A soft application for surface solar radiation estimation in Algeria

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Abstract. In this article, we have developed an application of four theoretical models that allows to estimate the solar radiation received on the ground for any region of the Algerian territory. The first model makes it possible to estimate the global solar radiation received on the ground. This model is a spectral model for the determination of direct and diffuse irradiance on a horizontal and sloping surface and for a clear sky. The second model is a Bird & Hulstrom time model that estimates solar radiation at ground level for a certain period (Hours, days, months, ... etc.). The third model is the Davies & Hay model, which makes it possible to trace the rates of absorption and diffusion of solar radiation by the various atmospheric constituents as a function of time and make comparisons. The last model is Lacis & Hansen which allows to trace the global radiation for a certain period. These models are based on the determination of the transmission coefficients of the various atmospheric constituents. These coefficients require the availability of current meteorological parameters (relative humidity, ambient temperature, atmospheric pressure, etc.) and geographical parameters of the site (latitude, longitude and altitude). The application developed made it possible to study several models for estimating global solar radiation at a few Algerian sites and to draw a conclusion on the most appropriate models of estimations.

1. Introduction

Solar energy occupies one of the most important places among the various possible sources of energy. An accurate knowledge of the distribution of solar radiation at a given geographic location is of major importance for the development of solar energy devices and for evaluating their performance. Unfortunately, for Algeria measurements of solar radiation are not readily available. For this reason, other solutions are often used to estimate the components of solar radiation on the ground.

Total solar irradiance is divided into two components: [1] the beam component from direct irradiation and the diffuse component. The ensemble forms the global radiation, which is determined by three groups of factors: the geometrical relations between the sun and the surface of the earth, the attenuation due to the crossing of the atmosphere, and the topographical factors. These parameters include day number, average temperature, relative humidity, altitude, longitude, zenith angle, and albedo of the soil.

These components can be measured directly by different measuring instruments or they can be estimated by analytical models that are established after several experimental measurements [2].

The objective of this work is to develop an application that allows to estimate the solar radiation received on the ground on any region of Algeria. Four models have been implemented by the Java language, a spectral model (Bird & Riordan) and three time models (Bird & Hulstrom, Davies & Hay and Lacis & Hansen), the curves of the different components of solar radiation for each model are presented by a graph.
In the following, an evaluation of the chosen models will be carried out in order to know the main difference between them. A graphic study was developed to judge the behaviour of the models and to know their strengths and their shortcomings.

2. **Bird & Riordan model**

This model is a spectral model for the determination of direct and diffuse irradiance on a horizontal and sloping surface and for a clear sky. Modifications have been made to the method used for the calculation of direct irradiance. These modifications include the addition of an Earth-Sun distance correction factor, the use of Leckner's expression of the water vapour transmittance with some modification of the Leckner absorption coefficients, and the use of the expression of Robinson's ozone mass given by Iqbal [3]. For this model, global solar irradiation for a wavelength \( \lambda \) is the sum of direct irradiance and diffuse irradiance:

\[
G_\lambda = I_{d\lambda} + D_\lambda
\]  

Determinations of direct irradiance

The direct irradiance for a wavelength \( \lambda \) is given by the following relation:

\[
I_{d\lambda} = H_{0\lambda} D T_{r\lambda} T_{a\lambda} T_{w\lambda} T_{o\lambda} T_{u\lambda} (1 - T_{r\lambda} 0.95) 0.5 C_S
\]  

Determinations of diffuse irradiance

Diffuse irradiance is induced by the diffusion effects of air molecules and aerosols. It should also be noted that aerosols are elemental atmospheric particles that cause a significant problem in the evaluation of solar irradiance, particularly in the study of diffuse irradiance, and this difficulty lies in the evaluation of their number, size, distribution and their optical properties.

In the case of this Bird model, the diffuse irradiance \( D_\lambda \) on a horizontal surface is the sum of three components:

1. The Rayleigh \( D_{r\lambda} \) diffusion component.
2. The component of diffusion by \( D_{a\lambda} \) aerosols.
3. The component that takes into account multiple reflections of the radiation between the ground and the atmosphere \( D_{g\lambda} \).

In this case, the total diffuse radiation \( D_\lambda \) will be given by the sum of the different components, namely:

\[
D_\lambda = D_{r\lambda} + D_{a\lambda} + D_{g\lambda}
\]  

According to the modified Bird spectral model, the expressions of the diffuse radiation components are given by:

\[
D_{r\lambda} = H_{0\lambda} D \cos \theta Z T_{o\lambda} T_{u\lambda} T_{w\lambda} T_{a\lambda} (1 - T_{r\lambda}^{0.95}) 0.5 C_S
\]  

\[
D_{a\lambda} = H_{0\lambda} D \cos \theta Z T_{o\lambda} T_{u\lambda} T_{w\lambda} T_{r\lambda}^{1.5} (1 - T_{as\lambda}) 0.5 F_S C_S
\]  

3. **Davies and Hay model**

The Hay-Davies model is a model for radiation insolation (direct and diffuse). It is composed of the isotropic component and the circumsolar component. It is given by the relationship [5] and horizon brightening is not taken into account. The equations used in this model were partially the result of comparing several existing models [6].
3.1. Calculation of direct radiation

The relationship proposed by Davies & Hay for the calculation of direct radiation is expressed by equation (20):

\[ I = I_{sc} \times [(1 - \alpha_0) \times \tau_r - \alpha_w] \tau_a \times \cos \theta_z \quad (20) \]

Where, \( \alpha_0 \) is the coefficient corresponding to the absorption of direct solar radiation by the ozone layer; and \( \tau_r \) the coefficient of transmission after molecular diffusion or Rayleigh scattering is expressed by equation (21)

\[ \tau_r = 0.972 - 0.08262m_a^2 + 0.00095m_a^3 + 0.000437m_a^4 \quad (21) \]

\( m_a \) is the corrected air mass expressed by the following relation:

\[ m_a = \frac{p}{p_0} m_r = \frac{\exp(-0.0001184 \times z)}{\cos(\theta_z) + 0.15(93.885 - \theta_z)^{-1.253}} \quad (22) \]

\( \tau_a = (0.12445 \alpha - 0.0162) + (1.003 - 0.125\alpha) \exp[-\beta m_a (1.089 \alpha + 0.5123)] \quad (23) \]

Such that: \( \alpha \) and \( \beta \) are respectively the coefficient characterizing sky visibility and the Angstrom cloud coefficient. Their calculation is based on the experimental determination of two attenuation coefficients \( k a_{\lambda_1} \) and \( k a_{\lambda_2} \) corresponding to the wavelengths in which the absorption by water vapour does not occur (\( \lambda_1 = 380 \) nm and \( \lambda_2 = 500 \) nm respectively).

3.2. Calculation of diffuse radiation

The diffuse radiation on a horizontal plane is the sum of the three diffuse components: \( D_r \), \( D_a \) and \( D_m \). \( D_r \) represents the diffuse radiation after the Rayleigh scattering, of which \( \tau_0 \) is the transmission coefficient after absorption by ozone.

\[ \tau_0 = 1 - \alpha_0 \quad (26) \]

\[ D_a = I_{sc} (\tau_0 \tau_r - \alpha_\omega) \times [F_c \times \alpha_\omega (1 - \tau_a)] \cos \theta_z \quad (27) \]

3.3. Calculation of global radiation

The global radiation on a horizontal plane is calculated by:

\[ G = I + D \quad (28) \]

4. Bird & Hulstrom Model

In 1981, Bird and Hulstrom [6] developed a mathematical model that calculates the incident solar radiation on the ground. This model takes into account the effects of diffusion and absorption that the solar radiation undergoes during its crossing of the atmosphere [7]. It is based on the determination of the transmission coefficients of the different atmospheric constituents. These coefficients require the availability of current meteorological parameters (relative humidity, ambient temperature, atmospheric pressure, etc.) and geographical parameters (latitude, longitude and altitude).

5. Lacis & Hansen Model

The Lacis & Hansen model is a semi-empirical model, it allows to calculate global solar radiation on a horizontal plane [8]-[10]. The input parameters of this model are: Solar constant, day number of the year, zenith angle, ambient temperature, relative humidity, atmospheric pressure, latitude, longitude, and altitude of the place and the albedo of the soil.

6. Presentation of the software

The software was developed with the Java language under the NetBeans environment. It allows the user to choose between four models of solar radiation estimation. Each model has a graphical interface where the user must choose a region and enter the input parameters. The Figure 1 gives an overview on the developed software interface.
6.1. Bird & Riordan Example

Seven parameters are to be introduced in this model, meteorological parameters (average temperature and relative humidity of the air) and geographical parameters (latitude, longitude and altitude). The absorption coefficients as a function of the wavelength and describing the different elements of the atmosphere. Figure 2 shows an overview of the parameters to be introduced for the Bird & Riordan model.
The Figure 3 shows the results of the Bird spectral model for the Oran region.

![Figure 3](image)

**Figure 3.** Radiation estimated by the spectral model of Bird & Riordan

6.2. *Bird & Hulstorm Example:*

The Figure 4 shows an overview of the time model for the region of Tamanrasset.

![Figure 4](image)

**Figure 4.** Module overview of Bird & Hustorm model and estimated radiation from Tamanrasset region
6.3. Davies & Hay Example:
The Figure 5 shows the graph of the Davies & Hay model for the Ghardaia region.

![Figure 5. Module overview of Davies & Hay model and estimated radiation from Ghardaia region](image)

6.4. Hansen & Lancen Example:
The Figure 6 shows the graph of the Hansen & Lancen model for the Bechar region.

![Figure 6. Module overview of Hansen & Lancen model and estimated radiation from Bechar region](image)

7. Conclusion
In this work, a model of solar radiation by four models a spectral model Bird and Riordan, and three time model (Bird & Hulstorn, Davies, Lacis & Hansen) was presented and simulated. From the models considered it was possible to calculate the three components of solar radiation; direct, diffuse and global in the conditions of the clear sky.
From the results that we have reached and based on the comments we have made, we find that generally each of the models considered in this study can calculate each component of solar radiation on an inclined plane and on a horizontal plane.
These models have the advantage of being simple, they use mathematical equations not too heavy for the study the estimate of the solar radiation. The designed software can be applied for any region and any day of the year.
As a result, it should be noted that given the results obtained and presented above, the Bird and Hulstrom model has relatively better results. So given its universality and view that it holds in a more detailed manner the phenomena of attenuation of the solar radiation, we recommend its estimate of the various components of the solar radiation.

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