Daily Global Solar Radiation Based on MODIS Products: The Case Study of ADRAR Region (Algeria)

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Abstract. The Measurements of the solar radiation is important in choosing sites to install projects with solar systems. Adrar region is classified from the high potential solar areas in the world. In this study, we using the atmospheric products of satellite MODIS (Moderate Resolution Imaging Spectroradiometer) and bird model to estimate global solar radiation. The results of estimation were validated with observed data of Adrar station (lat = 36.6, lon = 028). The correlation is very significant and the linear correlation coefficient between estimated and measured values of global solar radiation equal 0.78.

Keywords: Global solar radiation · Satellite MODIS · Bird model · Estimated value · Measured value · Correlation

1 Introduction

The Measurements of the solar radiation is important in choosing sites to install projects with solar systems. the availability of measurements of observed solar radiation has proven spatially and temporally inadequate for many applications [1]. Many approaches were proposed to estimate surface irradiance using satellite measurements, geostationary and polar satellite. Taking advantage of the high spatial-temporal resolutions of this type of data, which being the best option for constructing accurate estimation of the variability of radiation at high spatial resolution.

The most important methods were summarized and reviewed in several studies [2–4].

MODIS sensors aboard the Terra and Aqua satellite platforms, is combined to derive daily integrated PAR and mapped to a local coordinate system. The results was Compared to field observations [5].

Wang et al. [6] with products from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor implemented a model at one kilometer spatial resolution. The derived surface fluxes are evaluated against the globally distributed Baseline Surface Radiation Network (BSRN) measurements and compared with products from independent sources.

Porfirio et al. present a method for estimating Direct Normal Irradiance and daily direct normal irradiation that uses a minimal set of regional meteorological information

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and avoids empirical adjustment with ground-based radiometric data [7]. A model to estimate global solar radiation under cloudless conditions is presented. Atmospheric perceptible water vapour content is the only experimental inputs to the model [8]. In other study, instantaneous solar irradiances on a horizontal surface at 10:30 and 13:30 local time (LT) were calculated from Moderate Resolution Imaging Spectroradiometer (MODIS) atmospheric data products with relatively high spatial resolution using a solar radiation model [9]. In order to estimates daily Surface shortwave net radiation, Wang et al. combined Terra and Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) data [10]. The results were validated against measurements at seven stations of the Surface Radiation Budget Network.

Houborg et al. [11] presents a satellite-based scheme for the retrieval of all-sky solar irradiance components, which links a physically based clear-sky model with a neural network version of a rigorous radiative transfer model. The scheme exploits the improved cloud characterization and retrieval capabilities of the MODerate resolution Imaging Spectroradiometer (MODIS), and employs a cloud motion tracking scheme for the production of hourly solar irradiance data throughout the day. An algorithm was developed to calculate surface PAR by combining a clear-sky PAR model and the parameterizations for cloud transmittances. In the algorithm, the transmittances for water vapor, ozone, Rayleigh, aerosol, and cloud are each handled across the whole PAR band (400–700 nm) [12].

Artificial neural network (ANN) is utilized to build the mathematical relationship between measured monthly-mean daily GSR and several high-level remote sensing products available for the public [13].

In this study daily mean solar radiation is estimated using Moderate resolution Imaging Spectroradiometer (MODIS) satellite data. The Bird model was used to derive the solar radiation reaching the Earth's surface in clear skies condition. MODIS data sets are freely available via the MODIS webservice tool. The spatial resolution of this data varies by band from 250 m to 1 km. in this study the data used has a spatial resolution of 1 km. The model is classified into the best and the results confirmed the good performance of the proposed model.

2 Data and Method

2.1 Model

In order to calculate instantaneous solar irradiances at overpass times of satellite MODIS on horizontal surface we using Bird model. With this model we calculated the direct and diffuse radiation [14–16].

Direct irradiance (I_b, W/m^2)

$$I_b = I_{sc} \times \cos(\theta) \times T_r \times T_a \times T_w \times T_o \times T_u / E_r \tag{1}$$

$$T_r = exp\left\{-0.0903 \times (m')^{0.84} \times \left(1 + m' - (m')^{1.01}\right)\right\} \tag{2}$$

$$T_a = exp\left\{-\tau_A^{0.873} \times \left(1 + \tau_A - \tau_A^{0.7088}\right) \times m^{0.9108}\right\} \quad (3)$$

$$\tau_A = 0.2758 \times \tau_{A0.38} + 0.35 \times \tau_{A0.50} \quad (4)$$

$$T_w = 1 - 2.4959 \times w \times m \times \left[(1 + 79.034 \times w \times m)^{0.6828} + 6.385 \times w \times m\right]^{-1} \quad (5)$$

$$T_o = 1 - 0.1611 \times O_3 \times m \times (1 + 139.48 \times O_3 + m)^{-0.3035} - 0.002715$$
$$\times \left[1 + 0.044 \times O_3 \times m + 0.0003 + 6.385 \times (O_3 \times m)^2\right]^{-1} \quad (6)$$

$$T_u = exp\left\{-0.0127 \times (m')^{0.26}\right\} \quad (7)$$

Where

I_{sc} solar constant equal 1366.1 w/m^2,
θ solar zenith angle (in degrees)
T_r transmittance of Rayleigh scattering,
T_u transmittance of absorptance of mixed gases,
T_w transmittance of water vapor absorption,
T_o transmittance of ozone absorption
T_a transmittance of aerosol absorptance and scattering
E_r the correction factor for the earth-sun distance
m is the relative air mass and m' is the pressure-corrected air mass.
O_3 is the ozone amount (atm-cm). w is the amount of precipitable water in a certical column from the surface (cm)

Diffuse irradiance (Is, W/m^2)

$$I_s = I_{as} + I_G \quad (8)$$

$$I_{as} = I_{sc} \times \cos(\theta) \times T_o \times T_u \times T_w \times T_{AA} \times \frac{[0.5 \times (1 - T_r) + B_a \times (1 - T_a/T_{AA})]}{\left[1 - m + (m)^{1.02}\right]/E_R} \quad (9)$$

$$T_{AA} = 1 - K_1 \times \left(1 - m + m^{1.06}\right) \times (1 - T_a) \quad (10)$$

$$I_G = r_g \times r_s \times (I_b + I_{as})/\left(1 - r_g \times r\right) \quad (11)$$

$$r_s = 0.0685 + (1 - B_a) \times (1 - T_{as}) \quad (12)$$

$$T_{as} = 10^{-0.045 \times (m')^{0.7}} \quad (13)$$

$$Q_b = I_b \times (1 - TCF) \tag{14}$$

$$Q_s = I_s \times (1 - TCF) + C \times K \times TCF \times (I_b + I_s) \tag{15}$$

$$C = \begin{cases} 1, TCF < 0.95 \\ exp(-0.03 \times P_p \times t), TCF \geq 0.95 \end{cases} \tag{16}$$

$$Q_g = Q_b + Q_s \tag{17}$$

Where,

I_{as} is the atmospheric scattering of diffuse irradiance (w/m^2)
I_G the solar irradiance under clear sky.
T_{AA} is the transmittance of aerosol absorptance, $B_a = 0.84$
r_g is the ground albedo, r_s the sky albedo, T_{as} is the transmittance of dry air absorptance and scattering.
TCF is the total cloud fraction.

The Global solar radiation Q_g is the sum of direct and diffuse irradiances on horizontal surface under real conditions.

2.2 Data

The ground measurements of global solar radiation used in this study are obtained from pyranometers recorded in Adrar Site (27.88°N, 0.28°W), possessed and maintained by the Renewable Energy Research Unit in Saharian Medium (Table 1).

Table 1. Geographic and data records period of the studied station.

Station	Adrar
Latitude (°N)	27.88
Longitude (°E)	−0.27
Elevation (m)	269
Data series period	2010–2015
Mean GH (MJ/m^2.day)	6.89

Bird model used in this study requires many input data, including mod05_l2 (MODIS Atmosphere level 2 precipitation water vapor product), mod06_l2 (MODIS Atmosphere level 2 cloud product) and mod07_l2(MODIS Atmosphere profile product).

These products data contains the needed inputs for the model. The first product is using to obtain the values of: the amount of precipitation water in a vertical column from the surface, latitude and longitude. From the second product we acquire the total cloud fraction (TCF), solar zenith angle, solar azimuth and land surface elevation. And from the third we acquire the ozone amount.

In order to facilitate the calculation, because in Adrar region there is no change in ground situation over the year, so the ground albedo accept mean value equal 3.2 in all time of the year.

2.3 Data Measurement

The estimated global solar radiations are validated by comparing with ground measurements recorded in URERMS station, adrar region. In this study the data from January to December 2016 are used. In this station the data recorded hourly, but we need only the values in the time of overpass of the satellite in the pixel ***STRUCTURE OF THE TEXT***

3 Results and Discussion

Modis data products are downloaded and registered. The global solar radiation calculated in four steps summarized in (Fig. 1).

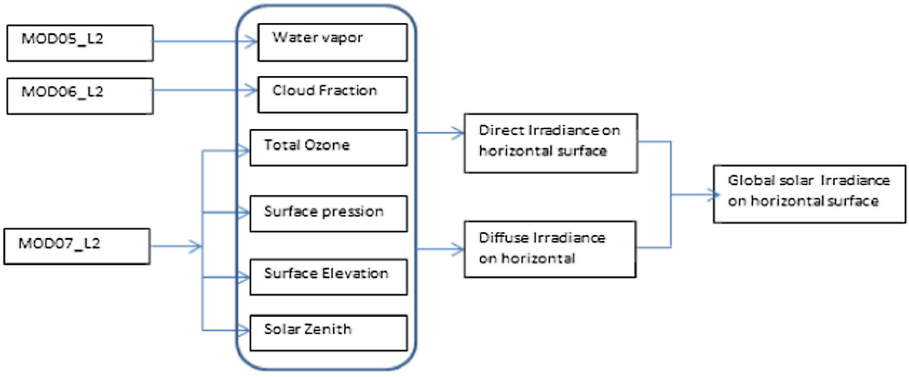

Fig. 1. Estimation of global solar radiation using MODIS products

A time series of instantaneous global solar radiation form 2016 year are estimated at one kilometer resolution. Some pixels presents well value of global soar radiation but others accept extremes values.

The validation results are presented in the scatter plot in (Fig. 2).

To deepen this validation the linear correlation coefficient between estimated and measured values equal 0.7863 so, the correlation between instantaneous solar radiation is generally significant.

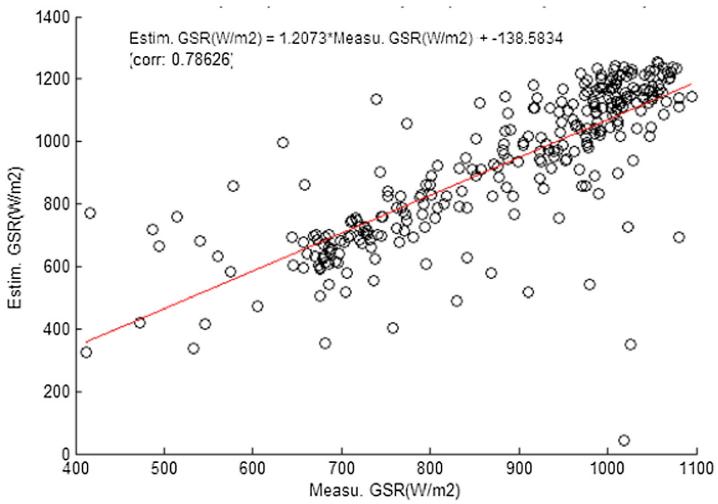

Fig. 2. Correlation between estimated and measured values of global solar radiation in Adrar station year 2016.

3.1 Conclusion

This study proposes a simplified model to estimate daily global solar radiation form the polar satellite images, especially the MODIS data products.

The model proposed in this study allows estimating global solar radiation instantaneously using MODIS Atmospheric Profiles product. This method provides global solar radiation estimates at one kilometre spatial resolution.

Using MODIS data products, offers advantage of freely and available data; which are widely used and continuously improved.

In our study, the model is evaluated using one year of global solar radiation measurements at Adrar site.

The correlation between estimate and measured values of global solar radiation is very significant, but some pixels in different period present extremes values. May be the inputs data require some corrections. The linear correlation coefficient equal 0.78.

The experimental results demonstrate that this model is applicable for estimating daily global solar radiation from polar satellite observations with acceptable performance.

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