Estimating Solar Radiation at The Earth's Surface from Satellite data

Jongjit Hirunlabh, Rangsit Sarachitti and Pichai Namprakai
Energy Technology Department, School of Energy and Materials,
King Mongkut's University of Technology Thonburi, Bangkok, Thailand.

Abstract

An estimation of solar radiation at the earth's surface using meteorological satellite data is presented. The statistical relationship between insolation and satellite data is based on the energy balance between surface and atmosphere. Daily horizontal global radiation measured from selected ground stations all over Thailand are used. Satellite data used in analysis is albedo which is obtained from NOAA satellites. In other case, station latitudes are also considered. The mean correlation coefficient is 0.65 and the mean standard error is 20 % of the measured mean. Statistical tests showed that most of the relations are significant though the data are somewhat scattered. Finally, it can be summarized that the measured solar radiation and satellite image data are correlated.

Keywords : Solar radiation / Solar atmospheric transmission / Satellite reflectivity measurement / Albedo / NOAA satellites

1. Introduction

Solar energy is an important non-conventional energy source and it has high potential for use as reserve energy in the future. Solar energy can be used in several applications such as solar collector heating system and solar cells system. Knowledge of the solar radiation reaching the earth's surface and its geographical distribution is very important for solar energy and other applications. To design a solar system one needs to know the quantity of incident solar radiation on the system area. At present, solar radiation measuring stations equipped with pyranometers are widely distributed in several regions, but the availability of solar radiation data is limited by the sparsity of the pyranometer network. Because the pyranometers have high cost and need supervision, few stations have this equipment and since the distance between stations is rather far, the available data have low accuracy. Estimation of solar radiation from satellite images is one method that can solve these problems. By considering energy balance, the incident radiation and radiation reflected upward to space are correlated. The statistical relations of these parameters can be used to estimate the potential of solar energy and to design the solar system.

Two types of meteorological satellites monitor the earth's surface and atmosphere conditions continuously. Defined according to the types of orbit, they are called geostationary and polar orbiting satellites. Geostationary satellites are placed on an orbit over the earth's equator at an altitude of about 35,000 kilometers and remain stationary with respect to the earths. The polar orbiting satellites pass over or near the earth's poles. The globe rotates under their orbit.

Two satellites in orbit are considered in this study : NOAA-12 and NOAA-14. They are polar orbiting satellites of National Oceanic and Atmospheric Administration, USA, rotating around the earth at an altitude about 850 kilometers above the surface. NOAA-12 moves from north to south and passes the equator at about 7:30 A.M. and 7:30 P.M. local time. NOAA-14 moves from south to north and passes the equator at about 2:30 A.M. and 2:30 P.M. local time. The data recording system is AVHRR (Advanced Very High Resolution Radiometer). The recorded images are divided into 5 channels.

Channel 1, 0.58 - 0.68 μm (Visible)
Channel 2, 0.725 - 1.10 μm (Near Infrared)
Channel 3, 3.55 - 3.93 μm (Infrared)
Channel 4, 10.3 - 11.3 μm (Thermal Infrared)
Channel 5, 11.5 - 12.5 μm (Thermal Infrared)

The image resolution is 1.1 kilometers at nadir. The image width is about 2,800 kilometers. Each satellite records two images per day. The data can be used to examine cloud temperature, surface temperature, sea surface temperature and vegetable index [1,2].

2. Principle and methodology

The estimation of incident solar radiation from meteorological satellite images is based on the energy balance between earth's surface and atmosphere. The quantities in this model are as follows :

G_O= Extraterrestrial radiation
G_A = Radiation absorbed by the atmosphere
G_G= Radiation absorbed by the surface
G_R = Radiation reflected upward to space
G_S = Incident solar radiation at the surface
A_S = Surface albedo

The extraterrestrial radiation equals the sum of radiation absorbed by the surface, radiation absorbed by the atmosphere and radiation reflected upward to space. It can be expressed by the equation

$$G_O = G_G + G_A + G_R \tag{1}$$

Since the radiation reflected by earth surface is $A_S G_S$ then radiation absorbed by earth surface equals $G_S(1-A_S)$:

$$G_O = G_S(1-A_S) + G_A + G_R \tag{2}$$

Solving for G_S and normalizing G_S by G_O yields

$$\frac{G_S}{G_O} = \frac{1}{(1-A_S)}\left[1 - \frac{G_A}{G_O} - \frac{G_R}{G_O}\right] \tag{3}$$

Supposing that radiation fraction absorbed by the atmosphere and surface albedo are constant throughout the studying period,

$$\frac{G_S}{G_O} = a + b\frac{G_R}{G_O} \tag{4}$$

where $a = (1-G_A/G_O)/(1-A_S)$ and $b = -1/(1-A_S)$ are estimated from the linear regression of G_S/G_O on G_R/G_O. The parameter G_S is measured from ground stations. G_O may easily be calculated from solar constant, declination angle and station latitude [3]. G_S/G_O is called atmospheric transmissivity. And G_R/G_O is earth-atmosphere albedo, A, is measured by satellite.

This method was developed and used by Hay and Hanson [4]. The success of the method depends on the stability of parameters a and b. The physical analysis by Nunez [5] showed that aerosol absorption affected radiation transmission most. The next most significant factors are cloud albedo, water vapor absorption and surface albedo, respectively. If these parameters are constant, equation (4) can be used.

This research was done in Thailand. The studied data periods are from January to December 1995. Daily horizontal global solar radiation measured by 17 ground stations all over Thailand which was obtained from King Mongkut's University of Technology Thonburi and Department of Energy Development and Promotion are used. Table 1 shows the positions of all stations. Only NOAA images of second channel (0.725 - 1.1 μm) are analyzed. GCPs (Ground control points) technique is used to define the correspondence between points in the image and geographical locations. This method is easy, but it is a slow process since it requires human interaction for the recognition of GCPs. Calculation of albedo A in the 0.725 to 1.1 μm window for NOAA images. Assuming that satellite reflectivity fraction in this wavelength corresponds with the transmissivity of solar radiation (0.3 - 3.0 μm) through the atmosphere. It computes by using linear conversion function to convert gray level to be the percent albedo [6,7]. The analysis of data is separated into two cases. The first one is to find the relationship between atmospheric transmissivity and albedo. In the other case, the station latitudes are considered together with the parameters in the preceding form.

Table 1 Location of radiation stations.

Station	Latitude (°N)	Longitude (°E)
Chiang Mai	18.95	98.95
Mae Hong Son	18.19	97.98
Loe	17.90	101.65
Nong Khai	17.88	102.72
Sakhon Nakhon	17.15	104.14
Mukdahan	16.53	104.72
Khon Kaen	16.33	102.85
Nakhon Sawan	15.68	100.14
Si Sa Ket	15.31	104.21
Ubon Ratchathani	15.22	104.86
Nakhon Ratchasima	15.08	102.12
Kanchanaburi	14.75	98.64
Bangkok	13.73	100.57
Chachoengsao	13.67	101.22
Prachuap Khiri Khan	11.83	99.83
Ranong	9.98	98.62
Surat Thani	9.47	100.07

3. Results and discussion

The analyzed relationships between atmospheric transmissivity and albedo are shown in table 2. Because of having few satellite images, data from all ground stations are analyzed without considering the station positions. From table 2, the coefficients b are negative. The results have low correlation because few data are available and the geography and position of each station is neglected. By statistical test, the results of January, February, June, July, August, October, November and December have significant meanings. So it can be concluded that the atmospheric transmission correlates with albedo. If sufficient data are used and unmixed between stations, better correlations will be received. Figure 1 and 2 show relations of atmospheric transmissivity and albedo in June and August, respectively.

In addition, the following is another model in which latitude of ground stations is considered :

$$\frac{G_S}{G_O} = a + bA + c\phi \qquad (5)$$

where ϕ is latitude and a,b,c are regression coefficients. The results shown in table 3 for January, February, June, July, August, October and November are significant. Compared with the first form, the correlation coefficients increase a little but the standard errors are nearly equal. The number of significant months is less than the first results. From a statistical point of view, it is possible that position of stations may affect the relations less. More data should be added before making a conclusion. However, equation (4) is more appropriate than equation (5) to estimate solar radiation.

Table 2 Relations of daily atmospheric transmissivity and albedo for each month.

Month	a	b	Correlation coefficient	Standard error	Average G_S/G_O	Number of observations
January	0.6024	-0.0594	0.7225	0.1287	0.4125	13
February	0.5413	-0.0237	0.6421	0.0728	0.4324	13
March	0.6912	-0.0318	0.5543	0.0585	0.5140	11
April	0.8049	-0.0196	0.4950	0.1208	0.5027	16
May	0.5862	-0.0216	0.4984	0.1049	0.4260	14
June	0.6486	-0.0114	0.7585	0.0734	0.3709	12
July	0.5294	-0.0047	0.6271	0.0989	0.3604	16
August	0.6740	-0.0118	0.7003	0.0630	0.4082	13
October	0.8405	-0.0244	0.6966	0.0875	0.4309	14
November	0.6315	-0.0113	0.8354	0.0736	0.4503	17
December	0.7143	-0.0160	0.5979	0.1113	0.4890	13

Remark : The data for September is the worst so it is not shown.

Table 3 Relations of daily atmospheric transmissivity, albedo and latitude for each month.

Month	a	b	c	Correlation coefficient	Standard error	Average G_S/G_O
January	1.0293	-0.0766	-0.0243	0.7747	0.1235	0.4125
February	0.6982	-0.0198	-0.0114	0.7103	0.0701	0.4324
March	0.8375	-0.0252	-0.0119	0.6324	0.0577	0.5140
April	1.0016	-0.0104	-0.0219	0.5952	0.1160	0.5027
May	0.8169	-0.0179	-0.0169	0.6005	0.1011	0.4260
June	0.7516	-0.0113	-0.0066	0.7686	0.0759	0.3709
July	0.4611	-0.0049	0.0049	0.6367	0.1016	0.3604
August	0.7711	-0.0096	-0.0095	0.7518	0.0610	0.4082
October	0.8048	-0.0247	0.0028	0.6999	0.0910	0.4309
November	0.5168	-0.0102	0.0064	0.8427	0.0746	0.4503
December	0.9617	-0.0203	-0.0127	0.6417	0.1117	0.4890

4. Conclusion

The analyzed relationships of the measured solar radiation and satellite images show that most of the relations are significant. So the relationships are validated. However, the data are highly scattered because few satellite images and no geographical data are used. In addition, data measured by pyranometers may have some errors. It may be concluded that albedo derived from satellite data and incident radiation on earth's surface are correlated.

5. References

[1] Lillesand, T.M. and Kiefer, R.W. (1994), Remote Sensing and Image Interpretation, John Wiley & Sons, New York.

[2] Richards, J.A. (1986), Remote Sensing Digital Image Analysis; An Introduction, Springer-Verlag, Berlin.

[3] Duffie, J.A. and Beckman, W.A.. (1980), Solar Engineering of Thermal Processes, John Wiley & Sons, New York.

[4] Hay, J.E. and Hanson, K.J. (1978), A Satellite-Based Methodology for Determining Solar Irradiance at the Ocean Surface during GATE, Bulletin of the American Meteorological Society, Vol.59.

[5] Nunez, M. (1983), Use of Satellite Data in Regional Mapping of Solar Radiation. In Szokology, S.V., Solar World Congress, Vol.4, The International Solar Energy Society Congress, Perth.

[6] Islam, Md.R. and Exell, R.H.B. (1993), Operational Mapping of Solar Radiation at the Ground Using NOAA APT Images with a Low Cost System, D.Eng. Dissertation, Asian Institute of Technology.

[7] NOAA (1994), NOAA Technical Memorandum 107, Appendix-B for NOAA-J/14.

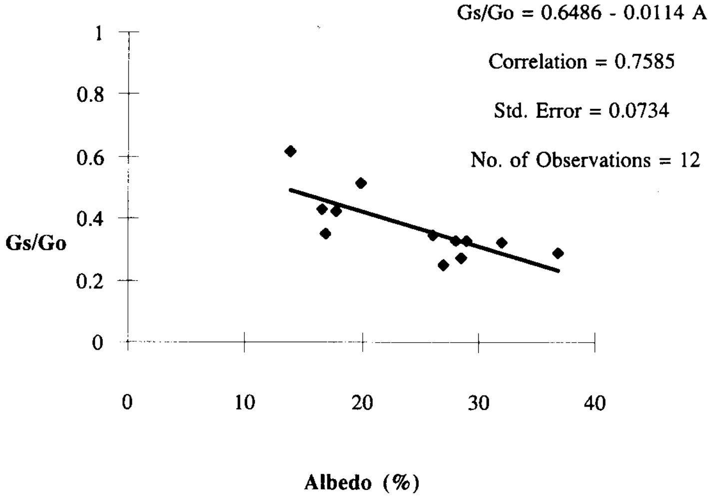

Figure 1. Relationship between atmospheric transmissivity and albedo in June.

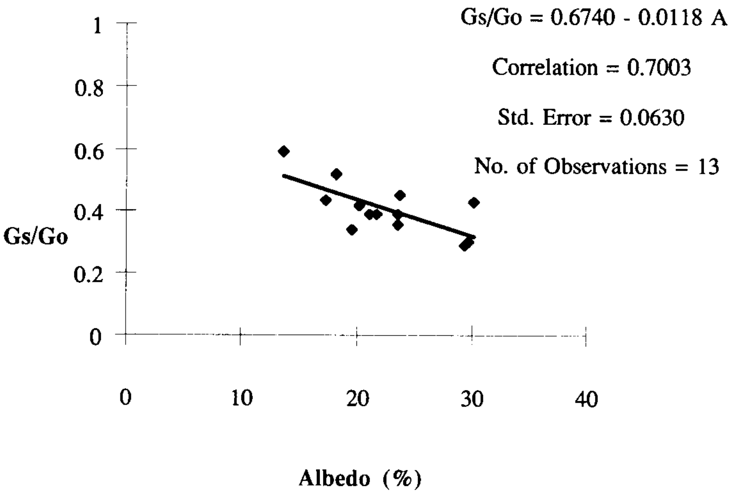

Figure 2. Relationship between atmospheric transmissivity and albedo in August.