

ESTIMATION OF SOLAR RADIATION IN BANGLADESH FROM NOAA AVHRR TIME SERIES DIGITAL IMAGES

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KEY WORDS: Solar Radiation, NOAA AVHRR, RMSE.

ABSTRACT

Retrieval of solar radiation from satellite data has become a valid alternative to ground measurements. In this study a simple statistical model has been used to estimate hourly solar global radiation over Bangladesh for two different time periods. Only the visible channel (0.63 μm) data of NOAA-AVHRR numerical images, obtained from Bangladesh Space Research and Remote Sensing Organization, has been processed to find the cloud index, a parameter which includes the horizontal extension of clouds and its optical thickness. Ground measured (pyranometer) data, obtained from Bangladesh Meteorological Department, has been used to obtain the total atmospheric transmission factor. One set of cloud index-atmospheric transmission factor data pairs has been used to find the regression coefficients using a statistical model. Once these coefficients are obtained these are then applied to the other set to calculate the ground irradiation.

Ground solar global irradiation for two places has been estimated for two months through application of this method. Efficiency of the method for calculating surface insolation has been checked in two ways. Reasonably good correlation between the measured and estimated irradiation has been observed for all the cases. The root mean square error (RMSE) varies between 7.99% and 13.62% and mean bias error (MBE) from -7.22% to +9.54%. The method can be used for calculation of hourly irradiation over areas in a tropical environment.

1. INTRODUCTION

The interaction of atmosphere and geosphere has significant influence on the Earth's climate system. Accurate knowledge of surface radiation budget is of particular importance as it constitutes the principal forcing variable which drives the energy exchange process. One way of getting detailed knowledge of the temporal and spatial variation of solar irradiance is by interpolating between ground measurement stations. But as the pixel sizes of the modern satellites are becoming smaller, it has been observed that satellite retrievals are more accurate than interpolating ground measurements. This study focuses on one component of the surface radiation budget, i.e., the downwelling solar surface irradiance. Many algorithms have been developed for its estimation from satellite data. In a review paper, Noia et al. (1993) described the best known methods developed using both the statistical and physical models from geostationary satellite data. Also there are some other methods developed from sun synchronous polar orbiter satellite data (Islam and Excell 1996, Laine et al.1999 etc.).

2. OPERATIONAL METHOD

The method used in this study is a statistical one. Remote sensing data from sun-synchronous NOAA KLM series of satellites, captured by Bangladesh Space Research and Remote Sensing Organization (SPARRSO), have been used. The full resolution (1km) images of NOAA-17 satellite have been duly preprocessed. These images are then further processed for estimation of hourly solar irradiation on earth's surface. Only the visible channel data, bandwidth 0.58-0.68 μm , has been used to infer the cloud properties. Ground measured pyranometer data, obtained from Bangladesh Meteorological Department (BMD), has been used to obtain the transmission factor of the atmosphere. From the simultaneous measurements of ground based radiometer and satellite based sensor, regression coefficients for the model have been determined, which are then used for estimation of hourly global radiation.

2.1. Cloud Index

Using the preprocessed images, cloud index (C) for each pixel has been calculated from the monthly time series images using the equation proposed by Cano et al (1986),

$$C_{(x,y)} = \frac{R_{i(x,y)} - R_{o(x,y)}}{R_{c(x,y)} - R_{o(x,y)}}, \quad (1)$$

where $R_{i(x,y)}$ is the instantaneous reflectance of the pixel (x,y), $R_{o(x,y)}$ is the reference ground reflectance for the time series for the pixel (x,y) and $R_{c(x,y)}$ is the reference cloud reflectance for the time series for the same pixel (x,y).

2.2. Atmospheric Transmittance Factor

Total atmospheric transmittance factor has been calculated as:

$$T = \frac{E_m}{E_{xt}}, \quad (2)$$

where E_{xt} is the hourly extraterrestrial horizontal irradiation for a particular latitude and E_m is the hourly measured global horizontal irradiation at the same geographical location. Extraterrestrial irradiation has been calculated using the equation (M. Iqbal 1983):

$$E_{xt} = I_0 E_0 (\sin \delta \sin \phi + (24 / \pi) \sin(\pi / 24) \cos \delta \cos \phi \cos \omega_i), \quad (3)$$

where E_0 is the eccentricity correction factor, δ is solar declination, ϕ is the latitude and ω_i is the hour angle at the middle of the hour.

2.3 Correlation of Satellite and Ground Measurement

Satellite derived cloud index and ground based atmospheric transmittance factor are considered to correlate by a linear relationship of the form:

$$T = a \times C + b, \quad (4)$$

where ‘a’ and ‘b’ are the regression coefficients to be determined. The coefficient ‘a’ is greatly influenced by cloudiness conditions, whereas coefficient ‘b’ is more stable than ‘a’.

2.4 Estimation of Radiation

A pyranometer measures radiation with a fine time scale but a particular geographical point,

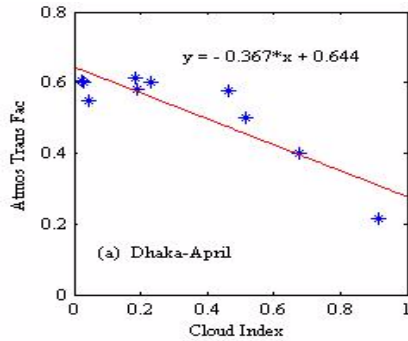


Fig.1. Finding out of regression coefficients using the first data group for station Dhaka, month April-May [first approach].

whereas cloudiness factor from satellite images has a poor time scale (one or two images in a day) but with averaged over a very large area. According to Tarpley (1979) averaging satellite data over a larger area is equivalent to averaging point measurements (pyranometer) over longer time periods. To correlate space based measurement and ground measurement in estimating hourly radiation, atmospheric transmittance factor (T) for the new images has been calculated using Eq.(4). In this study, regression coefficients ‘a’ and ‘b’ are considered constant for a month, it is thus possible to estimate the downward global radiation at a point on the earth’s surface as:

$$E_{st} = T \times E_{xt} \quad (5)$$

3. RESULTS AND DISCUSSIONS

The performance of the method in estimating global solar irradiation has been tested in two ways. In the first approach, the monthly data-set (satellite based cloud index and ground based atmospheric transmission factor) for each station have been divided into two groups. One set of the data has been used to find out the regression coefficients for the month for the station. These coefficients are then applied on the second data set of the same station to estimate irradiation at that station. The selection of data for a particular group has been made by random choice. Fig.1. gives the regression coefficients ‘a’ and ‘b’ obtained from the linear relation of Eq.3. for one case. Here the coefficient ‘a’ represents the slope and ‘b’ represents the intercept of the line. The overall processing for one month at one station (in this case month, April-May and station-Dhaka) has been shown in table-1(a) and 1(b). The performance of the method has been tested by calculating relative deviation, root mean square error (RMSE) and mean bias error (MBE) between the results obtained by means of satellite data and that provided by pyranometer. The same method has been followed to estimate irradiation for the rest of the cases i.e., station Dhaka, month February-March; station Rangamati, month April-May; station Rangamati, month February-March and the results have been summarized as shown in table-2. In this case it is observed that the root mean square deviation between the hourly measured and model estimated radiation for the study period varies between 7.99% and 13.62% and the bias varies between +6.98% and -4.62%.

In the second approach, the regression coefficients (a and b) for each station have been determined using all the data-pairs of the respective stations for a month. These coefficients of one station are then applied on the other station to estimate irradiation for the later station for same month. The accuracy of the model in this case has been shown in table-3 and in

Table-1(a): Dataset for finding regression coefficients of the month April-May for Station Dhaka.

Date (Time)	Extraterrestrial Irradiation	Ground Measured Hourly Irradiation	Atmospheric Transmittance Factor	Cloud Index from Satellite Data	Regression Coefficients	
					a	b
20 April (10:40)	1240.263	495	0.399109	0.675	-0.367	0.644
21 April (10:15)	1192.876	720	0.603583	0.024		
24 April (10:45)	1258.63	693	0.550599	0.042		
26 April (10:00)	1163.437	697	0.599087	0.232		
28 April (11:00)	1275.992	735	0.576022	0.463		
30 April (10:10)	1195.095	600	0.502052	0.516		
7 May (10:45)	1270.962	736	0.579089	0.19		
9 May (10:45)	1263.228	270	0.213738	0.916		
12 May (10:55)	1280.913	770	0.601134	0.028		
16 May (10:40)	1262.291	776	0.614755	0.185		

Table-1(b): Dataset for estimation of radiation of the month April-May for station Dhaka

Date (Time)	Calculation of Atmospheric Transmittance Factor Using Coefficients form table-1(a)	Estimation of Hourly Irradiation	Ground Measured Hourly Irradiation	Calculation of Errors		
				Relative Deviation	Root Mean Square Error (RMSE)	Mean Bias Error (MBE)
19 April (11:00)	0.60547	772.8961	750	0.0305	0.136253	0.069763
25 April (10:20)	0.60547	735.744	790	-0.0687		
4 May (10:10)	0.277	330.8228	280	0.1815		
11 May (11:00)	0.57978	745.0095	605	0.2314		
18 May (10:00)	0.47775	557.1474	572	-0.026		

Fig.2. which present the scatter plots between the ground measured and model estimated irradiation for four cases. In this approach rms error varies from 11.46% to 13.41% and bias from -7.22% to +9.54%.

Biases for the two stations show an opposing trend for the two time periods. In the first approach, when the training and estimation station is same, station-Dhaka shows positive bias

Table-2: Estimation Errors in the form of RMSE and MBE (first approach)

Month	Station	Root mean square error (RMSE)%	Mean bias error (MBE) %
April-May, 2005	Dhaka	13.62	6.98
April-May, 2005	Rangamati	8.13	-4.62
February-March, 2005	Dhaka	7.99	-2.17
February-March, 2005	Rangamati	11.65	4.22

(over estimation) in April-May and negative bias (under estimation) in February-March. On the other hand, station-Rangamati shows positive bias in February-March and negative bias in April-May. In the second approach, when the training and estimation stations are different, station-Dhaka shows positive bias in February-March period and negative bias in April-May period whereas station-

Rangamati shows positive and negative bias in April-May and February-March periods respectively.

Table-3. Evaluation of the method by calculation of errors taking coefficient from other station (2nd approach)

Month	Estimation Station	Using Coefficient From Station	RMSE (%)	MBE (%)
February-March	Dhaka	Rangamati a= -0.3176, b=0.6862, R ² =0.6822	13.41	9.54
February-March	Rangamati	Dhaka a= -0.3927, b=0.6494, R ² =0.9181	12.04	-7.22
April-May	Dhaka	Rangamati a= -0.4909, b=0.6554, R ² =0.69	13.49	-3.95
April-May	Rangamati	Dhaka a= -0.3775, b=0.6401, R ² =0.8085	11.46	1.19

Tarpley (1979) developed a regression technique to estimate daily insolation using GOES satellite data. The standard error in this method was within 10% of the average daily measurement.

Cano et al. (1986) developed an empirical method using METEOSAT satellite for application in Europe for the prediction of hourly global radiation. The average rms error (hourly measurement), for

two different approaches, in this study were 117 Whm⁻² and 67 Whm⁻² respectively.

Islam and Excell (1996) developed a bispectral statistical method for Thailand using data from polar orbiter NOAA APT images. This method suffers from a standard error of 6-19% for daily measurement.

Deneke et al. (2005) applied a physical retrieval method from NOAA-14 satellite data for estimation of irradiation over Netherlands. It was observed that for individual assessment of 30 stations rms error was 86 Wm⁻² and this error was reduced to 33 Wm⁻² when all the stations were averaged.

4. CONCLUSION

A simple statistical method for retrieval of downwelling solar radiation from a polar orbiter satellite data has been presented. The accuracy of the method has been tested in two different approaches. The results thus obtained have been compared with other methods. It is found

that the method's output has reasonably good agreement between the measured and model estimated radiation values.

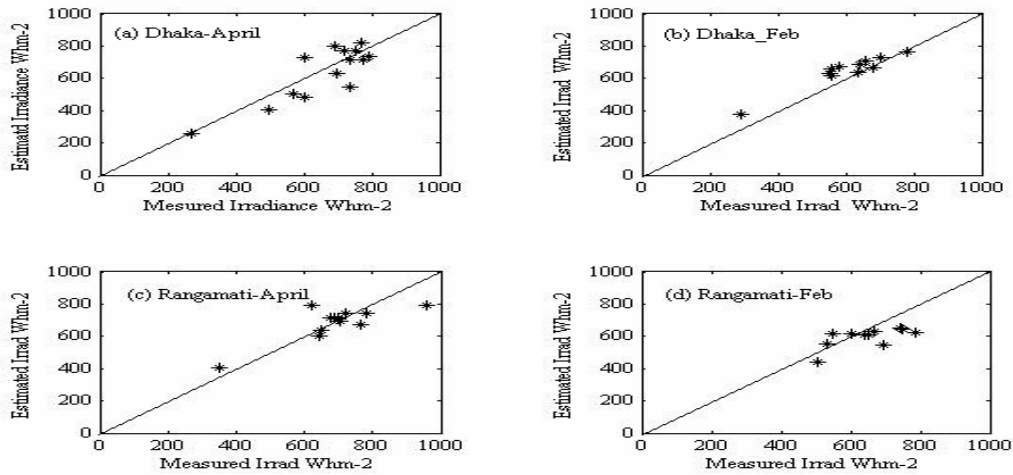


Fig.2. Measured versus estimated hourly irradiation for the two time periods for two stations. (a) Station- Dhaka, Month: April-May (b) Station- Dhaka, Month: February-March (c) Station-Rangamati, Month: April-May and (d) Station-Rangamati, Month: February-March. The diagonal line indicates the perfect agreement between the measured and estimated values.

REFERENCE

- [1] Cano, D., Monget, J.M., Albuissou, M., Guillard, H., Regas, N. and Wald, L., 1986. A method for the determination of global solar radiation from meteorological satellite data. *Solar Energy*, **37**, pp. 31-39.
- [2] Deneke, H. A., Feijt, A., van Lammeren and Simmer, C., 2005. Validation of a physical retrieval scheme of solar surface irradiances from narrow-band satellite radiances. *J. Appl. Meteorol.* **44**, pp. 1453-1466.
- [3] Islam, M.R. and Exell, R.H.B 1996. Solar radiation mapping from satellite image using a low cost system. *Solar Energy*, **56**, (3), pp. 225-237.
- [4] Laine, V., Venalainen, V., Heikinheimo, M. and Hyvarinen, O., 1999. Estimation of Surface Solar global radiation from NOAA AVHRR data in high latitudes. *J. Appl. Meteorol.* **38**, pp. 1706-1719.
- [5] Muhammad Iqbal, 1983. An Introduction to Solar Radiation. Academic Press Canada, pp. 59-84.
- [6] Noia, M., Ratto, C.F. and Festa, R., 1993. Solar radiation estimation from geostationary satellite data-I and II. *Solar Energy*, **51**, pp. 449-465.
- [7] Tarpley, J. D., 1979. Estimating incident solar radiation at the surface from geostationary satellite data. *J. Appl. Meteorol.*, **18**, pp. 1172-1181.