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A simple approach towards estimating solar irradiance

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सार—किसी क्षेत्र की कृषि क्षमता के अभिलक्षण ज्ञात करने में सौर विकिरण अत्यन्त महत्वपूर्ण भूमिका निभाता है। फिलहाल इसके बारे में सूचना ग्रहण करने के लिए विस्तृत संजाल उपलब्ध नहीं है। ताप परिसर, जैसे जलवायुविक आंकड़ों से इसे आंकने का प्रयत्न किया गया है।

पुणे के 1986-90 के दैनिक आंकड़ों के आधार पर, वायु तापमान के दैनिक परिसर और वायुमंडलीय संचारण के बीच संबंध विकसित किया गया है। विकसित मॉडल का स्वतंत्र आंकड़ों पर परीक्षण किया गया और सौर किरणन का सही अनुमान लगाया गया। इस सरल विधि द्वारा दैनिक सौर विकिरण में लगभग 70 प्रतिशत परिवर्तन समझाए जा सकते हैं। सूक्ष्म जलवायु पर सौर किरणन के प्रभाव की भी चर्चा की गई है। विकसित मॉडल की जांच हैदराबाद और कलकत्ता के लिए की गई और परिणाम उत्साहजनक पाए गए।

ABSTRACT. Solar radiation is of vital interest in characterizing an area with respect to its agricultural potential. However, these are not readily available for a large network. An attempt has been made to deduce solar irradiance from climatic data, such as temperature range.

Based on daily data of Pune for 1986-90, a relationship has been developed between atmospheric transmittance and the daily range of air temperature. The model developed has been tested on independent data and found to give fairly accurate estimation of solar irradiance. Nearly 70% of the variation in daily solar radiation could be explained by this simple method. The effect of solar irradiance on microclimate has also been discussed. The model developed has been tested for Hyderabad and Calcutta and found to give encouraging results.

Key words — Atmospheric transmittance, Solar irradiance, Microclimate, Daily range of air temperature.

1. Introduction

Solar radiation is the fundamental source of energy on earth, activating not only vital biological processes but also all meteorological systems on micro and macro scales. Plant growth is a direct function of solar radiation. As many meteorological methods in vogue to compute evapotranspiration from crop surface need radiation information and as, over vast tracks of the world, there is still a paucity of radiation observations, it would be desirable to estimate solar radiation indirectly through other readily available and simple meteorological parameters. Increased demand for suitable radiation data has led to the development of numerous predictive methods ranging from simple empirical formulae (Ganesan 1970) to extremely complex numerical models, depending on the available input data. Parameters used as inputs in the such models include sunshine duration, air temperature, cloudiness, relative humidity, precipitable water content etc (Huxley 1973, Goldberg *et al.* 1979). It may be pointed out that the physics involved in the interaction between solar irradiance and the highly variable atmospheric constituents is extremely complex and not well documented, particularly for cloudy skies (Rizzi *et al.* 1980).

The object of this paper is to determine relationship between atmospheric transmittance and the daily range of air temperature. The method used here is similar to that adopted by Bristow and Campbell (1984).

2. Material and method

The study pertains to data collected at Central Agrimet Observatory, Pune (18.5°N, 73.9°E, 556 m asl). Daily maximum and minimum temperature data from January 1986 to December 1990 were used. The solar irradiance data recorded by Moll Gorczynski Pyranometer at Pune were utilized. The technique was tested on a plateau station, *i. e.*, Hyderabad and one station on plain, *i. e.*, Calcutta.

(*i*) *Temperature analysis*

The range in daily temperature $\triangle T$ on Ith day was calculated as :

$$\triangle T(I) = T_{\max}(I) - [T_{\min}(I) + T_{\min}(I+1)]/2 \quad (1)$$

where, $T_{\max}$ is the daily maximum temperature (°C), $T_{\min}$ is the daily minimum temperature (°C) and I represents any day. The minimum temperature, $T_{\min}$ for any day is the mean of the minimum temperatures recorded on (I) th and $(I+1)$ th day. This was done to reduce effect of large scale advection of airmasses, both cold or warm which generally sweep the area particularly during non-monsoon months. A warm airmass moving through the area on Ith day would increase $T_{\max}(I)$ above a value possible from incoming radiation alone. By not incorporating $T_{\min}(I+1)$, the difference between $T_{\max}(I)$ and $T_{\min}(I)$, would imply a greater radiation load than actual occurred. The opposite situation occurs in the case of cold airmass and an underestimation of incoming radiation would result. However, if advective effects are ignored, the radiation or heat balance on any day, would depend on its magnitude during the preceding day as revealed in the soil heat storage and factors affecting partitioning of net radiation into sensible heat and evapotranspiration.

(ii) Analysis of irradiance

The total transmittance for any day includes the direct and diffuse components incident on a horizontal surface. It, thus, incorporates the atmospheric attenuation coefficients implicitly. The transmission coefficient T_t is computed as :

$$T_t = \frac{\text{Measured irradiance}}{\text{Extra-terrestrial insolation}}$$

Total extra-terrestrial insolation, Q_0 incident on a horizontal surface (Jm^{-2}), was computed using Gate's (1980) equation:

$$Q_0 = 86400 \; S_0 \, (\bar{d}/d)^2 \, (h_s \sin\phi \sin\delta + \cos\delta \sin h_s) \quad (2)$$

where, S_0 is the solar constant (1360 Wm^{-2}), $\bar{d}$ is mean distance between the sun and the earth, d is the actual distance between them on any particular day, h_s is the half day length and is given by :

$$\cos h_s = -\tan\phi \tan\delta$$

where, ϕ is the latitude of the place and δ is the solar declination. Solar declination and the latitude, and hence the day length are in radians. $(\bar{d}/d)^2$ generally does not differ by more than 3.5% from unity (Gate's 1980) and was, therefore, taken as unity.

The equation used to compute T_t as a function of $\triangle T$ has the form:

$$T_t = A\,[1 - \exp(-B \triangle T^C)] \quad (3)$$

In this, the constants A, B and C are determined empirically.

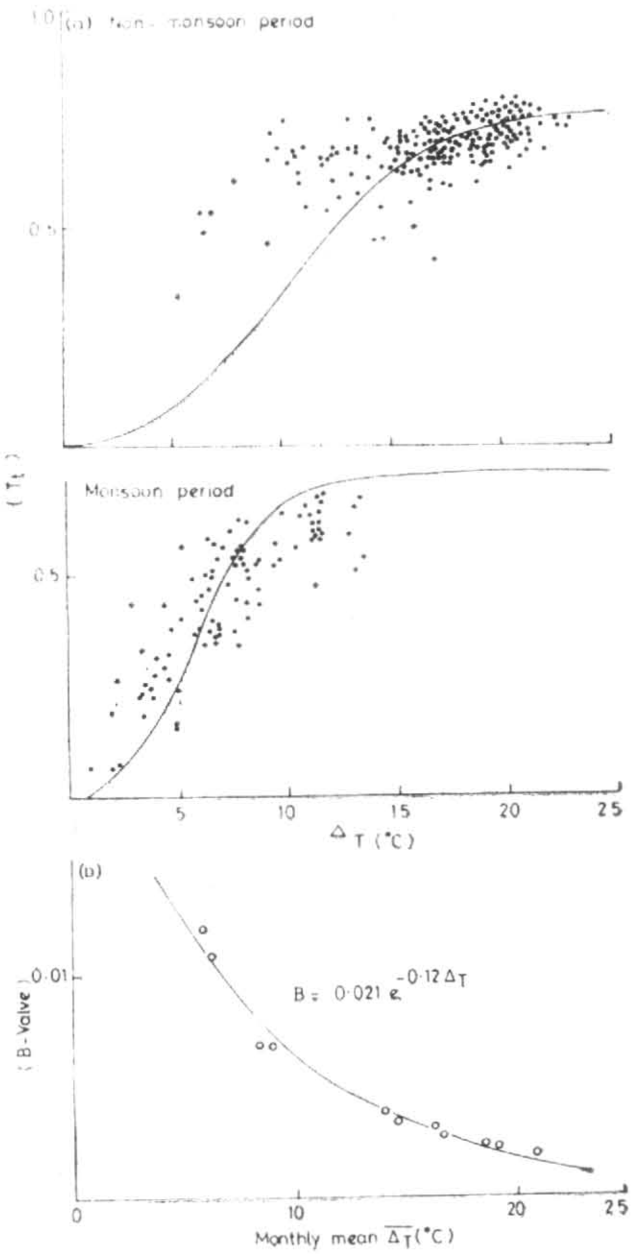
3. Results and discussion

3.1. *Radiation climatology*

Based on the five years data (1986-90) the average portrayal of the irradiance has been prepared [Fig. 1(a)]. The solar radiation income at Pune is largest (exceeding 20 MJm^{-2}) in pre-monsoon (March to May) season. This is presumably due to largest solar radiation received at the top of the atmosphere. May, for a month with frequent cloudiness associated with pre-monsoon thunderstorm, and fairly large atmospheric turbidities, surprisingly gets highest solar income. Because of persistent cloudy weather, lowest radiation is received during June-September. Here again in September a month in which normal rainfall is more than that in August, radiation is quite large. Because of low solar declination, the winter months (December to February) have low solar income. Though the rainfall is less in August than in September, August is more cloudy which contributes to comparatively less incoming solar radiation in this month. More rainfall in September at Pune may be attributed to enhanced convective activity during this period.

3.2. *Atmospheric transmission as a function of* $\triangle T$

The constants A, B, C determined from Eqn. (3) though empirical do have some physical significance.

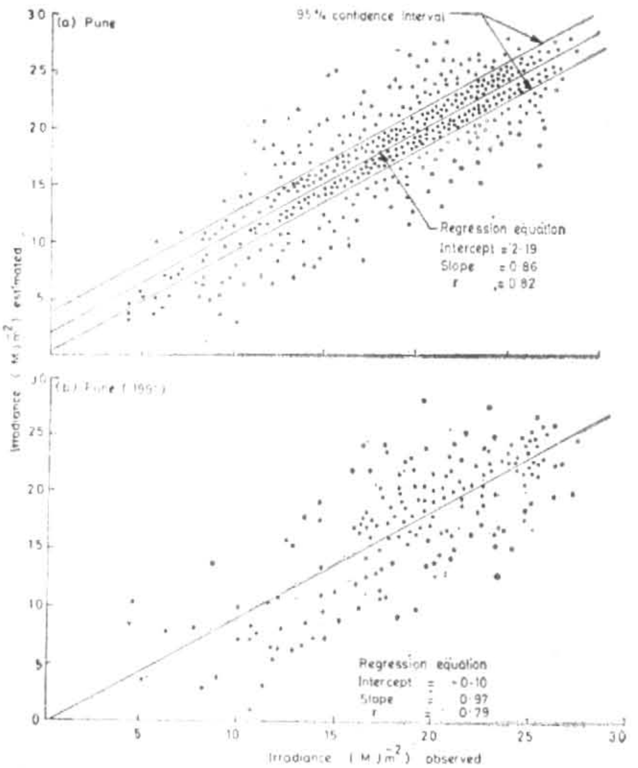


Figs. 1(a & b). (a) Scatter of T_t *versus* $\triangle T$, and (b) relation between B and monthly mean $\overline{\triangle T}$ (°C)

A for instance represents maximum clear sky T_t characteristics of the area. It is dependent on elevation of the place and pollution contents of the air.

B and C are functions of time and determine how soon maximum T_t is achieved as $\triangle T$ increases. They also display partitioning of energy and differ from humid to arid climate. B is dependent on sky conditions and is different in clear sky compared to cloudy ones.

Plotting of $\triangle T$ against T_t and smoothing the scatter furnished a value of A as 0.725. B and C have been determined by method of least square from Eqn. (3). For clear days, B was found equal to 0.0024 and for cloudy days 0.01. The value of C was found to be 2.38. For the data used in this study, it is found adequate to hold C constant at 2.38 and to vary only B in order to distinguish between seasonal data.



Figs. 2 (a & b). (a) Comparison between measured irradiance and estimated irradiance, and (b) observed and estimated irradiance for independent data set (1991)

Daily variation of atmospheric transmission in relation to temperature range $\triangle T$ is depicted separately for monsoon and non-monsoon months in Fig. 1(a).

The scatter between the two is found rather wide. This is mainly due to the variations in energy incident on the earth surface. Monsoon months, *i.e.,* June to September are characterised by persistent cloudiness with temperature range $\triangle T$ rarely exceeding 10°C. As such, average value of the transmission coefficient (T_t) observed during this period is only 0.44. On the other hand, in non-monsoon months $\triangle T$ is rarely below 10°C and is mainly concentrated between 15°C and 25°C. The average value of T_t observed during this period is 0.65 which is about 48% more than that in monsoon season. However, average value of solar irradiance during non-monsoon period (20.64 MJm^{-2}) is only about 18% more than that in monsoon period (17.46 MJm^{-2}). This is mainly because of low solar income during winter months.

3.3. *Variation of B with* $\triangle T$

As seen in Fig. 1(a) the slope of the curves vary between the two seasons. An attempt was made to include this variation in slope, by plotting the B values against monthly mean $\triangle T$. The result is shown in Fig. 1(b).

It is apparent from the Fig. 1(b) that B and $\triangle T$ are related exponentially. The following equation could be obtained between the two :

$$B = 0.021 \exp(-0.12 \triangle T) \qquad (4)$$

It has been observed that for temperature range above 20°C, B is lower than 0.002.

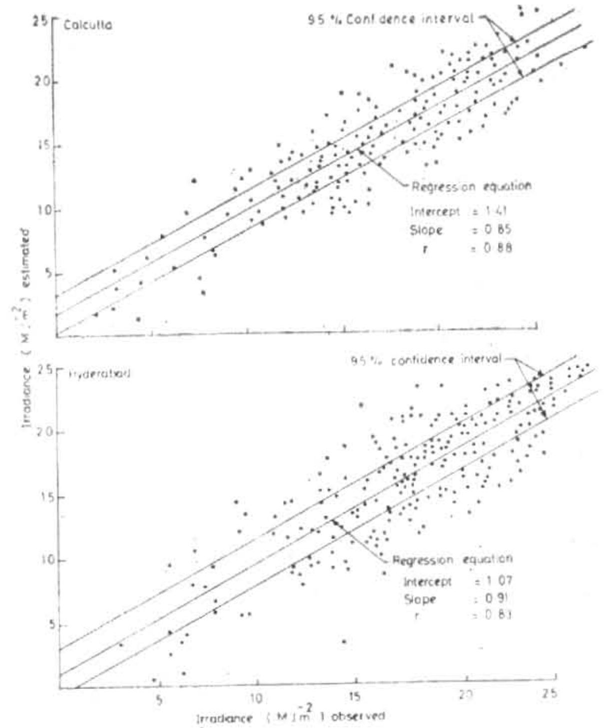


Fig. 3. Comparison between measured irradiance and estimated irradiance

3.4. *Validation of the technique*

In an attempt to validate the technique developed in the study, Eqn. (3) was used to compute irradiance using observed value of $\triangle T$ for monsoon and non-monsoon (October to May) season. The plot of computed *versus* measured irradiance is shown in Fig. 2(a). The correlation between the two was as high as 0.82, which indicates that the equation used to compute irradiance is quite reliable. The correlation coefficient implies that about 70% of the variation in solar irradiance could be accounted for by the technique described above. This is all the more significant since overcast skies have been incorporated in the analysis alongwith clear sky conditions.

A students t-test at the 0.05 level of significance, indicated that the slope did not differ significantly from zero. During monsoon period, after the rainfall occurs, accumulation of raindrops on outer glass dome and of water vapour between outer and inner glass domes of pyranometer, may cause refraction and absorption of the irradiance, ultimately affecting the radiation. This results in more deviation between recorded and calculated values.

After establishing the T_t *versus* $\triangle T$ relationship, one more data set was analysed to investigate the efficacy of the method. This was done for the data series for 1991 at the station. Results of this analysis are presented in Fig. 2(b). The correlation coefficient was found to be 0.79 and the slope was not significantly different from unity for this year also.

With a view to investigate the reliability of the method to other Indian stations, two stations one on plateau (Hyderabad) and another located on the plains (*i.e.,* Calcutta) were selected. The technique was applied to the

TABLE 1

Mean monthly values of rainfall (R), solar irradiance (S), and temperature range ($\triangle T$) for Pune

Year	Elements	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	R (mm)	000.0	000.0	000.0	000.0	035.0	264.1	063.9	099.9	071.4	000.6	002.3	035.5
	S (MJm^{-2})	16.94	21.02	23.64	25.61	26.34	15.92	16.98	16.37	21.68	20.57	19.07	16.76
	$\triangle T$ (°C)	17.6	18.2	19.4	19.5	14.0	07.2	06.2	06.2	10.3	16.9	16.6	17.7
1987	R (mm)	005.2	002.5	000.0	004.0	116.8	072.7	061.0	223.6	023.1	166.4	008.3	035.3
	S (MJm^{-2})	17.90	20.42	22.82	25.30	25.21	20.74	18.05	16.42	20.49	18.52	16.90	16.27
	$\triangle T$ (°C)	17.3	19.8	18.3	17.8	15.4	10.0	06.9	06.6	10.0	13.5	14.7	15.8
1988	R (mm)	000.0	000.0	000.0	048.0	015.6	067.0	299.9	084.1	431.1	000.3	000.0	000.0
	S (MJm^{-2})	17.38	20.77	23.70	23.37	25.50	20.89	13.99	15.81	17.17	21.03	17.91	16.22
	$\triangle T$ (°C)	18.8	20.7	19.9	17.1	14.1	09.1	15.9	15.8	17.3	15.1	18.4	17.1
1989	R (mm)	000.0	000.0	007.7	024.7	027.0	170.1	187.7	074.9	154.8	021.5	000.0	000.2
	S (MJm^{-2})	16.96	20.21	18.67	22.74	25.82	18.63	18.90	15.68	17.66	21.19	19.15	17.24
	$\triangle T$ (°C)	19.7	22.5	18.4	20.3	14.2	07.7	06.8	05.6	08.7	15.1	16.8	16.3
1990	R (mm)	000.0	000.0	000.0	000.0	081.2	173.8	248.6	197.6	037.9	125.4	038.2	000.0
	S (MJm^{-2})	18.80	19.68	23.91	26.06	23.31	18.39	14.87	13.11	17.49	17.87	18.34	
	$\triangle T$ (°C)	20.5	22.8	18.8	20.0	12.1	06.9	05.1	05.0	08.0	11.2	14.3	15.7

daily data of these stations by working out the constants A, B and C. The constants for these stations did not differ by more than 5% from that at Pune. Computed radiation for the model was found to have 0.83 correlation with observed daily values at Hyderabad and 0.88 at Calcutta (Fig. 3). Thus, it is clear that methodology suggested could be used with a great degree of confidence to measure atmospheric irradiance at stations where pyranometer is not available.

3.5. *Irradiance and microclimate*

Neglecting soil heat flux which is near zero when averaged over a day (Campbell 1977), net radiation can be partitioned between sensible and latent heat. This partitioning of energy is commonly expressed as the Bowen's ratio (sensible heat/latent heat) and for a specific Bowen's ratio on any given day, greater the solar radiation load, greater is the heating of the air. This results in a larger difference between daily maximum and minimum air temperature.

When water is freely available to the plants, as in the case of rainy season (or when the fields are irrigated in the non-rainy period), the amount of net irradiance converted into sensible heat will be less. On the other hand, energy used for evapotranspiration in such situations will be more, resulting in increasing latent heat and hence a lower value of Bowen's ratio. When the skies are clear, the temperature range is large, the Bowen's ratio would be high as very little moisture then becomes available for conversion into evapotranspiration and latent heat. For testing this hypothesis, mean rainfall, mean irradiance and mean $\triangle T$ for each month of the period 1986-1990 for Pune was prepared and given in Table 1. It is seen that in June 1986 the lower level of radiation of 15.92 MJm^{-2} but a higher rainfall of 264.1 mm vide Table 1 would have given lower Bowen's ratio than in August 1986 with 16.37 MJm^{-2} of solar energy, but a lower rainfall of 99.9 mm. The temperature range in the two cases does not differ by more than 1°C. Similarly in July and August 1988, the temperature range were practically the same but a lower radiation (*i.e.*, 13.99 MJm^{-2}) and higher rainfall of 299.9 mm in July would yield, a lower level of heat balance (*i.e.*, low Bowen's ratio) than in August 1988 with 15.81 MJm^{-2} radiation but a lower rainfall (*i.e.*, 84.1 mm). In September 1988 inspite of high radiance level and fairly large $\triangle T$ which in turn raise the sensible heat to a greater proportion, the Bowen's ratio is likely to be low because of large rainfall.

4. Conclusions

Many transpiration models require solar irradiance as an input. The present study has shown that the solar irradiance can be computed from the daily range of air temperature. Other climatic factors, like rains and cloud, do affect the relationship to some extent which require an in depth study. The following conclusions could be drawn from the study:

(*i*) The solar radiation income is largest in pre-monsoon season (March to May) and lowest in monsoon season (June to September).

(*ii*) A useful relationship exists between solar irradiance and the range in daily temperature extremes, as expected.

(*iii*) Atmospheric transmittance attains maximum value during non-monsoon season (October to May) when the temperature range is fairly large.

(*iv*) When enough water is available to the plants during rainy season, the amount of net irradiance converted into sensible heat is less.

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