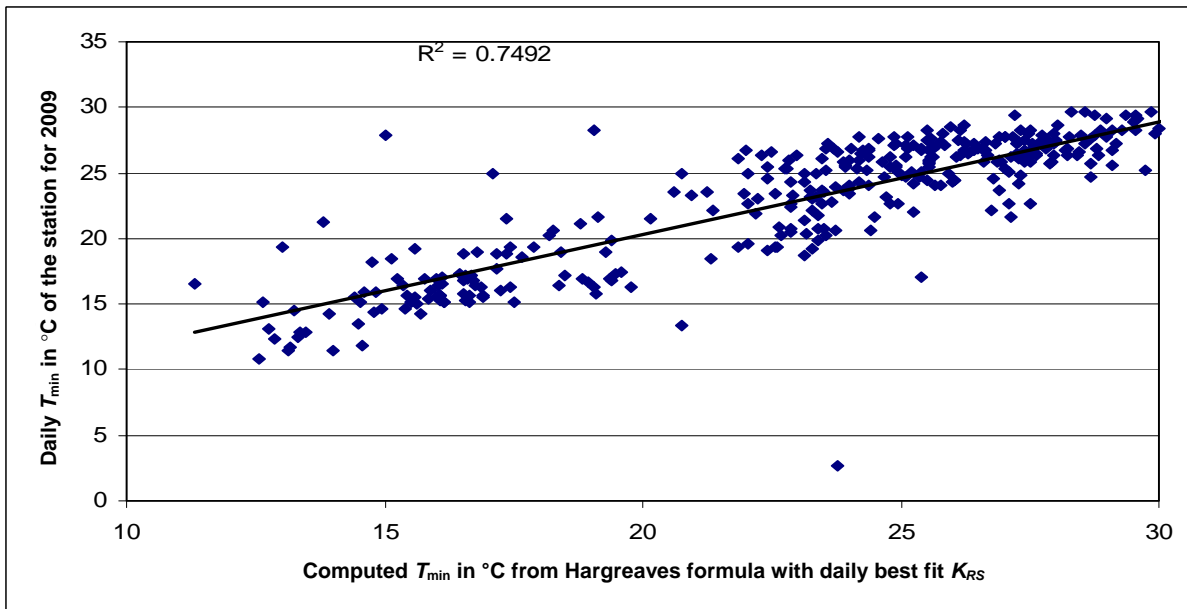
Fig. 8. Computed T_{min} in °C from Hargreaves formula with daily best fit K_{RS} *versus* Daily T_{min} in °C of the station for 2009 (Validation)

Here, R_s is the global solar radiation and the date wise value was computed by taking date wise average of daily observed values of R_s of twenty seven years (1980-2007) of Dumdum (a station located near Alipore). From the daily values of R_s, R_a, T_{max} and T_{min} the daily K_{RS} was calculated. This daily K_{RS} was used as a standard for

determining T_{max} or T_{min} and then it was validated with the observed data of T_{max} of 2008 to 2011 and correlated [Figs. (3-6)] and T_{min} [Figs. (7-10)] respectively which showed a marked correlation. Also the probability curve of error of prediction w. r. t. observed values was found out for both T_{max} and T_{min} for the years 2008 to 2011.
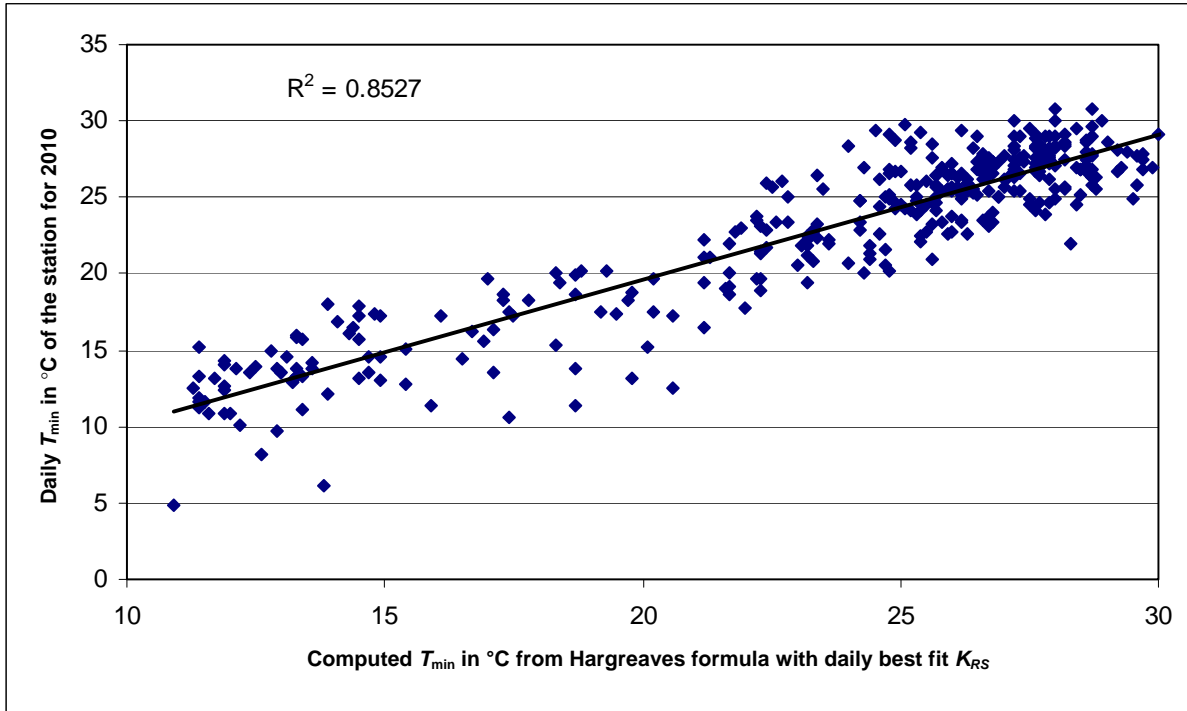
Fig. 9. Computed T_{min} in °C from Hargreaves formula with daily best fit K_{RS} *versus* Daily T_{min} in °C of the station for 2010 (Validation)
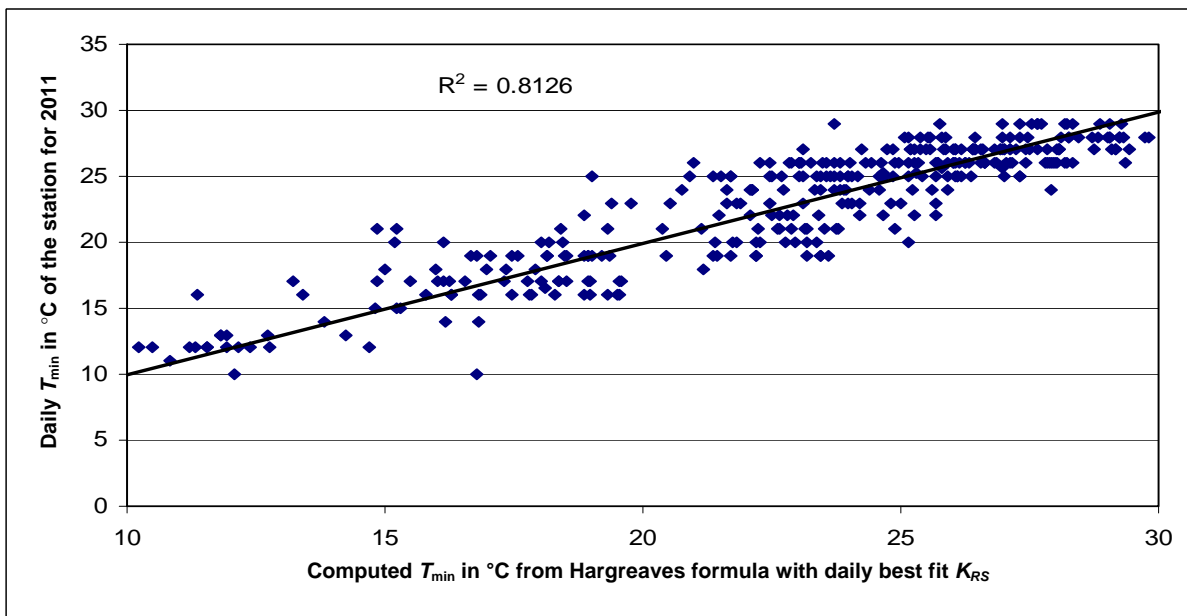

Fig. 10. Computed T_{min} in °C from Hargreaves formula with daily best fit K_{RS} *versus* Daily T_{min} in °C of the station for 2011 (Validation)

4. Results and discussion

While validating with T_{max} of 2008 to 2011 observed data of this station with the predicted maximum temperature data it was found that it showed a correlation of 0.82, 0.82, 0.87 and 0.82 (approx.) respectively and with T_{min} of 2008 to 2011 observed data of this station with the predicted minimum temperature data it was
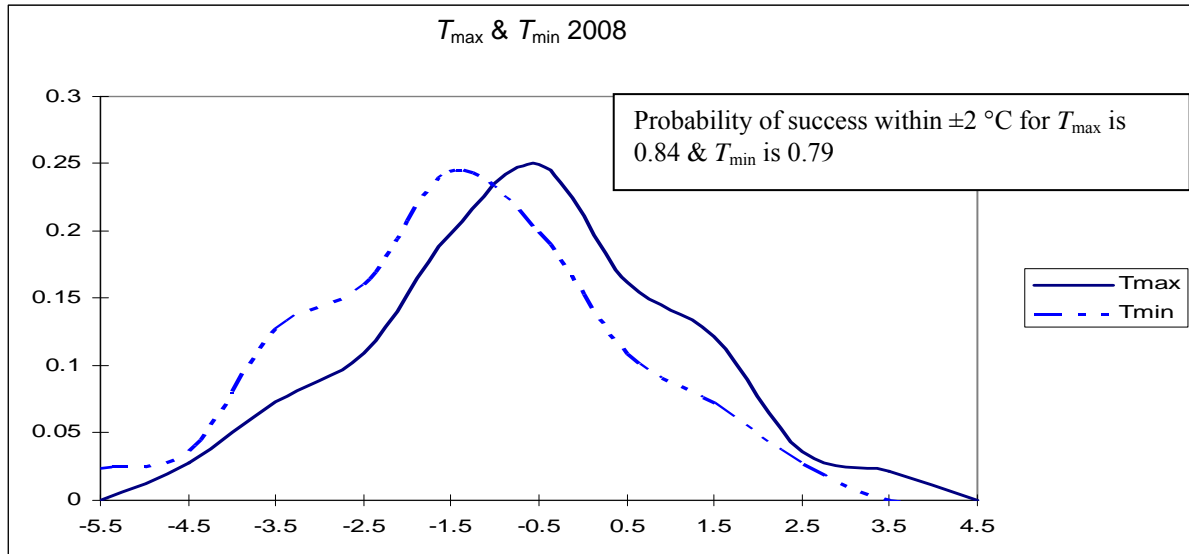
Fig. 11. Probability curve of error of prediction w.r.t. observed values of T_{max} and T_{min} of 2008
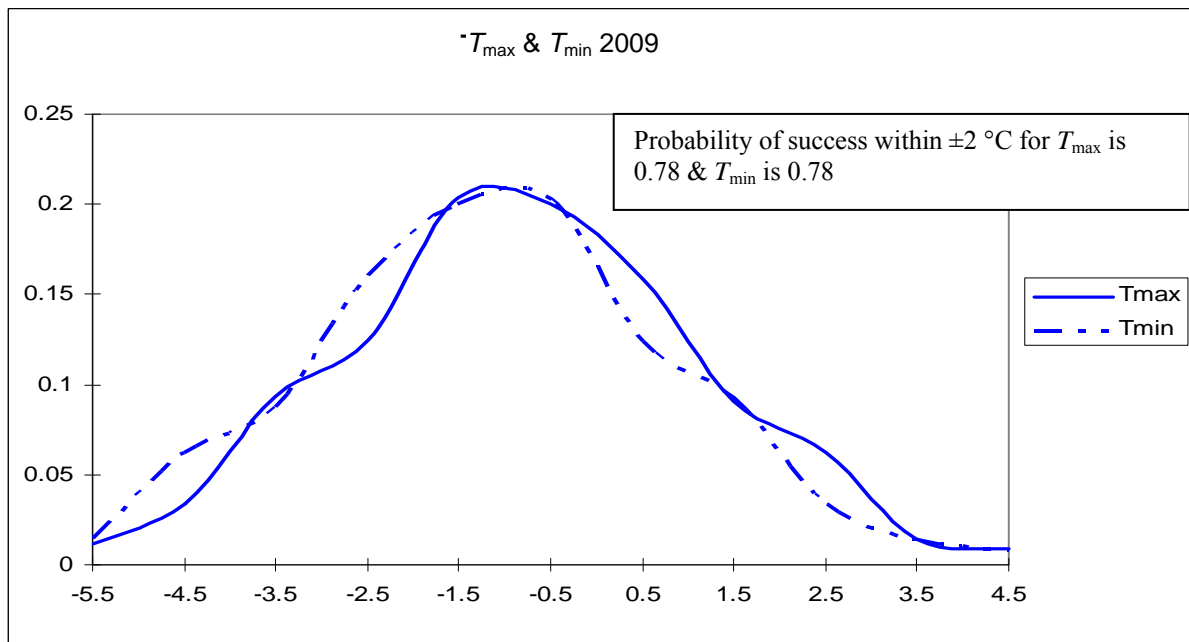

Fig. 12. Probability curve of error of prediction w.r.t. observed values of T_{max} and T_{min} of 2009

found that it showed a correlation of 0.9, 0.87, 0.92 and 0.90 (approx.) respectively. There were some days in which there was wide aberration in prediction of T_{max} and T_{min} and is probably due to some system prevailing at the station which is the case to be studied so that the corrections calculated from these events can be applied and the aberration can be minimized. It also showed that

the correlation w. r. t. T_{max} was less compared to T_{min} which emphasizes the fact that the day time is more subjected to development of weather system than the night and thus the aberration was more in the case of T_{max}.

From the computed daily best fit K_{RS} it was found that for Alipore (District - South 24 parganas) the K_{RS}
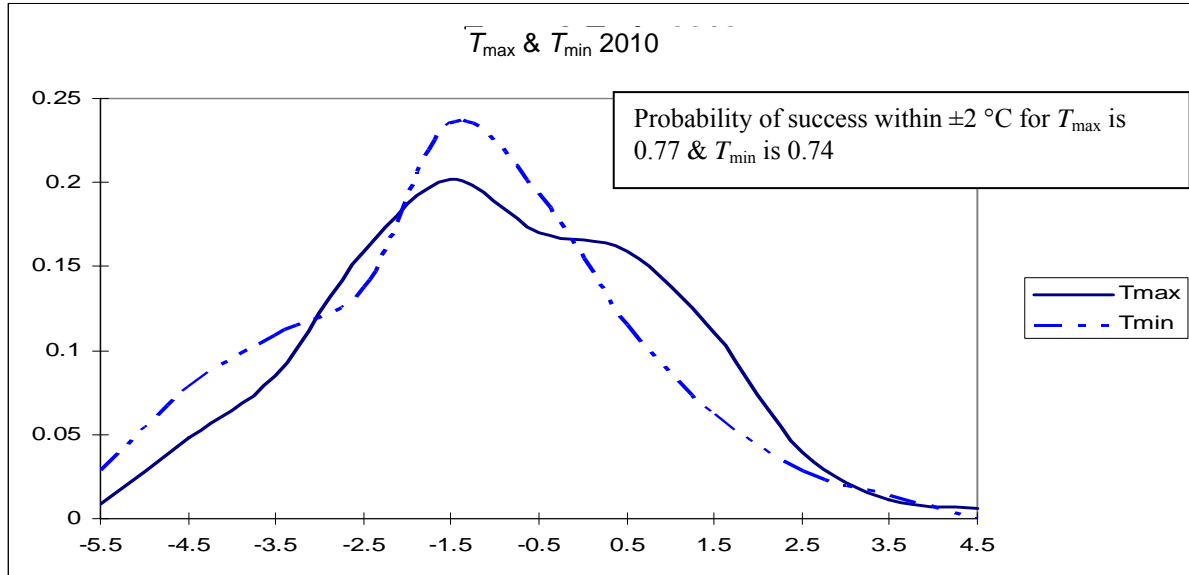
Fig. 13. Probability curve of error of prediction w. r. t. observed values of T_{max} and T_{min} of 2010
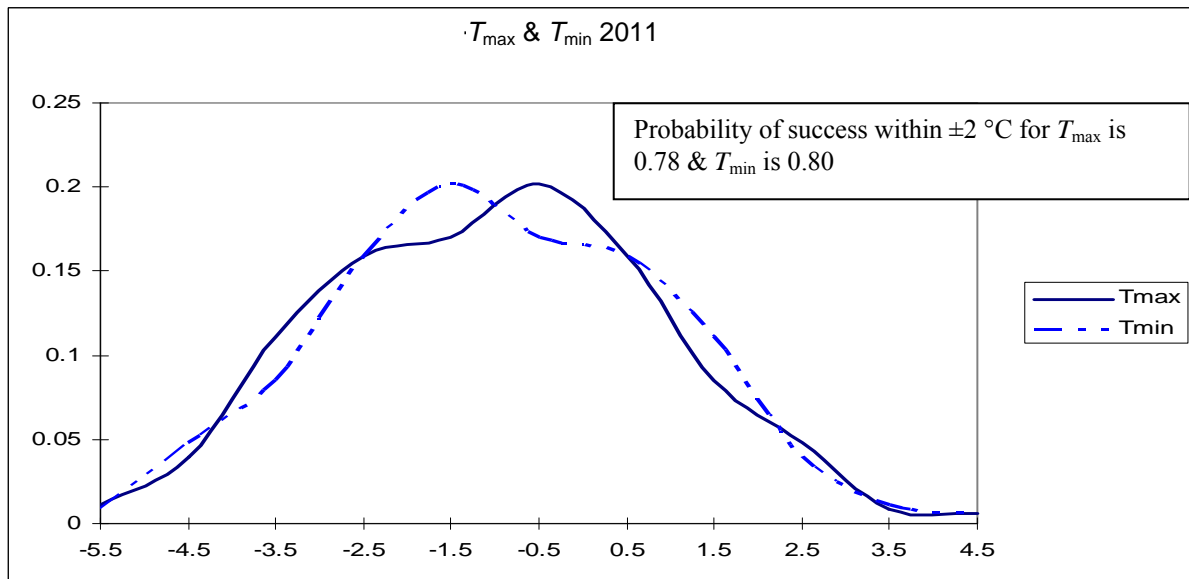

Fig. 14. Probability curve of error of prediction w. r. t. observed values of T_{max} and T_{min} of 2011

ranged from 0.13 to 0.19 (approx.) which was modification of the universal constant that was taken to be 0.19 for the coastal stations for calculation of solar radiation from Hargreaves formula. The probability of success of forecast within ± 2 °C range is 0.84 for T_{max} and within ± 2 °C range is 0.79 for T_{min} for the year 2008 (Fig. 11), within ± 2 °C range is 0.78 for T_{max} and within ± 2 °C range is 0.78 for T_{min} for the year 2009 (Fig. 12), within ± 2 °C range is 0.77 for T_{max} and within

± 2 °C range is 0.74 for T_{min} for the year 2010 (Fig. 13) and within ± 2 °C range is 0.78 for T_{max} and within ± 2 °C range is 0.80 for T_{min} for the year 2011 (Fig. 14).

5.   Conclusion

The daily best fit K_{RS} for Alipore (District - South 24 Parganas) was found from the observed global solar radiation data. This data can be used for predicting T_{max}

or T_{min} values if either one of the parameter is known. It can be also used for calculating the T_{max} or T_{min} values if either one of the parameter is missing from the records. Also the best fit K_{RS}, T_{max} and T_{min} data can be used for calculating the global solar radiation of the neighbourhood region which will be of great help mainly to the agricultural research institutes who are continuously conducting experiments with different crop varieties and need this global solar radiation data. Future studies may be made for finding the daily best fit K_{RS} of all the districts of West Bengal so that the global solar radiation data can be calculated using Hargreaves formula befitting West Bengal region from maximum air temperature (T_{max}) and minimum air temperature (T_{min}) as there are no means for getting direct global solar radiation data in these remote areas due to financial constraints of installation of sophisticated instruments and it's maintenance. The probability values for percentage error of forecasting (within range ± 2 °C) can be increased by considering other dependent factors while forecasting T_{max} and T_{min}.

References

Al-Lawati, A., Dorvlo, A. S. S. and Jervase, J. A., 2003, "Monthly average daily solar radiation and clearness index contour maps over Oman", *Energy conversion and management*, **44**, 691-705.

Al-Zoheiry, A., Brown, L. A., Keener, H. and Matte, M. T., 2006, "Modeling daily solar radiation using available meteorological data in Ohio for applications with alternative energy sources for micro-irrigation", American society of Agricultural and Biological Engineers Annual International Meeting presentation, Paper number : 062081.

Allen, R. G., Pereira, L. S., Raes, D. and Smith, M., 1998, "Crop evapotranspiration : guidelines for computing crop water requirements, FAO Irrigation and Drainage", Paper 56, FAO, Rome.

Almorox, J. and Hontoria, C., 2004, "Global solar radiation estimation using sunshine duration in Spain", *Energy Conversion and management*, **45**, 1529-1535.

Angstrom, A., 1924, "Solar and terrestrial radiation", *Quarterly Journal of Royal Meteorological society*, **50**, 121-125.

Black, J. N., 1956, "The distribution of solar radiation over the earth's surface", *Arch. Met. Geoph. Biokl.*, **7**, 165-189.

De Jong, R. and Stewart, D.W., 1993, "Estimating global radiation from common meteorological variables in western Canada", *Canada Journal of Plant Sciences*, **73**, 509-518.

Duffie, J. A. and Beckman, Wr., 1991, "Solar engineering for thermal processes", Second edition, John Wiley & sons, Inc., New York, NY.

Elagib, N. A., Babiker, S. F. and Alvi, S. H., 1998, "New empirical models for global solar radiation over Bahrain", *Energy conversion and management*, **39**, 8, 827-835.

Hargreaves, G. H. and Samani, Z. A., ASCE, 1982, "Estimating potential evapotranspiration", *Journal of Irrigation and drainage Division*, **108**, I IR3, 223-230.

Murugappan, A., Sivaprakasam, Subbarayan and Mohan, S., 2011, "Prediction of Solar Radiation with air temperature data in a coastal location in Tamilnadu", *Mausam*, **62**, 1, 85-90.

Prescott, J. A., 1940, "Evaporation from a water surface in relation to solar radiation", *Trans. R. Soc. Sci. Australia*, **64**, 114-125.