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The solar radiation evaluation by satellite images processing

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Abstract. To evaluate the global solar irradiation flux received at the ground surface for Algeria, an analytical model is implemented by processing satellite images and solving the equation of radiative transfer. This model is derived from that initially worked out by C. Gautier *et al.* in 1980 using high-resolution Goes images. We get that it is well adapted to the processing of lesser resolution images such as those collected by Meteosat 2 following the B2 format. The data base under study mainly consists of clear-sky B2 Meteosat images recorded every three hours in the visible channel (i.e., [0.4 – 1.1 µm]) during the 1986/87 period and representing North Africa and Southern Europe. Hourly and daily global solar irradiation fluxes received at the ground on a horizontal surface have therefore been evaluated by applying the analytical model to the Meteosat images. The obtained results were compared to the hourly ground solar measurements recorded in the radiometric stations of Bouzareah (Algiers) and Oran during the 1986/87 period. Since the deviations between both types of solar data do not exceed 10%, the radiances estimated by modelling are found to be close to the related ground measurements.

Key words

Solar radiation, Satellite images, Modelling, Atmosphere.

1. Introduction

In general, the development of solar applications in a given site depends on the evaluation of the solar energy resources. In Algeria, the meteorological network is much denser in the north than in the south. It consists of more than fifty meteorological stations spread over all the national territory. In these stations, the measurements of global solar radiation flux are rare whereas sunshine duration data have been recorded every day during long periods of time. The Southern region of Algeria is very large and sunny almost all the time making it suitable for the exploitation of solar energy systems such as those based on thermal and photovoltaic conversion. However, owing to the importance of its area, this region cannot be obviously covered by the Algerian meteorological network. Fortunately, there is a large variety of models reported in the literature, which can be used to satisfactorily estimate global solar radiation flux incident on a horizontal surface for every point of Algeria. These models are mainly based on the processing of meteorological images arising from satellite observations. Briefly, these models differ from one to another by the way used to fulfil such estimation. They are usually classified as statistical, physical and analytical models since they mostly consist in evaluating the physical and statistical features of solar radiation crossing the atmosphere and arriving at the ground surface [1]. Among these models, that developed by Gautier *et al.* seems to be the most efficient [2-3]. This model is analytic since it consists in the processing of high-resolution images collected by the Goes satellite and the resolution of the equation of radiative transfer in the atmosphere. In this paper, we have applied this model to the evaluation of global solar radiation flux for every site of Algeria using clear-sky B2 Meteosat images. The methodology used and the obtained results are presented hereafter.

2. Experimental data

The meteorological images under consideration arise from the observations performed by Meteosat 2 in the visible channel [0,4 - 1,1µ m] during the period running from 01 August 1986 to 31 August 1987, at the rate of three images per day (i.e., at 09 h, 12 h and 15 h UTC). The ground measurements used in this study, are hourly global solar radiation data recorded by the radiometric station of

Bouzareah (36.47°N, 03.00°E) and the meteorological station of Oran (35.48°N, 0.48°W) during the 1986/87 period. Meteosat 2 is one of the first generation of seven geostationary satellites launched by the European Spatial Agency (ESA) during the 1972/2000 period. Each of these satellites scans every half-hour the whole Earth disc and then provides visible and infrared images of 5000x5000 pixels in three channels with a resolution of 5x5 km^2. It also provides B2 images obtained by decimating the high resolution images into 416x416 pixels. The B2 images processed herewith are made of 170x150 pixels coded on 8 bits. They represent the South of Europe, the Mediterranean sea and North Africa. To illustrate this kind of Meteosat images, fig. 1 represents the visible B2 image obtained on 12.08.1986 at 12 h UTC.

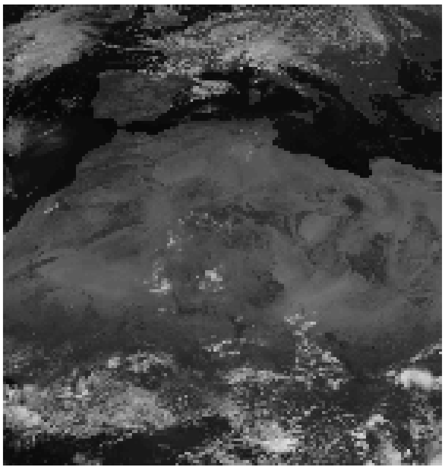

Fig.1. Visible B2 image of North Africa provided by Meteosat on 02.08.1986 at 12 h UTC.

3. Methodology

The analytical model developed by Gautier *et al.*, is based on the computation of the radiative transfer of solar energy from the Sun to the Earth through the atmospheric layers. Such energy exchanges principally depend on the direction of solar rays, their intensity and their spectral features. It is also influenced by the absorption and diffusion features of the atmosphere. The resulting radiance variations against the optical path followed by the solar rays through an atmospheric layer are then expressed using the equation of radiative transfer. In the case of global solar radiation flux detected by the satellite under clear sky conditions, the results of the resolution of this equation are summarized by the diagram of fig. 2 where two optical paths are considered. The first one corresponds to the reflection of solar rays by the upper atmosphere towards the satellite. The second one is the path followed by the solar rays towards the earth through the atmosphere, their reflection by the ground surface and their return towards the satellite through the atmosphere. In this diagram, F_0 is the extraterrestrial solar radiance (W/m^2), I_0 , the solar constant, θ, the zenith angle, α, the atmospheric absorption coefficient, α_1, the atmospheric diffusion coefficient, u_1, the solar elevation angle, u_2 , the satellite angle, $\alpha(u_1)$ and $\alpha(u_2)$, the absorption coefficients of water vapour obtained for u_1 and u_2 respectively, A, the albedo of the Earth. The methodology adopted to compute the global solar radiation flux from the B2 Meteosat images therefore consists of the following steps:

1. Quality control of the solar data (satellite and ground measurements).
2. Division of the data base into clear and overcast sky images.
3. Computation of the geographical coordinates of the site under consideration.
4. Computation of the different angles (zenith, azimuth, sun elevation and satellite angles).
5. Determination of the atmospheric parameters (diffusion and absorption coefficients).
6. Conversion of the numerical counts into brightness values.
7. Calculation of the albedo of ground surface.
8. Calculation of the solar radiance incident on the ground surface.

Let $W\uparrow$ and $W\downarrow$, the global solar radiances observed at the satellite and the ground surface respectively. From the analytic model, we get:

$$W\uparrow = F_0\alpha + F_0(1-\alpha)[1-a(u_1)][1-a(u_2)](1-\alpha_1)A \qquad (1)$$

$$W\uparrow = F_0(1-\alpha)[1-a(u_1)][1+A\alpha_1] \qquad (2)$$

According to the calibration procedure given by Köpke, $W\uparrow$ is proportional to the numerical counts N characterising the satellite observations, i.e. [4]:

$$W\uparrow = C_{sat}\, N \qquad (3)$$

C_{sat} is the calibration factor of the satellite, equalling $C_{sat} \approx 1.3$ $W/m^2/sr$ per numerical units.

Following the Coulson approach, we get $\alpha_1 \approx 0.76$ and the α coefficient is given by [5]:

$$\alpha = 0.05 \exp[-5.81 \cos\theta] \qquad (4)$$

Finally, the $a(u_1)$ et $a(u_2)$ coefficients are computed using the equations of Paltridge [6].

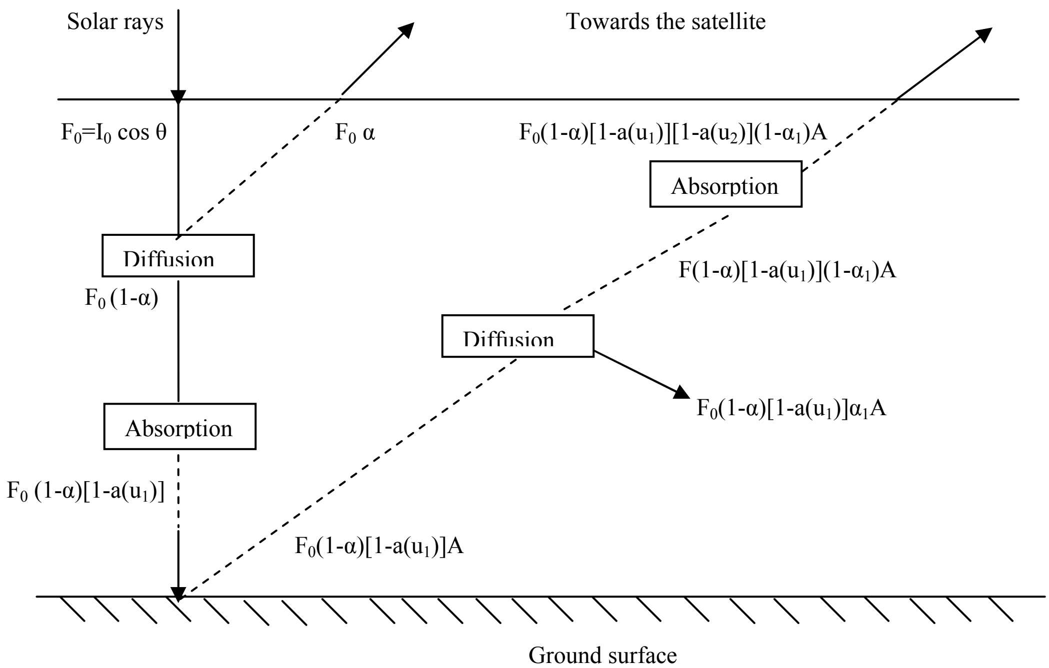

Fig. 2. Radiative exchanges in the ground - atmosphere system under clear sky conditions.

3. Presentation of the results

The results obtained from the visible B2 Meteosat images are illustrated in figs. 3 and 4. The latter give the global solar radiances estimated for Bouzareah and Oran respectively by using the analytical model described above.

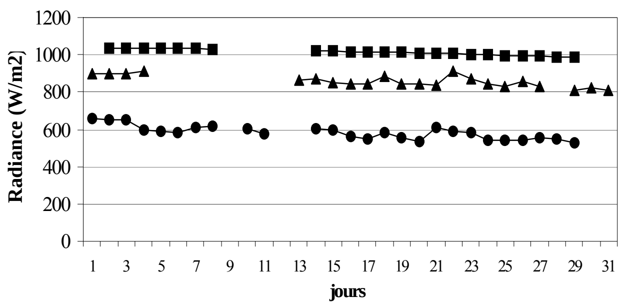

Fig.3. Radiances estimated for Bouzareah in August 1986.

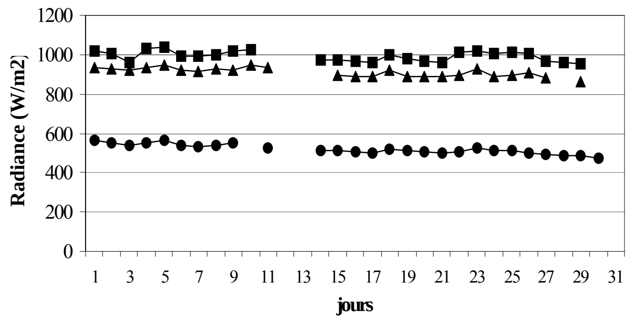

Fig.4. Radiances estimated for Oran in August 1986.

4. Comparison of the results

These results were compared with the ground solar data collected in both radiometric stations using horizontal pyranometers. However, the measurements given by these pyranometers are hourly global solar irradiances (I_{meas}) expressed in Wh/m^2. To fulfil such a comparison, the estimated radiances have been transformed into irradiances. For this purpose, let us assume that under clear sky conditions, the variations of solar radiance reaching the ground surface are similar to those observed off-atmosphere. These variations expressed against the geographical coordinates, are written as:

$$R = R_g\,[\cos L \cos \delta \cos \omega + \sin L \sin \delta] \qquad (5)$$

In this expression, R_g is the solar constant observed at the ground, L, the latitude of the site, δ, the declination and ω, the hourly angle.

To get the hourly irradiances (I_{est}), the estimated radiances R = W↓ are integrated using the trapezium method which consists in computing the following sum:

$$I_{est} = \sum_{k=0}^{n} \frac{R(t_k)}{2\,(t_{k+1} - t_k)} \qquad (6)$$

In this expression, $R(t_k)$ is the radiance estimated from the satellite observations at hour (t_k). Let t_0 and t_{n+1} be the instant of sunrise and sunset. Under clear sky conditions, we obviously get: $R(t_0) = R(t_{n+1})$.

For Bouzareah and Oran, scattergrams are then built by plotting the set of couples of points (I_{est} , I_{meas}). Next, they are fitted to the regression line using the mean-squares method. Fig. 5 shows the scattergram of irradiances obtained for Bouzareah.

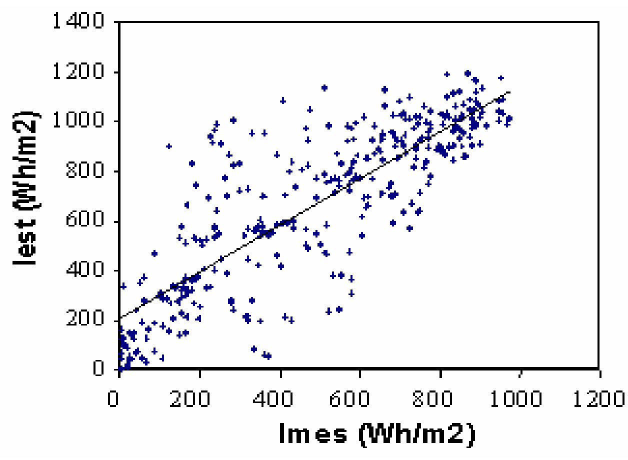

Fig.5. Global irradiances estimated (I_{est}) from Meteosat images against the related ground measurements (I_{meas}).

The radiances can also be obtained from these scattergrams by applying the inverse transformation of equation (6). For Bouzareah, the resulting scattergram and regression line of radiances is given by fig. 6

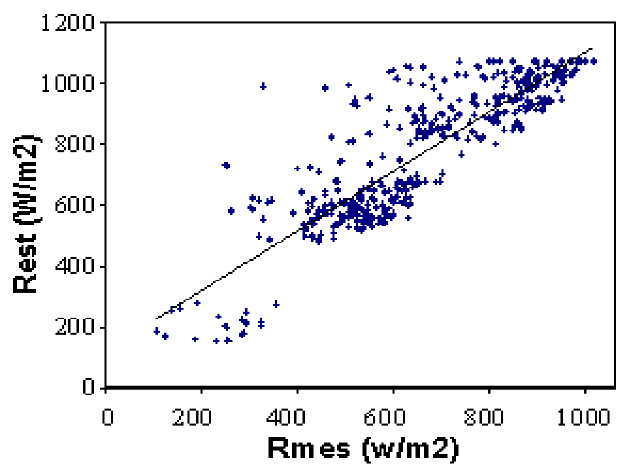

Fig.6. Global radiances estimated (Rest) from Meteosat images against the related ground measurements (Rmeas).

From these scattergrams, it is then deduced that the correlation coefficient between the measured and estimated values is nearly equal to 90 % for Bouzareah and Oran. In addition, the estimation deviations obtained between the estimated and measured data do not exceed 10 %. These results mean that the analytical model described above is also well adapted for the processing of lesser resolution satellite images.

4. Conclusion

For Bouzareah and Oran, the comparison of estimated and measured solar radiation data has shown that the obtained results are very satisfactory. In spite of the complexity of the computations and the weakness of the image resolution, the approach developed in the previous sections, yields good estimates of the global solar radiation flux in any location of Algeria under clear sky conditions. This approach is carried out as an analytical model based on the equation of radiative transfer, which takes into account the hourly variations of global solar radiance estimated from B2 Meteosat images. It has the advantage of its ability to suitably reproduce hourly global solar radiation data in every location where weather is sunny almost all the time, such as in the Sahara desert for Algeria. It is then useful for the generation of reliable series of solar data without any ground solar instrumentation and the development of solar energy applications in arid regions. Notice that the analytical model could also be applied to the processing of satellite images describing overcast situations provided that the absorption and diffusion of solar radiation by cloudy masses are considered. The performance of the analytical model could be improved if the second generation of Meteosat images are considered. The latter are collected every fifteen minutes in twelve channels and their resolution is typically equal to 2.5 km/pixel whereas the B2 Meteosat images were recorded every three hours with resolution equalling 36 km/pixel. Such perspectives obviously need further investigations to look for possible improvements of solar radiation modelling.

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