Prediction of Solar Irradiance and Illuminance Using REST2 Model

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Abstract

In this study, an analysis of the predictions based on the high-performance solar radiation REST2 model is presented. REST2 (Reference Evaluation of Solar Transmittance, 2 bands) is a two-band model developed by Gueymard to predict cloudless-sky broadband solar radiation. Model estimations of solar irradiance and illuminance are compared with experimental data. Data used in this study are obtained from a solar radiometric station sited at the Low Atmospheric Research Center, C.I.B.A., at Valladolid (Spain).Predictions for different time of the day and different periods along the year are analyzed. In summer time where the radiation is high, the predicted and measured values practically coincide while more deviation occurs when the radiation is low. RMSE values about 9% are obtained for both type of magnitudes, radiance and illuminance.

1. Introduction

Atmospheric radiative transfer codes such as REST2 model [1] allow us to predict some variables related to solar radiation reaching the earth surface such as irradiance and illuminance. Solar illuminance is the part of the irradiance sensitive to the human eye and it is obtained from the relationship:

$$L = K_m \int_{380nm}^{770nm} V_\lambda I_\lambda d\lambda \qquad (1)$$

where I_λ is the spectral irradiance, V_λ is the normalized human eye response and K_m is the maximum luminous efficacy, 683 lm/W, corresponding to 555nm. V_λ describes the average visual sensitivity of the human eye to light of different wavelengths and its maximum value is 1 at 555nm. It should not be considered perfectly accurate in every case, but it is a very good representation of visual sensitivity of the human eye. V_λ is a standard function established by the Commission Internationale de l'Éclairage (CIE) and, as above, may be used to convert radiant energy into luminous energy.

The ratio of the global horizontal illuminance to the global irradiance is denominated global horizontal luminous efficacy K_g :

$$K_g = \frac{L_g}{I_g} \qquad (2)$$

and numerous modelizations of this parameter can be often found in the literature in order to predict illuminance values throughout known values of the irradiance . A similar definition of the beam and diffuse luminous efficacy is established when the corresponding components of the radiation are considered separately in the expression 2.

As modelled in REST2, the irradiance and consequently the illuminance are function of the solar position through the solar zenith angle and of the several atmospheric data that determinate the transmission of the radiation in the atmosphere.

2. Experimental data

Data used in this study have been collected from a solar radiation station installed in the Low Atmospheric Research Center C.I.B.A. (41.82ºN, 4.93ºW). This center is sited in a rural area close to the city of Valladolid, Spain, in the Northwest of the Iberian Peninsula. It is situated in a flat terrain (840m altitude above the sea level) with a type of vegetation dry and low. The ground cover is quite homogeneous for a large extension and does not experiment significant changes along the year so that the ground reflectivity doesn't have a relevant variation in time. Calibrated sensors CM11 Kipp&Zonnen and LICOR Li210-SA have been used to measure global horizontal irradiance and illuminance respectively on a 10-min basis. Sensors are placed on a flat platform 1.5 m height. The data acquisition system used in the C.I.B.A. is a CR23X Campbell datalogger. The information is registered every 30 seconds and averaged and stored each 10 minutes.

The clear-sky data used correspond to a selection of 24 complete clear days distributed along the year 2007. The aim was to visualize the daily evolution of irradiance and illuminance levels at different times of the year.

Experimental measurements of the global irradiance and illuminance have been treated in the present study with the objective to assess the performance of the radiation model described in the next paragraph. Some of these data, specifically illuminance data, are described in Perez-Burgos et al. [4] in a study related to the prediction of vertical illuminances through the horizontal ones.

3. Methodology

In Figure 1, the daily evolution of the solar irradiance (in W/m^2) and illuminance (in klux) from experimental measurements is shown for the 24 days selected. The day number of the year is indicated in the graph. The variation range of these magnitudes from the figure 1 is (454, 1008) W/m^2 for irradiance and (47, 112) klux for iluminance, taken as a reference the values at noon. Those values really express the difference between winter and summer time. The luminous efficacy, that is the ratio of illuminance to irradiance, varies much less and it has an average value of 109±1.

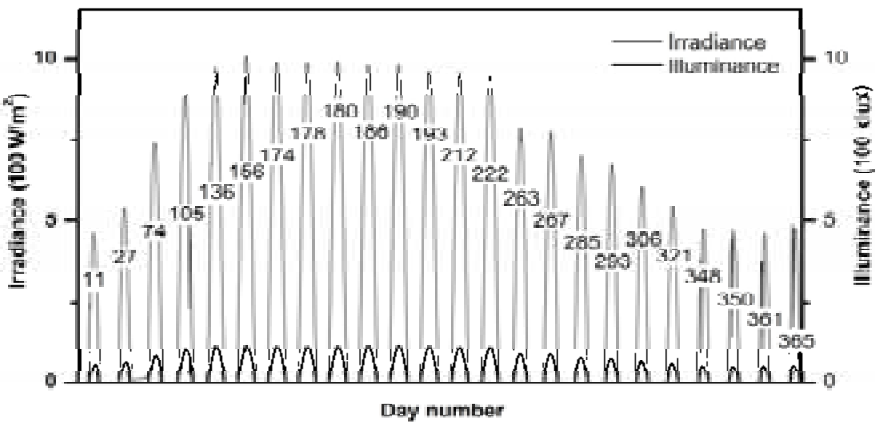

Fig. 1. Irradiance and illuminance evolution along the year 2007 at Valladolid , Spain

From a visual inspection of the figure 1, it is possible to see that for some winter days, the ordinary daily evolution of a clear day is lightly altered due to the presence of clouds in the last time of the afternoon. These points will be removed later, when analyzing the predictions of the model.

3. 1 REST2 Model

REST2 (Reference Evaluation of Solar Transmittance, 2 bands) is a high performance solar radiation model with a two-band scheme, developed by Gueymard who makes a complete description of the method in [1]. Basically, the model uses a two band-scheme in the sense that it divides the spectrum in two spectral ranges, band 1 (0.29 to 0.7 µm) and band 2 (0.7 to 4 µm). The model simplifies the retrieval of the illuminance whose spectral range corresponds almost perfectly to band 1. To calculate transmittances due to the different atmospheric components, the model requires the following input data: precipitable water (w), Angstrom turbidity coefficients (α , β), NO_2 content (u_n), O_3 content (u_o) and site pressure (p). The other inputs to the model are the solar zenith angle and the ground reflectivity of the site. Extinction due to aerosols affects, above all, to band 1 (290, 700nm) and so, the calculation of illuminance is strongly conditioned by the aerosols input data. The source of input data used in this work is described following:

3.1.1 Turbidity

Under Clear skies, aerosols are the most important source of extinction in the atmosphere. In spite of this, turbidity parameters are the most difficult to retrieve.The Angstrom turbidity coefficient β is a function of the aerosols content in the atmosphere, while the exponent coefficient α is a function of the aerosol size. In order to work with the model, the values of the coefficients α and β at the same time and location as those of the experimental values of radiation are required. This can be really a problem when evaluating the performance of any model. Several options are usually considered to input aerosols characteristics, the use of standard data typical of the geographical zone, the use of a climatic data bank (i.e. AERONET), the use of retrievals from satellites, etc... In this study, the atmospheric turbidity was calculated from measurements of the horizontal visibility. Data of visibility taken 5 times in the day are available from a weather station sited in the Villanubla airport, close to the C.I.B.A. station and managed by the Meteorological State Agency. A variation between 10 and 25 km was found along the year for the clear days selected. The Angstrom turbidity coefficient β was calculated trough the following relationship [3]:

$$\beta = (0.55)^{\alpha}(3.912/VIS - 0.1162)*(0.002472(VIS - 5) + 1.132 \qquad (3)$$

The α parameter is necessary to obtain the value of β. The value α =1.3, representative of rural and continental aerosols [1], has been used.

3.1.2 Precipitable water

Measurements of the air temperature and relative humidity taken each 10 minutes have been carried out simultaneously to the radiation measurements. Thus, the water vapor content w (in cm) is calculated from the Leckner formulae [2]:

$$w = 0.493*(0.01*h/T)*exp(26.23 - 5416/T) \qquad (4)$$

where h is the relative humidity in % and T the air temperature in K.

3.1.3 O_3, NO_2 and Pressure

The O_3 content has been taken from TOMS data, so that, one ozone value is assigned to each day. The NO_2 content has a very small influence in the calculations and a default value of 0.0002 atm-cm is assumed. The atmospheric pressure was obtained from data taken in the C.I.B.A. station, also, on a 10-min basis.

3.2 Performance of the model

In Figure 2, model estimated and measured values are compared. For this analysis, a lower limit of 0.6 in the clearness index (ratio of global to extraterrestrial irradiance) has been applied; this is due to, as said before, some light clouds could be present in the extreme hours of the day for some of the selected days. Also, data corresponding to solar altitude angles less than 5 º have been rejected; Thus, a few spurious data has been removed from the original data set and a total of 1411 data has been processed. Line 1:1 is draw. As we can see, the model fits really well for spring and summer days when the radiation is high and presents more deviation when the radiation is low, that is for the winter data. For all data set, the RMSE value about 9% is obtained for both magnitudes, irradiance and illuminance.

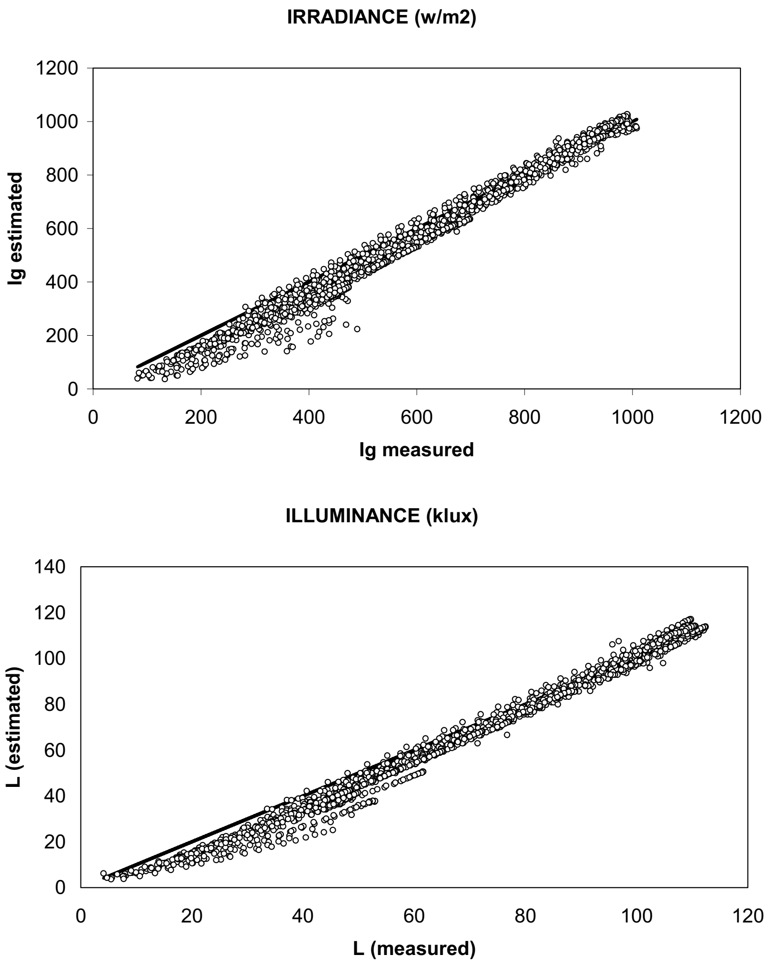

Fig. 2. Comparison of REST2 model estimations with experimental values

4. Conclusions

In this study, measurements of global irradiance and illuminance on a horizontal surface have been analyzed. The data correspond to the year 2007. Clear-sky days selected along the whole year have been considered. The main objective was to modelize these data having into account different weather conditions along the year. The model REST2 is tested in order to carry out the modelization. REST2 model predictions were compared with experimental data. The main input parameters are those relative to atmospheric turbidity and, at the same time, the most difficult to obtain. Several data source to obtain aerosols can be used; all of them have a certain uncertainty unless turbidity is measured at the corresponding radiometric station. One possibility is to estimate turbidity based on visibility. As visibility measurements are routinely made in a nearby airport, such type of data was checked. The expected results are good, high values of radiation (summer data) are better predicted than low values (winter data). For the total data set, RMSE values for irradiance and illuminance about 9% are obtained and considered very acceptable.

References

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