EVALUATION OF STATISTICAL APPROACH MODEL FOR DERIVING GLOBAL SOLAR RADIATION FROM NOAA SATELLITE IMAGES IN SOUTHEAST OF TEHRAN

EVALUATION DU MODELE D'APPROCHE STATISTIQUE POUR DERIVER DU RAYONNEMENT SOLAIRE GLOBAL DES IMAGES SATELLITAIRES DE LA NOAA AU SUD-EST DE TEHERAN

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ABSTRACT

The global solar radiation is an input required for studies on water resources, environment and agriculture. However, this parameter can be measured only at a few places. This has led researchers to develop a number of methods for simulation to estimate solar radiation. In this study, the remote sensing statistical approach for determining global solar radiation from NOAA-AVHRR satellite data was calibrated and evaluated in southeast of Tehran. This approach is based on the linear correlation between a satellite derived cloud index and the atmospheric transmission measured by the clearness index at the ground. The results of this study showed that statistical model with good accuracy estimated the solar radiation with an R2 of 0.86 and a root mean square error (RMSE) of 8.9 percent.

Key words: *Satellites images, global solar radiation, albedo, remote sensing, statical approach.*

RÉSUMÉ ET CONCLUSIONS

Le rayonnement solaire global (Rs) est un des paramètres les plus importants dans les modèles de balance d'énergie, croissance d'équipement et modèles d'evapotranspiration et le potentiel. Bien que ce soit un paramètre très important, sa mesure est limitée et cette faute est vue tant dans le développement que dans les pays développés. Son appareil de

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mesure est si cher et sensible, il devrait donc être régulièrement calibré. C'est pour pourquoi ce paramètre est restrictedly considéré dans la plupart des pays. Cela a mené des chercheurs à développer un certain nombre de méthodes pour estimer le rayonnement solaire basé sur les dossiers météorologiques souvent disponibles comme les heures de soleil ou de température aérienne. Au cours des dernières années, les modèles détectants lointains tirant leurs données d'entrée des images satellites sont utilisés pour déterminer quelques phénomènes. L'avantage d'images satellites consiste en ce que radious prolongé de surface de terre est couvert, dorénavant le déplacement de phénomènes pourrait être enquêté. Mais la plupart de ces phénomènes comme le rayonnement solaire global ne sont pas enquêtés par les satellites directement, donc les modèles avec les données d'entrée adaptées au satellite devraient être conçus et compilés. Les modèles employés pour estimer le rayonnement solaire global de surface des données satellites peuvent essentiellement être divisés dans à deux catégories : statistique (ou empirique), qui se composent d'établir un rapport entre les données satellites et les mesures faites sur la surface et physique (ou théorique), qui profitent des modèles de transfert radiatifs pour rattacher les données satellites avec les mesures de surface. Cette méthode est exacte, mais jouer il exige de différentes couches d'information de l'atmosphère qui sont préparées avec radiosounds transmis au ciel et ils sont limités. Faites une demande le coefficient d'atmosphère de rayonnement solaire extraterrestre est la voie qui utilisent les modèles expérimentaux. Un des objectifs de cette recherche est de reconsidérer les images de ce satellite pour déterminer l'incident de rayonnement solaire sur la surface de terre en utilisant la corrélation statistique du fait de détecter lointain pour une de région Iranienne. Dans cette étude, l'approche statistique détectante lointaine pour déterminer le rayonnement solaire global des données satellites NOAA\AVHRR a été calibrée et évaluée dans au sud-est de Tehran. Cette approche est fondée sur la corrélation linéaire entre l'index de nuage tiré d'un satellite et la transmission atmosphérique mesurée par l'index de clarté à la terre. Dans cette étude, ces données avec l'unité de w/m2 selon les temps d'images utilisées ont été extraites dans cette étude et ont été utilisées pour évaluer et examiner les modèles. La période d'étude de ce papier était de l'octobre de 2005 au décembre de 2008 et pendant ce temps 642 images ont été tirées du site Internet satellite Noaa qui a couvert la station météorologique Aboureyhan. Chaque fichier vidéo de satellite Noaa inclut des nombres numériques de pixels, coefficient d'étalonnage et une série d'ensemble de points de contrôle sol et de satellite orbital. Le coefficient d'étalonnage est utilisé pour convertir des nombres numériques de canaux visibles 1 et 2 à l'Albédo exprimé dans le pour cent et pour convertir des canaux de 3,4,5 dans la température exprimée dans le degré de Kelvin et montre la coordonnée pour les corrections géométriques d'images. Les résultats de cette étude ont montré que le modèle de rétrogradation linéaire multiple a estimé que le rayonnement solaire avec un R2 de 0.93 et une racine signifie que l'erreur carrée (RMSE) de 5.8 pour cent a estimé le rayonnement solaire global mieux que l'approche statistique.

Mots clés: *Images satellitaires, rayonement solaire global, albédo, télédétection, approache statistique.*

1. INTRODUCTION

Global solar radiation (R_s) is one of the most important parameters in the models of energy balance, plant growth and potential evapotranspiration. However, its measurement is limited in both developing and developed countries (Samani 2000). This is because of the very high cost of the measuring instruments and their sensitivity making it necessary to regularly calibrate them.

The global solar radiation incident at a level above the atmosphere is the extraterrestrial solar radiation (R_a) and it depends on the latitude, season and inter-annual variability and is studied analytically. The radiation passing through the atmosphere and reaching the surface of the earth (R_n) is influenced by atmospheric attenuation and depends on the cloudiness and humidity which is a complicated process. Generally, R_n in a clear weather is about 75% of R_a and in quite cloudy weather it is about 25% of R_a (Allen.et.al 1998).

In general, simulation and experimental methods are presented to determine the atmospheric attenution effects and global solar radiation. In simulation method, the effect of high levels of the atmosphere attenution to the ground, is analyzed physically and global solar radiation is determined by solving it (Trnka.et.al 2005). This method is accurate, but to perform it requires different information layers of the atmosphere, which are prepared with radiosounds transmitted to the sky and they are limited in application. Applying a coefficient to R_a is the way that the experimental models use to estimate R_n. This coefficient is determined based on the parameters indicating the weather cloudiness, daily sunshine hours and the difference between daily maximum and minimum air temperature (Trnka.et.al 2005). This model is useful in the meteorological station.

In recent years, satellite remote sensing data on attributes influenced by radiation are processed to indirectly estimate radiation. The advantage of satellite images is that an extended radius of ground surface is covered, hence the displacement of phenomena could be investigated. Most of the satellite sensor data include reflection of visible spectrum near and thermal infrared from top surface of atmosphere and beyond it.

The remote sensing models for determining solar radiation are based on linear regression between cloud index derived from visible spectrum data of satellite images and clearness index measured in meteorological station (Beyer.et.al 1996). Hence if correlation equation between these two indexes for each region is certain, by cloud index calculated for each pixel of satellite images, solar radiation received by that region is determined.

Based on statistical approach, it is assumed that the reflection or albedo from sea and ground surface to the top part of the atmosphere which is read by satellite sensor is less than cloud albedo. Therefore an increase in albedo yields an increase in cloudiness. In other words, in this approach it is assumed that albedo variation of any pixel is derived from cloudiness variations and these variations coverage of vegetation and soil moisture, which influence albedo in different seasons are constant. This approach was examined in different areas and regions of Europe by Geostationary Meteosat satellite image and percentage of error between 12 and 32 percent were estimated (Beyer.et.al 1996, Mefti.et.al 2008 and Zarzalejo.et.al 2009). Iran is not covered by this satellite, but Noaa satellite which is a type of sun synchronous satellite scans the earth twice in 24 hours and covers Iran.

One of the objectives of this research is to review the images of this satellite to determine the solar radiation incident on the earth surface by using statistical correlation of remote sensing data for one of Iranian areas. Comparison of the results of the above mentioned models as well as the results derived from research studies in some areas of Europe is the other purpose of this study.

2. MATERIALS AND METHODS

2.1 The study region and solar radiation data

Automatic meteorological station Pardis Aboureyhan of Tehran University in the geographic location of Pakdasht, is located on 51° 41′ of East longitude and 35° 28′ North latitude at an altitude of 1020 meters amsl. The station was developed in October 2005 and the global solar radiation is measured instantaneously and then the average of them is recorded at 10-minute intervals. Pakdasht region is one of the most important agricultural areas in South East of Tehran. It is a semi-arid region with an average rainfall of 230 mm and evaporation of 1390 mm in a year. In this study, the radiation data in the unit w/m^2 were extracted and were used for evaluating and examining the models.

2.2 NOAA satellite data

AVHRR sensor of NOAA satellite measures the reflected and diffused radiation from the earth surface in 5 channels. These channels include: visible channels (0.56-0.68 µm), near infrared (0.725-1.10 µm), middle infrared (3.55-3.98 µm) and two thermal infrared (10.3-11.3 µm). The spatial resolution (pixel dimensions) of Noaa satellite images is about 1.1 km at nadir point for all channels. This satellite photographs a region twice a day (once at day time and once at night).

The present study period was from October 2005 to December 2008, and during this time 642 images were derived from Noaa satellite website which covered the Aboureyhan meteorological station. The transition time of the images is from 11.5 AM to 1.5 PM in Iran. The number of used images in every month of the mentioned data is presented in Table 1.

Each image file of Noaa satellite includes digital numbers of pixels, calibration coefficient and a series of coordinates of ground control points and orbital satellite. The calibration coefficient is used for converting digital numbers of visible channels 1 and 2 to the Albedo expressed in percent and for converting channels of 3, 4, 5 into the temperature expressed in ^{0}K and points coordinate for geometric corrections of images.

The albedo value depends on the angle of solar irradiance and the angle changes during different hours and days. In remote sensing statistical models for determining global solar radiation, Albedo is normalized to solar zenith angle so that albedo changes indicate the variation in cloudiness cover. In this paper, The ENV software version 4/2 was used for the processes mentioned above such as digital numbers calibration, geometric corrections of images and albedo normalization of 1 and 2 channels.

The calibrated and normalized values of 1 and 2 channels (B_1 and B_2), the mentioned angle above and 3, 4 and 5 channels (B_3, B_4 and B_5) in window 3×3 pixel dimension, at the center of which Aboureyhan meteorological station was located, were extracted and their average was used.

In this paper, the data of the years 2005-2007 were used for calibration and indicating the coefficient of statistical models and multiple correlation model and the data of the year 2008 were used as the validation data for evaluating models and coefficients.

Table 1. The number of used images in this study in every month of the 2005-2008 (Le nombre d'images utilisées dans cette étude dans chaque mois des 2005-2008)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	-	-	-	-	-	-	-	-	-	22	17	12
2006	16	15	15	21	18	21	24	17	24	14	15	13
2007	13	6	14	16	15	26	13	19	27	27	17	13
2008	6	15	15	20	19	24	25	4	8	16	19	1

3.2 Statistical methods of remote sensing for determining solar radiation

The statistical method consists of assuming a linear regression between the cloud-cover index per any pixel and clearness index of the studied area as:

$$k = a.n + b \qquad (1)$$

Where, K is the clearness index of the studied area, n is the cloud-cover index in each pixel, a and b are the experimental coefficients of the region.

The clearness index is defined as ratio of the solar radiation reaching the ground to extraterrestrial solar radiation (R_s/R_a) and this is measured in ground weather station. In this study, global solar radiation was extracted for each image through pass of satellite time from recorded data in Aboureyhan by meteorological station. The extraterrestrial solar radiation is function of year calendar, latitude and pass of satellite time and in this paper, this is evaluated by using the analytic relation of Allen et al, (1998).

The cloud-cover index of each pixel is calculated by using the satellite images as follows (Beyer.et.al 1996, Mefti.et.al 2008 and Zarzalejo.et.al 2009):

$$n = \frac{\rho - \rho_g}{\rho_c - \rho_g} \qquad (2)$$

Where ρ is the measured albedo by satellite sensor in visible band, ρ_g is the earth surface albedo, ρ_c is the compact cloud albedo, and all of the above parameters are expressed in the unit of percent. In statistical approach, it is assumed that albedo measured by sensor is equal to the earth surface albedo in clear atmosphere conditions. This albedo (ρ_g) is an exclusive and unique digit for each pixle and has the lowest value among a multi-year time series of satellite images. On the other hand, the compact cloud has the most value of albedo and for determining it, all of the images of cloud pixels of the region are studied, and the largest albedo is chosen for ρ_c.

According to equation 1, if a and b coefficients are known for the region, the global solar radiation per each pixel is:

$$R_s = R_a(a.n + b) \qquad (3)$$

The scattering of the cloud and clearness indexes is drawn by using the data of 2005-2007 at Aboureyhan meteorological station and then best line among these points has been fitted based on least squares method.

The slope and latitude of this line is the calibrated coefficients in equation 3 (a,b coefficient) for the pixel in which Aboureyhan meteorological station is located. For evaluating these coefficients and equation 3, the solar radiation reaching the ground is measured from the 2008 data and is compared with the measured values.

Statistical indexes

In this study, in addition to diagram, two statistical indexes of determination coefficient (R^2) and root mean square error (RMSE) were used to analyze the results. The determination coefficient represents the nearness rate of model estimations with the real values. This coefficient is calculated as a decimal number and its maximum is one. The RMSE is calculated as a percentage that shows the value error of the model evaluation with actual values. This index has been used by other researchers in this field and therefore the possibility of using results obtained from this study to compare their results is provided.

3. RESULTS AND DISCUSSION

All the data of one channel albedo related to Aboureyhan meteorological station pixel derived from Noaa satellite were arranged at an interval from October 2005 to Dec 2008 and the minimum value of them was 12.2 percent. This value was selected as the earth surface albedo (ρ_g) based on the assumptions of statistical model. All images used within this study were reviewed in the study region and a maximum albedo of channel 1 is 93.4 percent which is used as compact cloud albedo (ρ_c) in equation1. Using two values of ρ_g and ρ_c, the scattering of cloud and clearness indexes are presented for examination data model in Figure 1. It could be seen that most of the points are in the range of conditions in which the weather is almost clear, as the cloud index is between zero and 0.2 and the clearness index is between 0.6 to 0.8. The R^2 of the linear equation between the two above indexes is evaluated as about 0.58 which shows that just using one visible channel of NOAA satellite explains about 58 percent of the clearness index changes. The latitude and slope of the correlation equation which provide the coefficients of the equation 3 are 0.78 and - 0.44, respectively.

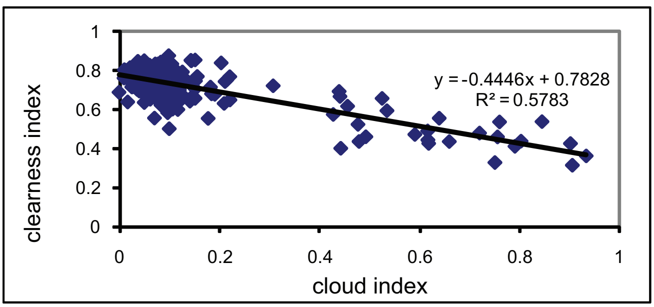

Fig. 1. The scattering of cloud and clearness indexes for Aboureyhan station from Oct 2005 to Dec 2007(Le fait de disperser de nuage et d'index de clarté pour la station Aboureyhande l'octobre de 2005 au décembre de 2007)

So the calibrated equation of statistical approach for the pixel dedicated to Aboureyhan station is:

$$R_s = R_a\,(-0.44.n + 0.78) \qquad (4)$$

For evaluating this equation, the global solar radiation is estimated by using the data of 2008 and it was compared with the measured actual data at Aboureyhan station. The scattering of the estimated and measured actual points with the best fitting line and the statistical indexes are presented in Figure 2. As may be seen, the R^2 and the RMSE of equation 4 for evaluation data are 0.86 and 9 percent, respectively. This value shows that around 86 percent of global solar radiation variation is justified by using the two parameters of cloud index which are derived from NOAA satellite channel 1 and extraterrestrial radiation. The important feature in this Figure is the uniform distribution of points around correlation line.

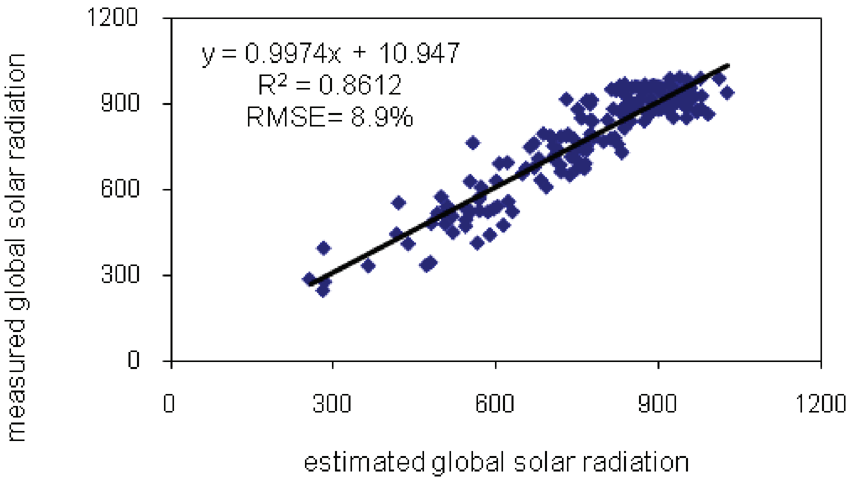

Fig. 2. The scattering estimated and measured of global solar radiation(w/m^2) Statistical model (Le fait de disperser estimé et mesuré du rayonnement solaire global (w/m^2) le modèle Statistique)

Comparison of the results of this study with European area results

The results of this review were compared with results of other similar research that used statistical regression model between the cloud and clearness indexes, and the summary is presented in Table 2. There is less error in value between the results of this study and the results of other researchers. The reason may be due to different cloud types and different atmospheric conditions between Europe and Iran and by the way different types of satellites which were used in remote sensing approach.

As was evident in Figure 2, weather is clear and without clouds in most days at the station used within this study. But the number of cloudy days in the European areas is much more than in Iran.

Table 2. Comparsion between the results of this study and the results of Eroupean countries(Comparsion entre les résultats de cette étude et des résultats de pays Eroupean)

Researcher	Used satellite	Country	Method	RMSE(%)
Beyer et al.	Geostationary Meteosat	Germany	statistical	20
Zarzalejo	Geostationary Meteosat	Spain	statistical	17
Mefti	Geostationary Meteosat	French	statistical	12-32
Present research	NOAA	Iran	statistical	8.9

4. CONCLUSIONS

In this study, the remote sensing statistical approach was evaluated for determining global solar radiation. The percent error in this method as compared to the values in European countries by using meteosat satellite is between 12 to 32 percent. The error in this method in the southeast of Tehran by using NOAA satellite was evaluated as about 9 percent which is about 25-72 percent less than that in the European regions. The reason may be due to the difference in atmospheric conditions between Europe and Iran or satellite types which are used, but more research in this field is needed.

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