Dhaka Univ. J. Sci. 61(1): 71-74, 2013 (January)

Accuracy Assessment of a Satellite Based Method for Solar Radiation Estimation

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Received on 05. 12. 2011. Accepted for Published on 12. 05. 2012

Abstract

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 digital 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. Accuracy 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 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.

Key Words: Solar Radiation, NOAA-AVHRR, RMSE, Bias error

I. Introduction

The interaction of atmosphere and geo-sphere 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 [1], Noia et al. 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 [2, 3].

II. Operational Method

The method used in this study is a statistical model. The basic idea of the model is that the amount of cloud covering over a given area statistically determines the global solar radiation received by that area. A ground based radiometer (as for example a pyranometer) measures radiation with a fine time scale but over a particular geographical point, whereas satellite based radiometer measures cloudiness over a very large geographical area but having a poor time scale (one or two images in a day). According to Tarpley [4], averaging satellite data over a larger area is equivalent to averaging point measurements (pyranometer) over longer time periods. So the most crucial part for this type of models is to find the proper correlation between space based measurement and ground measurement.

In this study, remote sensing data from sun-synchronous NOAA KLM series of satellites, captured by Bangladesh Space Research and Remote Sensing Organization (SPARRSO), have been used to find the cloudiness. The full resolution (1km) images of NOAA-17 satellite have been duly preprocessed. The preprocessing stages include- data collection and quality checking, selection of satellite radiometer channel, noise removal, geometric correction and image registration, radiometric calibration and conversion of DN values to physical parameters, sun angle effect and sun-earth distance effect correction, preparation of ground reflectance digital layer, preparation of cloud reflectance digital layer etc. These preprocessed 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, have been used in this work to infer the cloud properties. Ground measured pyranometer data, obtained from Bangladesh Meteorological Department (BMD), have been used to obtain the transmission factor of the atmosphere. Taking simultaneous measurements of ground

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based radiometer and satellite based sensor, model coefficients (a,b) have been determined using a regression technique. The method for estimation of incident radiation used in the present study operates in three main steps. In the first step cloud cover index for each point on the satellite image is determined. In the second step model coefficients are derived using regression technique and these coefficients are used in the third step to calculate the irradiation on the earth's surface. Details of the procedure has been described in our previous study [5, 6].

III. Result and Discussion

Accuracy of the method in estimating global solar irradiation has been tested in two ways. In the first approach, monthly data-sets (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 particular 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. The overall processing for one month at one station (in this case month April-May for 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. From the study, it is observed that the root mean square deviation between the hourly measured and model estimated irradiation for the study period varies between 7.99% and 13.62% and the bias varies between +6.98% and -4.62%.

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		
25 April (10:20)	0.60547	735.744	790	-0.0687		
4 May (10:10)	0.277	330.8228	280	0.1815	0.136	0.069
11 May (11:00)	0.57978	745.0095	605	0.2314		
18 May (10:00)	0.47775	557.1474	572	-0.026		

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

In the second approach, 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. Fig 2. presents 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 (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.

Tarpley developed a regression technique to estimate daily insolation using GOES satellite data [4]. The standard error in this method was within 10% of the average daily measurement.

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

Cano et al. developed an empirical method using METEOSAT satellite for application in Europe for the prediction of hourly global radiation [7]. The average rms error (hourly measurement), for two different approaches, in this study were 117 Whm^{-2} and 67 Whm^{-2} respectively.

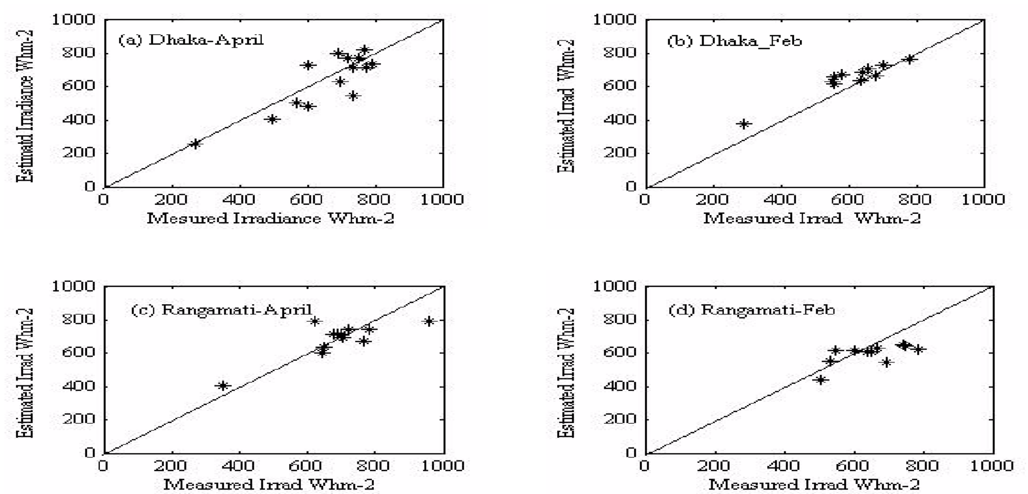

Fig. 2. Measured versus estimated hourly irradiation for the two time periods for two stations. (a) Station- Dhaka, Month: April-May (b) Station- Dhaka, Month: February-March (c) Station-Rangamati, Month: April-May and (d) Station-Rangamati, Month: February-March. The diagonal line indicates the perfect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

Islam and Excell developed a bispectral statistical method for Thailand using data from polar orbiter NOAA APT images [2]. This method suffers from a standard error of 6-19% for daily measurement.

Deneke et al. applied a physical retrieval method from NOAA-14 satellite data for estimation of irradiation over Netherlands [8]. 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.

IV. 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 model output has reasonably good agreement with the measured values.

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