DEVELOPING A MODEL FOR PREDICTING THE GLOBAL SO LAR FOR ENUGU USING MAXIMUM TEMPERATURE DATA

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Abstract

Using the maximum temperature, T_m, data, a model for predicting the global solar radiation, H_p, in Enugu has been developed. The coefficient of determination is 0.5168 and the percentage difference between the values predicted by the model and the measured values ranges from 2.97% to 17.19%.. The mean bias error (MRE) and the root, mean-square error (RMSE) statistical tests were found to be 1.95% and 8.71%, respectively. From these results it is concluded that the model can be used for both short term and long term prediction of solar radiation in Enugu.

Keywords : *Maximum temperature and solar radiation.*

Introduction

The amount of solar energy reaching a particular location in a unit time say a day, is of paramount importance. This is so not only because it is needed to characterize solar energy devices but also because of the impact of solar energy on socio-agricultural processes. Unfortunately, direct measurement of solar radiation cannot be undertaken in all meteorological sites in developing countries like Nigeria because of the high cost of the instrument and paucity of funds(Echiegu, 1993; Okonkwo and Aguwamba, 1997; Okpani and Nnabuchi, 2006).

This situation necessitates the use of other meteorological data such as sunshine hours, air temperature, relative humidity, cloud cover, precipitation, etc, to develop models for predicting solar radiation in sites of interest.

A good number of authors have used these meteorological parameters either singly or In combination to predict the monthly mean daily global solar radiation on a horizontal surface for some towns in Nigeria. For example, Sanusi and Aliyu (2005) used maximum temperature data to predict for Sokoto. Iheonu (2001) did the same for Ibadan. Badmus and Momoh(2005) did likewise for Birnin Kebbi. So did Awachie and Okeke(1990) for Nsukka. *Hussaini et al.* (2005) correlated solar radiation with sunshine duration, maximum temperature and relative humidity for Maiduguri. Sambo((1985) and Sambo and Doyle (1986) developed models for the estimation of solar radiation for a number of Nigerian cities using various meteorological parameters.These examples are by no means exhaustive.

The amount of solar radiation received at any surface of the Earth depends on the extraterrestrial solar irradiance and the conditions of the atmosphere.

The extraterrestrial solar irradiance is the rate at which solar energy arrives on a horizontal surface at the top of the atmosphere. It varies according to the latitude of the location, the distance of the

Earth from the Sun and the time of the year. On any particular day, it varies from zero at sunrise to a maximum at noon and back to zero at sunset.

When solar radiation enters the atmosphere a part of the incident energy is removed through the processes of scattering, absorption and reflection. The scattering of solar radiation is mainly by atmospheric molecules and aerosols. The absorption of solar radiation is mainly by ozone (O_3), water vapour (H_2O), oxygen (O_2), carbon (IV) oxide (CO_2) as well as clouds. The reflection of solar radiation is mainly by the clouds and this plays an overriding part in reducing the energy density of the solar radiation reaching the surface of the earth. The fate of solar radiation in the earth's atmosphere is shown in fig. 1.

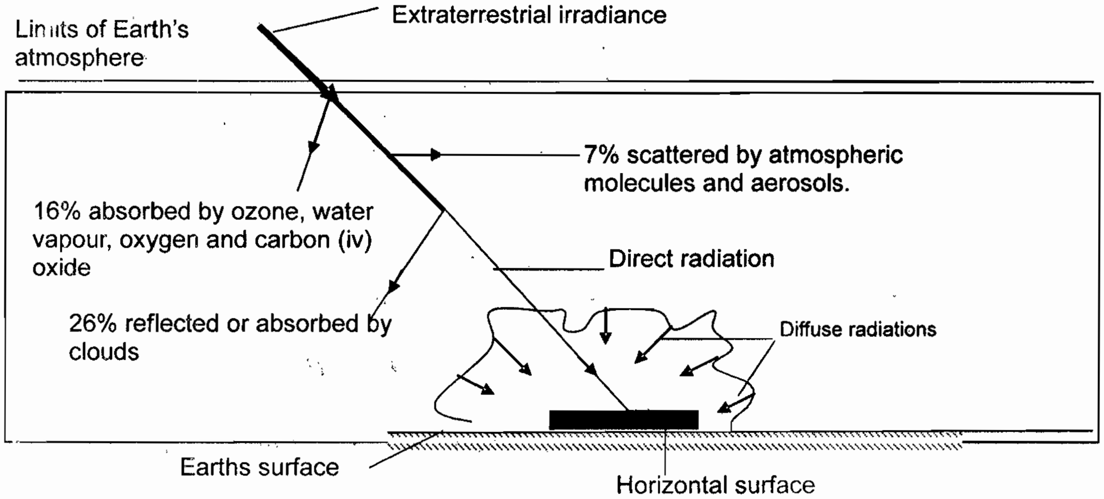


Fig.1: Fate of solar radiation in the atmosphere

The radiation arriving at the ground directly in line with the solar disc is called direct or beam radiation. A portion of the scattered and multiply reflected radiation goes back to space and a portion reaches the ground from the sky hemisphere as diffuse radiation. The sum total of direct and diffuse radiation is called global radiation. Global radiation can be measured by means of an instrument called a pyranometer which measures all the radiation incident on it within a solid angle of 2π. As stated before however, such an instrument is not available at all sites where solar radiation data are needed. It is therefore necessary to predict solar radiation levels using other meteorological data that are available.

In this paper, a model is developed for predicting the monthly mean daily global solar radiation on a horizontal surface in Enugu using maximum temperature data. Enugu is located at the junction of two geographical regions of Nigeria namely the South Eastern Scarplands and the Cross River Basin. The climate is Subtropical(Köppen's Af type). It has an annual rainfall of 200cm and an altitude between 180 and 250m above sea level. Its Latitude is 7.55° E and Longitude is 6.47° N.

Data Collection and Analysis

The maximum temperature data used for this work were recorded every day at the Akanu Ibiam International Airport, Enugu by the South Eastern Zone of the Nigerian Meteorological Agency for the period from January 1996 to April 2006 using the Six's combined maximum and minimum thermometer. The raw data were converted

to useful form for the purpose of this work by calculating the average value for each month using the 11-year values i. e. 1996-2006.
The measured solar radiation used for the development and comparison of the model was extracted from the records of the same organization during the same period. The solar radiation was measured using the Gunn-Bellani instrument. The readings recorded in millimeters were converted to MJm^{-2} day^{-1} using a conversion factor of 1.1364 proposed by Sambo (1985)
According to Iheonu (2001), the monthly mean daily solar radiation reaching a horizontal surface on the earth $\bar{H}_m$ is related to the maximum temperature $\bar{T}_m$ by the formula

$$\frac{\bar{H}_m}{\bar{H}_o} = a + b\bar{T}_m \qquad (1)$$

where $\bar{H}_o$ is the extraterrestrial monthly average daily radiation on a horizontal surface while a and b are regression coefficients. The value of for each month of the year was calculated from the formula

$$\bar{H}_o = \frac{1}{N_1 - N_2 + 1}\sum_{N_1}^{N_2} H_o \qquad (2)$$

where H_o is the extraterrestrial irradiation during the day from sunrise to sunset on a horizontal surface and N_1 and N_2 are the day numbers of the first and last days of the month. The value of H_o for any day of the month is given by (Igbal, 1983)

$$H_{o1} = \cos\phi \cos\delta \sin\omega_s$$

$$H_{o2} = \frac{\pi}{180}\omega_s \sin\phi \sin\delta \qquad (3)$$

$$H_o = \frac{24}{\pi} I_{sc} E_o \left(H_{o1} + H_{o2}\right)$$

where I_{sc} is the solar constant in $MJm^{-2}h^{-1}$, E_o is the eccentricity correction factor of the Earths orbit ϕ is the latitude δ is the solar declination and ω_s is the sunrise hour angle in degrees. The value of I_{sc} used in this work is 4.921 $MJm^{-2}h^{-1}$ (1367x3600/1000000). The values of E_o, δ and ω_s were calculated for each day using the formulas(Liou, 1980; Robison, 1966)

$$E_o = 1 + 0.033\cos\left(\frac{360N}{365}\right) \qquad (4)$$

$$\delta = 23.45\sin\left[\frac{360(N + 284)}{365}\right] \qquad (5)$$

$$\omega_s = \cos^{-1}\left(-\tan\phi \tan\delta\right) \qquad (6)$$

where N is the day number.

Results and Discussion

Table 1 shows the measured monthly mean daily maximum temperature $\bar{T}_m$ and solar radiation $\bar{H}_m$ as well as the extraterrestrial solar radiation $\bar{H}_o$ and the clearness index $k_t = \bar{H}_m / \bar{H}_o$. Figure 2 shows the scatter diagram of the clearness index against the monthly mean daily maximum temperature. A careful examination of the diagram reveals a clear linear correlation. Regression statistical analysis was then carried on $\bar{T}_m$ and k_T using Mathcad. The values of the regression coefficients a and b from eqn. (1) are

a = -0.1442 (7)
b = 0.0172 (8)

Hence, the monthly mean daily solar radiation on a horizontal surface for any month of the year can be predicted using the formula

$$\bar{H}_p = (-0.1442 + 0.0172\,\bar{T}_m)\,\bar{H}_o \qquad (9)$$

where $\bar{T}_m$ is the mean daily maximum temperature and $\bar{H}_o$ is the mean daily extraterrestrial solar radiation for that month.
The values of the correlation coefficient R and the coefficient of determination R^2 were also evaluated using Mathcad. They are

R = 0.7189 (10)
R^2 = 0.5168 (11)

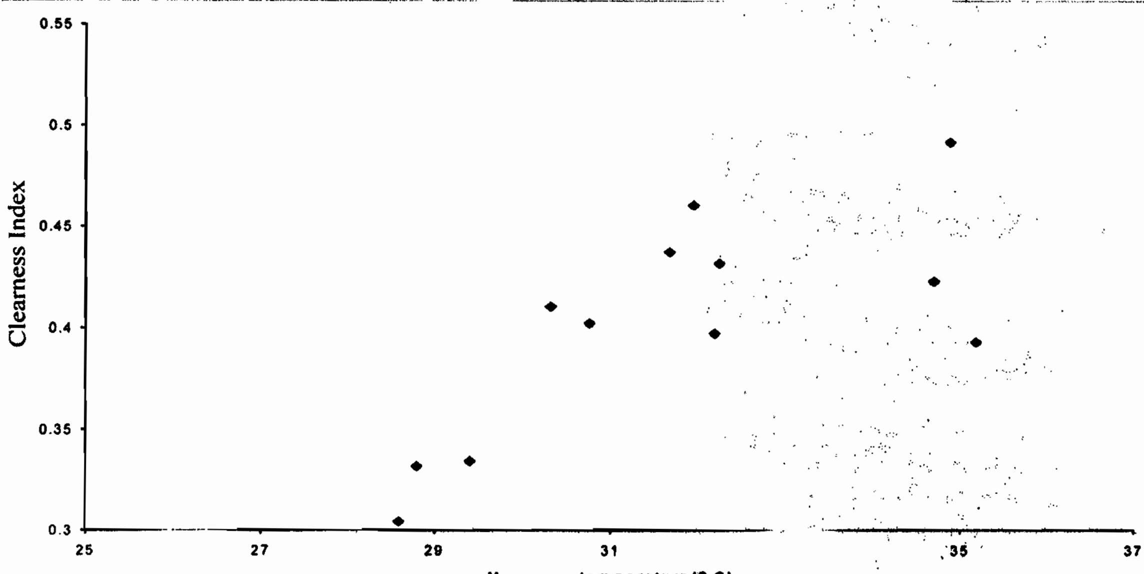
This value of R (0.7189) indicates that there is a high positive correlation between the measured monthly mean daily maximum temperature $\bar{T}_m$ and the monthly mean daily clearness factor k_T and hence the monthly mean daily global solar radiation on a horizontal surface (Hamburg,1987).

Table 1: Measured values of monthly $\bar{T}_m$ $\bar{H}_m$ $\bar{H}_o$ k_T

Month	$\bar{T}_m$ (?C)	$\bar{H}_m$ (MJm^{-2})	$\bar{H}_o$ (MJm^{-2})	$k_T = \bar{H}_m / \bar{H}_o$
JAN	32.2	14.25	35.82	0.3978
FEB	34.71	15.65	37.01	0.4229
MAR	35.19	14.77	37.54	0.3934
APR	34.9	14.27	36.11	0.4916
MAY	32.27	14.85	34.41	0.4316
JUN	30.33	13.61	33.15	0.4106
JUL	29.4	11.65	34.85	0.3343
AUG	28.6	10.8	35.47	0.3044
SEP	28.8	12.26	36.95	0.3318
OCT	30.77	15.18	37.73	0.4023
NOV	31.97	16.51	35.83	0.4608
DEC	31.7	15.42	35.22	0.4378

Table 2: Measured values of monthly $\bar{H}_m$, $\bar{H}p$ and the percentage difference between measured and predicted values, PD.

Month	$\bar{H}_m$ (MJm^{-2})	$\bar{H}p$ (MJm^{-2})	PD (%)
JAN	14.25	14.67	2.97
FEB	15.65	16.76	7.08
MAR	14.77	17.31	17.19
APR	14.27	16.62	16.46
MAY	14.85	14.14	4.80
JUN	13.61	12.51	8.06
JUL	11.65	12.59	8.13
AUG	10.8	12.33	14.16
SEP	12.26	12.97	5.79
OCT	15.18	14.53	4028
NOV	16.51	14.54	11.93
DEC	15.42	14.12	8.43



F... Scatter diagram showing the variation of clearness index with maximum ...perature

$\bar{H}_m$

Also the value of R^2 i. e. 0.5168 indicates that 51.68% of the variation in the monthly mean daily global solar radiation on a horizontal surface $\bar{H}_m$ can be explained by the regression model which makes the model highly acceptable (Mosteller and Tukey, 1977).

Table 2 shows the predicted values $\bar{H}_p$ for the months of January through December as well as the percentage difference between the measured and the predicted values PD. Values of $\bar{H}_m$ are also shown here for easy visual comparison. Figure 3 shows the variations of $\bar{H}_p$ and $\bar{H}_m$ during the year.

To further asses the accuracy of the predicted results, the mean bias error(MBE) and the root mean square error(RMSE) were computed using relations given by Iqbal(1983). The results of these tests are

MBE = 1.95% (12)

RMSE = 8.71% (13)

Since the MBE result is less than 5% , the model is acceptable for long term performance. Also since the RMSE is less than 10%, the model is equally satisfactory for short term performance (Sanusi and Aliyu,2005).

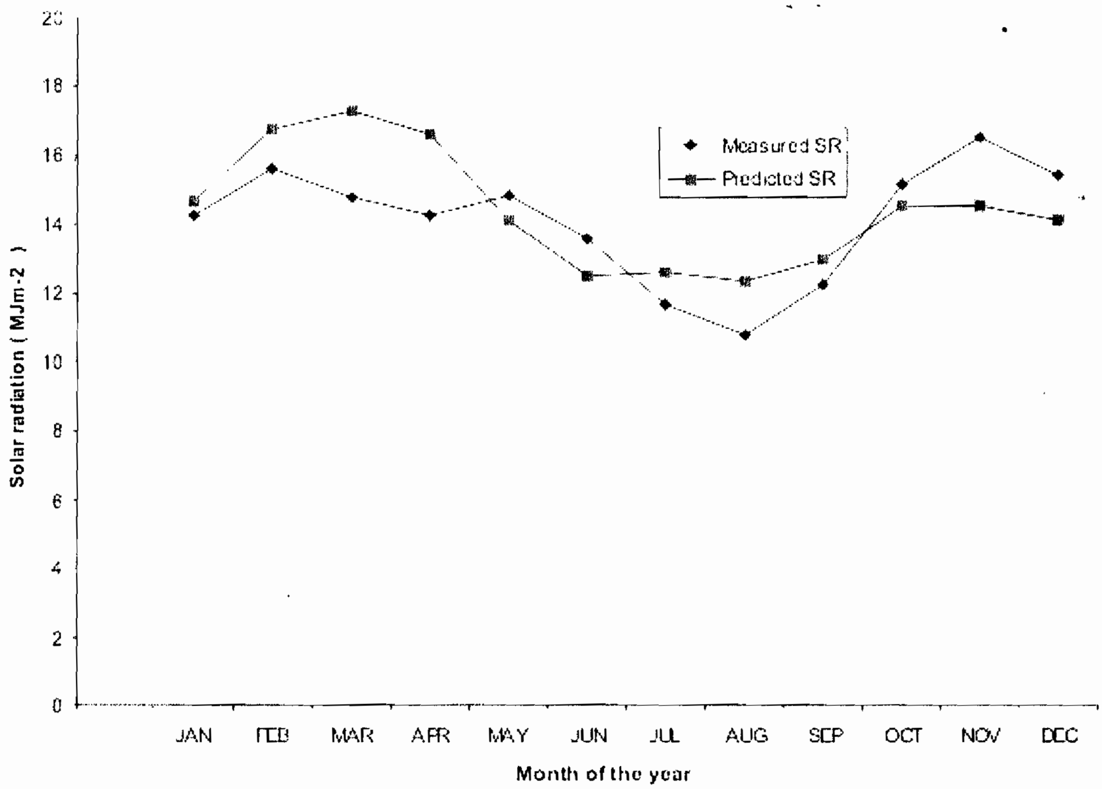


Fig 2: Variation of the measured and predicted monthly mean daily solar radiation on a horizontal surface

The values of the regression coefficients a and b obtained for Enugu are found to be different from the values that have been obtained for other towns in Nigeria. For example, Sanusi and Aliyu (2005) using maximum temperature data obtained 0.3132 and 0.005 as a and b respectively for Sokoto. Iheonu (2001) likewise obtained 0.0186 and 0.0124 as a and b respectively for Ibadan. Badmus and Momoh(2005) also using maximum temperature data obtained 0.2445 and 0.0096 as a and b respectively for Birnin Kebbi. Awachie and Okeke(1990) used similar data to obtain -0.87 and 0.8 as a and b respectively for Nsukka. Hussaini *et al*(2005) correlated sunshine duration, maximum temperature and relative humidity with global solar radiation on a horizontal surface for Maiduguri and obtained various values of a ranging from 0.232 to 343 and b ranging from 0.4350 to 0.505. These differences are due to the fact that regression coefficients associated with maximum temperature and other meteorological data changes with latitude. Moreover, even places on the same latitude (which implies that they have exactly the same monthly average daily extraterrestrial solar radiation) may have different solar radiation maximum temperature regression coefficients because of the great influence of the ever changing atmospheric conditions which greatly modify the solar radiation reaching the earth's surface.

Conclusion

Using measured values of the maximum air temperature and solar radiation a model given by

$$\bar{H}_p = (-0.1442 + 0.0172\, \bar{T}_m)\, \bar{H}_o \quad (14)$$

was developed for predicting the monthly mean daily global solar radiation on a horizontal surface from the monthly mean daily maximum temperature data. Further statistical tests show that the model is highly acceptable and satisfactory for both short - term and long - term performance.

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