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Estimation of Daily Global Solar Radiation from Daily Temperature Range

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ABSTRACT. A relationship between daily atmospheric transmittance and the daily range of air temperature was proposed for calculating incident solar radiation. The proposed formula has been applied to solar radiation and air temperature data of Kuwait. It is shown that the daily temperature difference accounts for 74-81% of the variation in daily solar radiation. It is also shown that the same solar radiation data set correlates equally well with temperatures recorded at weather stations having marked differences in the daily temperature range.

Several models have been developed for calculating incident solar radiation from meterological parameters such as daily sunshine duration, air temperature, relative humidity, cloud cover, precipitable water and atmospheric particle content (Sabbagh *et al.* 1977, Goldberg *et al.* 1979, Hussain 1984, Wendler and Kodama 1986, Turton 1987, and Reddy 1987). Bristow and Campbell (1984) proposed an empirical formula to calculate incident solar radiation from the daily temperature range. The daily solar radiation is expressed in terms of daily atmospheric transmittance, defined as the ratio of daily global solar radiation to daily extraterrestrial radiation on a horizontal surface. Solar radiation data of three stations were investigated using the proposed formula (Bristow and Campbell 1984). It was found that 70 to 90% of the variation in daily solar radiation can be accounted for by the proposed relationship.

The paper investigates the relationship between the daily solar radiation and the daily temperature range in Kuwait. Kuwait climate is characteristic of hot arid maritime regions. It has a long hot summer with frequent dust storms and short mild winter with a relatively small number of cloudy and rainy days.

Model and Data

The proposed relationship between the daily atmospheric transmittance τ, and the daily temperature range, $\triangle T$, is

$$\tau = A(1 - \mathrm{Exp}(-B \triangle T^{C})) \quad (1)$$

Where A represents the maximum clear sky transmittance and B and C are constants that determine how soon maximum τ is achieved as $\triangle T$ increases. B and C are determined empirically. According to Bristow and Campbell (1984), $\triangle T$ was calculated as the difference between the daily maximum temperature and the mean of the minimum temperatures on both sides of the maximum, *i.e.*

$$\triangle T_{(j)} = T_{max\ (j)} - \frac{T_{min(j)} + T_{min(j+1)}}{2} \quad (2)$$

In our analysis we wanted to answer the following questions:

1. How suitable is the proposed model for predicting daily solar radiation in Kuwait?
2. What difference does it make if $\triangle T$ is calculated as per equation 2 or calculated as the difference between maximum and minimum temperatures of the same day?
3. How good is the correlation between solar radiation measured at one station and temperature range measured at another station, when the daily temperature range at the two stations is different?

The subject data are the solar radiation and air temperature data recorded at the Kuwait Institute for Scientific Research (KISR) weather station and the air temperature data recorded at the weather station of Kuwait International Airport (KIA). The former is a coastal station and the latter is an inland station located at about 15 km from the former. The subject data cover the period October 1986 to September 1987.

Analysis and Results

Figure 1 shows the monthly mean daily global solar radiation on a horizontal surface recorded at KISR weather station. Also shown in the figure are the monthly mean daily temperature ranges at KISR and KIA. No solar radiation data of KIA is available for the period of investigation and it is assumed that solar radiation should be similar at the two stations because they are close together. The temperature curves show KIA to have a greater mean daily temperature range than KISR. Figure 2 shows the cumulative distribution of the daily temperature range at the two stations. It is shown that KIA experiences a larger daily temperature range than KISR. This can be explained in terms of solar radiation partitioning into sensible and latent heat. At KISR weather station, which is located on the coast, a larger portion of solar radiation, than at KIA, is converted into latent heat. The relatively smaller portion of solar radiation converted into sensible heat means a smaller daily temperature range at KISR than KIA.

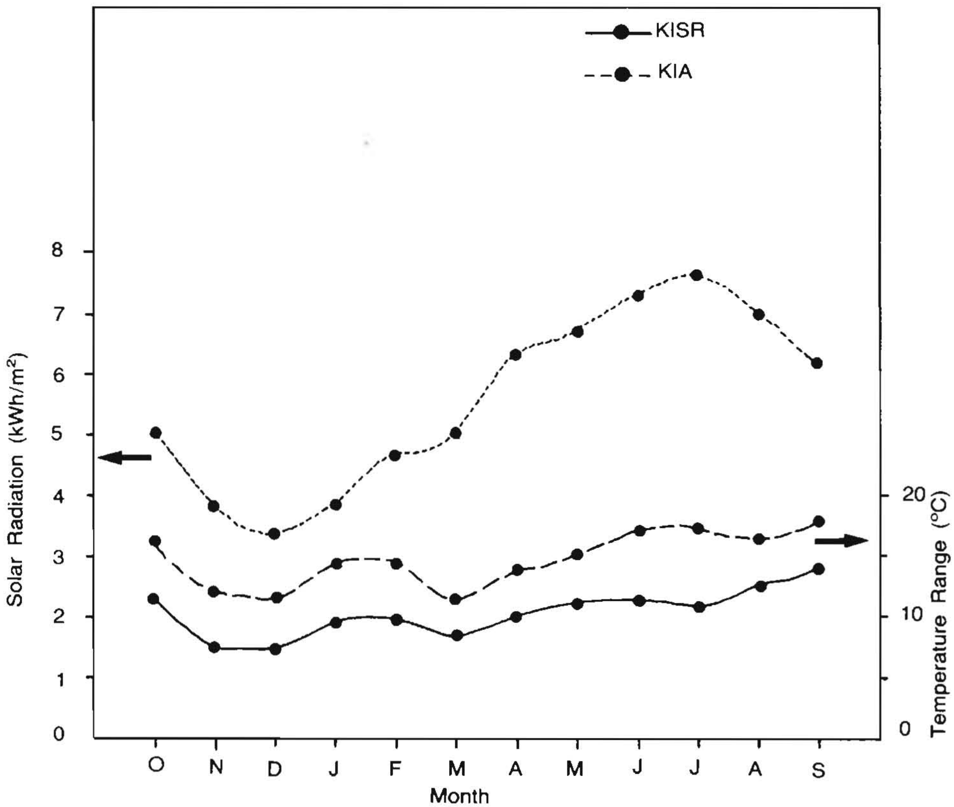

Fig. 1. Variation of monthly mean daily global radiation and monthly mean daily temperature range at KISR and KIA weather stations.

Daily solar radiation (kWh/m^2) and temperature range (°C) were investigated using the Statistical Analysis Systems (SAS) software package. The daily atmospheric transmittance was calculated from measured daily solar radiation and computed daily extraterrestrial radiation on horizontal surface. The daily temperature range was calculated as the difference between the maximum and minimum temperature of the same day, denoted $\triangle T_1$, or as per eq. 2 and is denoted $\triangle T_2$. In fact, the difference between $\triangle T_1$ and $\triangle T_2$ was not large and was mostly within 1°C. Such a difference would impact only solar radiation predictions on days having small $\triangle T$. These are, normally, associated with low transmittance.

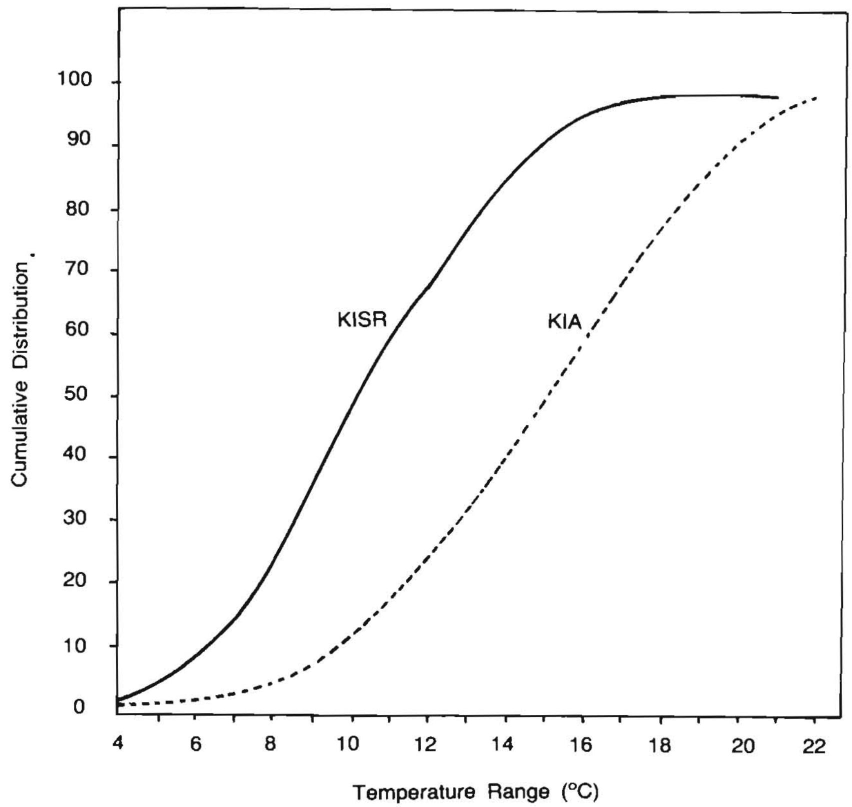

Fig. 2. Cumulative distribution of the daily temperature range at KISR and KIA weather stations.

Data on τ and $\triangle T_1$ recorded at KISR were investigated for each month separately. A was taken as the maximum τ during the concerned month. B was allowed to vary between 0.001 and 0.02 and C between 2 and 3. The results showed A, B, and C to vary from one month to the other. But because the variation of A and C was smaller, in relative terms, than the variation of B, it was suggested to fix A (=0.7) and C (=2.5) and allow B to vary.

The monthly variation of B showed no consistent pattern. Bristow and Campbell (1984) showed a relationship between B and the average monthly daily $\triangle T$, but no similar relationship for the subject data was developed. Accordingly, it was suggest to fix A and C as above and analyze the data to calculate a single value for B. A non-linear regression of τ *versus* $\triangle T_1$ was performed ($A = 0.7$ and

C = 2.5). B was calculated to be 0.0195. A similar correlation of τ *versus* $\triangle T_2$ was performed (A = 0.7 and C = 2.5). B was calculated to be 0.0152. When τ was correlated with KIA data B was calculated to be 0.0055 and 0.0047 for $\triangle T_1$ and $\triangle T_2$, respectively.

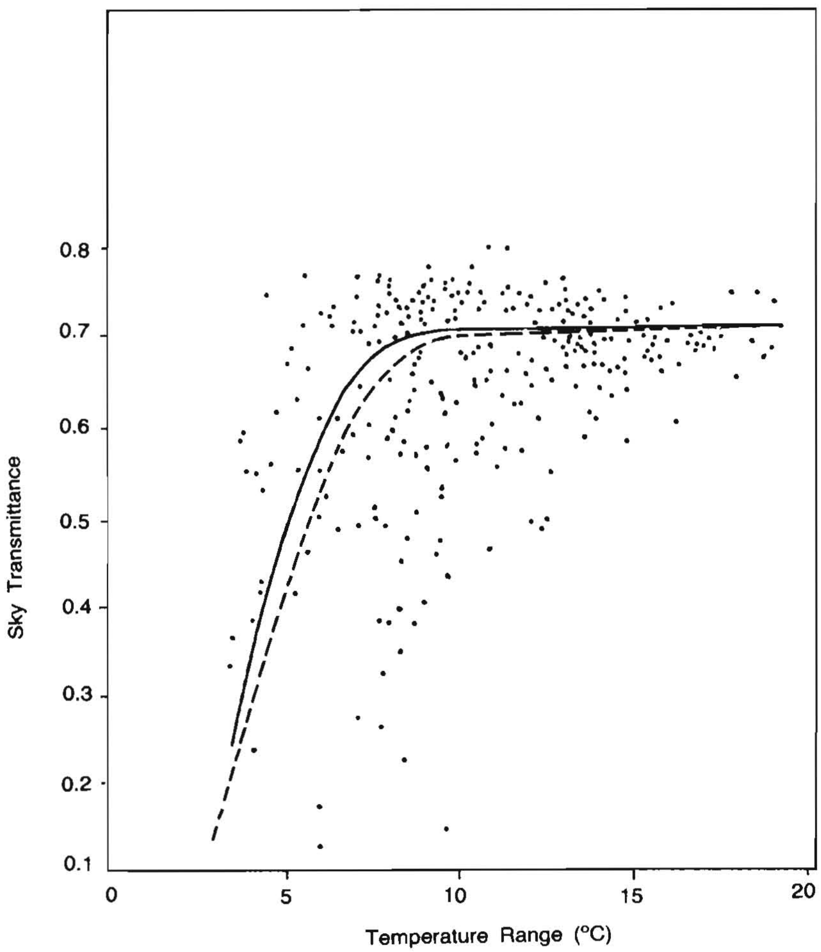

Fig. 3. Scatter of τ_t *versus* KISR $\triangle T$. Solid line is best-fit curve with $\triangle T_1$, and broken line is best-fit curve with $\triangle T_2$.

Figures 3 and 4 show the scatter of τ against the daily temperature range at KISR and KIA, respectively. The best-fit curves based on $\triangle T_1$ and $\triangle T_2$ are also presented. The curves make similar predictions of solar radiation except at small $\triangle T$ where noticeable differences are exhibited. In fact, the scatter of τ at small

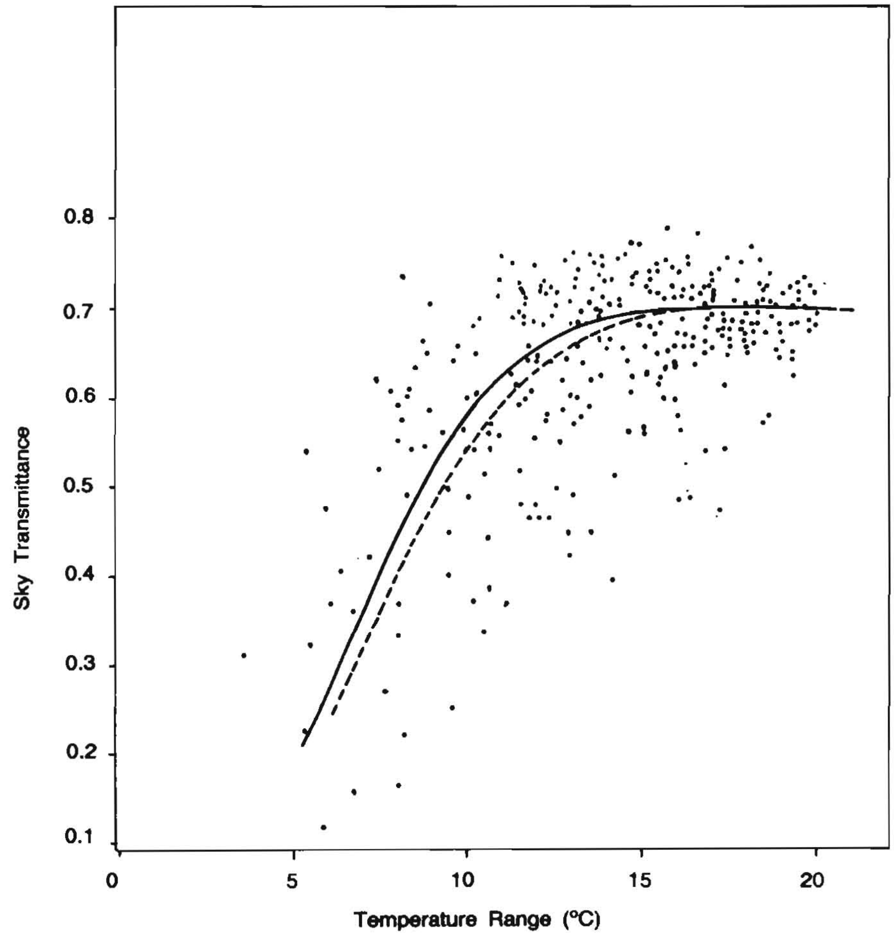

Fig. 4. Scatter of τ_t *versus* KIA $\triangle T$. Solid line is best-fit curve with $\triangle T_1$, and broken line is best-fit curve with $\triangle T_2$.

$\triangle T$ is more marked than at large $\triangle T$. Evidently, it would make little difference whether $\triangle T_1$ or $\triangle T_2$ is used for modelling the subject data, especially at large $\triangle T$

It should be mentioned that a large $\triangle T$ is, normally, associated with clear sky conditions, which indicates a high sky transmittance and high solar radiation. When data of daily temperature range was investigated it was found out that a small $\triangle T$ is, normally, associated with rainy, cloudy or dusty conditions. It is under such conditions that the proposed model tends to fail to make reasonable predictions of solar radiation. A detailed investigation of measured and predicted daily solar radiation showed the model to make predictions within $\mp$ 15% of measured values for about 80% of days of the year. For the remaining days the difference was much larger. This, no doubt, imposes limitations on the applicability and usefulness of the model as compared to other models of solar radiation calculation.

The computed and measured solar radiation data were analyzed to calculate the coefficients of linear regression (y = a+bx) for the various combinations of B and $\triangle T$. Linear regression was performed for daily, weekly and monthly solar radiation data. The results are presented in Table 1. It is seen that, for the same station, it makes little difference to the results of linear regression whether $\triangle T_1$ or $\triangle T_2$ is used for modelling purposes. This is true for the temperature conditions of Kuwait, where abrupt changes of weather conditions are not frequent. It is also seen that solar radiation correlates equally well with data on daily temperature range recorded at coastal and inland weather stations, where it would be expected that solar radiation is partitioned differently between sensible and latent heat. The results of linear regression, however, indicate that the daily temperature range accounts for about 74-81% of the variation in daily solar radiation. It is seen that a relatively larger percentage of solar radiation is accounted for at KIA than at KISR. It is, however, premature at this stage to explain this difference in terms of larger daily temperature range at KIA. A more comprehensive judgement would probably be made when a larger data base is available.

Table 1. Linear regression (y=a+bx) coeffients of computed (y) *vs.* measured (x) solar radiation in Kuwait.

Location	Inegration period	Slope b	Intercept a	Correlation coefficient
KISR, $\triangle T_1$				
	Day	0.87	0.99	0.86
	Week	1.07	−1.19	0.97
	Month	1.14	−16.01	0.99
KISR, $\triangle T_2$				
	Day	0.86	0.96	0.86
	Week	1.07	−1.26	0.96
	Month	1.13	−16.58	0.99
KIA, $\triangle T_1$				
	Day	0.93	0.50	0.90
	Week	1.09	2.69	0.97
	Month	1.13	−18.55	0.99
KIA, $\triangle T_2$				
	Day	0.92	0.54	0.90
	Week	1.09	−2.74	0.97
	Month	1.12	−18.41	0.99

Conclusion

The correlation of solar radiation, expressed in terms of atmospheric transmittance, and air temperature data of Kuwait shows that the daily temperature range accounts for about 74-81% of the variation in daily solar radiation. It is also shown that the same solar radiation data correlate equally well with air temperature data recorded at neighbouring weather stations having marked differences between daily temperature ranges. The model is shown to make better estimation of incident solar radiation under clear sky conditions, characterized by large daily temperature range, than cloudy or dusty days, characterized by relatively small temperature range. Seemingly, the model is of limited applicability, except for applications where accurate estimates of solar radiation over short durations, up to one day or so, are not crucial such as in some agricultural applications.

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حساب الإشعاع الشمسي من المدى اليومي لدرجة الحرارة

سعود عياش و مي رصاص

معهد الكويت للأبحاث العلمية ـ ص. ب ٢٤٨٨٥ الصفاة ١٣١٠٩ ـ الكويت

اقترح نموذج رياضي تجريبي لحساب مقدار الإشعاع الشمسي اليومي من المدى اليومي لدرجة الحرارة. ويعبر عن الإشعاع الشمسي في النموذج بمقياس نفاذية الجو، وهي نسبة الإشعاع الشمسي الساقط على السطح الأفقي على الأرض إلى الإشعاع الشمسي الساقط على السطح الأفقي على سطح الغلاف الغازي المحيط بالأرض. وأما المدى اليومي لدرجة الحرارة فهو الفرق بين درجتي الحرارة العظمى والصغرى لليوم نفسه.

وتم استقصاء جدوى النموذج الرياضي باستخدام بيانات الإشعاع الشمسي ودرجة الحرارة المسجلة في محطة الأرصاد التابعة لمعهد الكويت للأبحاث العلمية، وبيانات درجة الحرارة المسجلة في محطة الأرصاد التابعة لمطار الكويت الدولي. وقد بيّن التحليل الإحصائي للنتائج أن حوالي ٧٤ ـ ٨١٪ من التغير في الإشعاع الشمسي اليومي يمكن تفسيره بتغير المدى اليومي لدرجة الحرارة. وبيّن التحليل أيضاً أنه يمكن تفسير حوالي ٩٤٪ و ٩٨٪ من الإشعاع الشمسي الأسبوعي والشهري، على التوالي، بتغير المدى اليومي لدرجة الحرارة. ومن الواضح أن النموذج أكثر ملائمة لحساب الإشعاع الشمسي خلال الفترات الزمنية الطويلة نسبياً (أسبوع، شهر) مما للفترات الزمنية القصيرة (ساعة، يوم).