Analysis of Atmospheric Variables Influence on The Surface Global Solar Irradiation

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Abstract

The current national energy scenery indicates the need of clean and renewable energy sources applications. Then, it is necessary to study the renewable energy resources and their variability. Therefore, the article aims at studying the influence of atmospheric aerosols and precipitable water in the global solar irradiation at the surface. Stochastic models were developed to compar the ratio between the global solar irradiation at the surface and at the top of the atmosphere (K_t) with the atmospheric variables by using data acquired at the Southern Space Observatory, located in the Brazilian Southern region. Only clear sky days were used. After data validation, it was observed that the developed models have presented low statistical deviations, however, there was significant improvement in the estimates provided by the one that used as input variables the transmittances associated with atmospheric aerosols and Rayleigh scattering, and vapor water absorptivity.

Introduction

According to Pereira (2006), solar and wind energy resources are increasingly required due to the need for fossil fuel replacement in power generation in order to reduce greenhouse gases emissions to the atmosphere. However, the investments and implementation of the solar and wind energy applications require reliable information on resource assessment and variability throughout the Brazilian territory.

Currently in Brazil, the SONDA network (National Environmental Data Organization System), coordinated by the Center of the Earth System Science (CCST/INPE), working together with the Center for Weather Forecasting and Climate Studies (CPTEC/INPE), was set up to provide solarimetric and meteorological database that meets this demand for information. The SONDA network has 15 surface measuring stations sites distributed over all the Brazilian microclimate regions.

In accordance with Guarnieri (2006), the best solar radiation estimates for locations not monitored by surface sensors are produced using numerical models based on satellite information. The main sources of uncertainty for solar estimates are due to the geographical variability of atmospheric variables. In the context, the surface solar radiation data acquired in SONDA sites is used to validate and develop new parameterizations for radiative processes in the atmosphere.

The paper aims at studying the aerosols and precipitable water influence on index Kt for clear sky days occurred, in the Southern Space Observatory – SSO/CRS/CCR/INPE - MCT, located at São Martinho da Serra/RS, in the Southern region of Brazil. The index Kt is the ratio between global solar irradiance at the surface and at the top of atmosphere.

Method

To carry out the work it was used data acquired between September 2009 to December 2010 in the SONDA network station. It was used a CM21 pyranometer (Kipp & Zonen), which measures the surface global solar irradiance, and a photometer CIMEL CE 318 (CIMEL Eletronique) which measures aerosol optical thickness and precipitable water. Diffuse solar irradiation data was obtained with a pyranometer CM22 (Kipp & Zonen) shaded with a concealed-shaped disc positioned by the Solar Tracker Two Axis Positioner – 2AP (Kipp & Zonen). The Total Sky Imager TSI-440 (Yes, Inc.) was used for selection days of clear skies, necessary for the study.

The solar irradiation data are stored with one minute time resolution. The TSI acquires an image every fifteen minutes. The selection of clear-sky days was achieved by observing the daily cycle of global and diffuse solar irradiation data measured at the SONDA site. The sky imager allowed checking for the clear sky condition in selected days.

Statistical models were developed to estimate the parameter Kt (Equation 1) by using the least squares method.

$$K_t = \frac{I}{Io} = \frac{I}{I_{SC} E_0 \cos\theta_z} \quad (1)$$

Where I_{SC} is the solar constant $(1368 W.m^{-2})$, E_0 is the Earth's orbit eccentricity factor and θ_z is the zenith solar angle at the data acquisition time.

For the first model, hereafter called Model A, it was used optical thickness aerosol and precipitable water measurements and calculated the Angstrom parameter as shown in Angstrom (1929).

For the model A, it was considered that on clear sky days, precipitable water and aerosols play a more significant role in the solar radiation attenuation by atmosphere. It was decided to develop a model with direct application of the Angstrom parameter and the precipitable water content without the transmittance of solar radiation determination by these atmospheric constituents.

For the second model, hereafter called Model B, the vapor water absorptivity, the Rayleigh scattering attenuation and the aerosols attenuation transmittance were obtained from parameterizations using meteorological data as described in Iqbal (1983).

The developed empirical models to estimate the parameter Kt are presented in Table 1 below.

Table 1 – Empirical models developed to estimate the Kt parameter.

Model A	$K_t = 0,77k^{-0,03}\beta^{-0,02}w^{-0.04}$
Model B	$K_t = 0,46\,\tau_a^{0,18}\,\tau_r^{0,52}\,\alpha_w^{-0,26}$

The statistical deviations MBE (Mean Bias Error) and RMSE (Root Mean Square Error) were used to evaluate the reliability of the estimates provided by the both models, using data from December 2010. The deviation values are divided by the measures average value, expressing the result as a percentage.

Results

The MBE and RMSE statistical deviations between the estimates provided by models and surface data from January/2009 to November/2010. The data acquired in December/2010 was used in validation step. The mean bias error, root mean square error and correlation factor are presented in Table 2.

Table 2 - Statistical deviations and the correlation factor between the model estimates and the measurements in São Martinho da Serra - RS.

	MBE(%)	RMSE(%)	Correlation
Model A	-0.2	6.7	0.3
Model B	-0.1	4.5	0.8

By observing the values of the statistical deviations, it is noted that both models have presented low deviations. However the Model B using the atmospheric transmittance has achieved better performance as indicated by correlation factor. Figure 1 and 2 presents a comparison between the global solar irradiance measurements acquired at the surface and estimates provided by the models. It may be noted from Figure 1 that the Model A was unable to represent the radiative processes in the atmosphere using only the two chosen parameters, making clear the importance of determining the atmospheric transmittance constituents and Rayleigh scattering in the solar radiation attenuation on clear sky days. The Figure 2 and the correlation value of 0.8 clearly show that the B model adequately represent the radiative processes. The causes of the dispersion shown in Figure 2 around the diagonal of the plot have not been investigated and will be subject of study in future research. One of the hypotheses being considered is the partially cloudy sky conditions on the horizon line and the increase of optical path for large solar zenith angle. In condition like that, it is expected that the model overestimate the surface incident radiation.

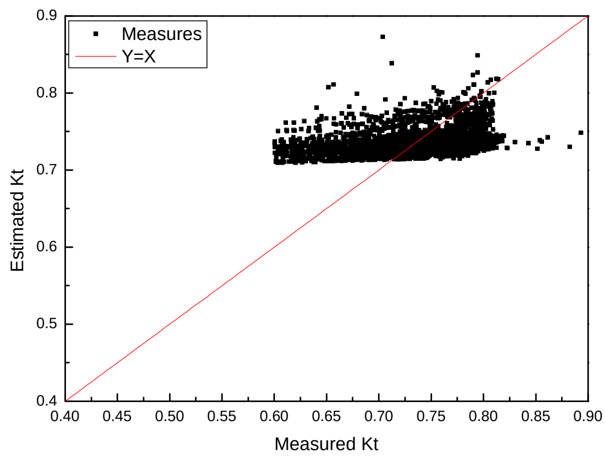

Figure 1 – The Model A measured and estimated values for the Kt parameter.

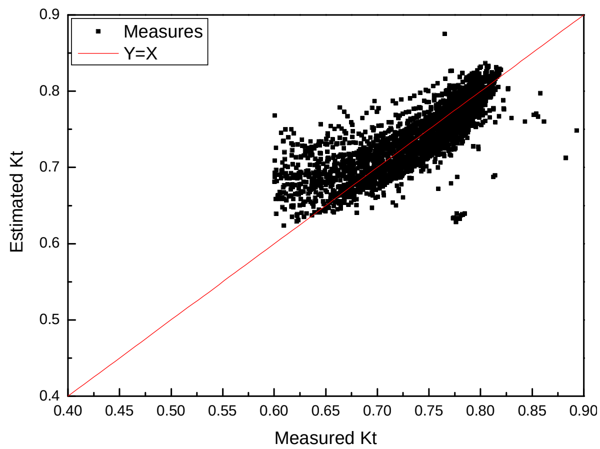

Figure 2 – The Model B measured and estimated values for the Kt parameter.

Conclusions

Analyzing the statistical deviations, it may be noted that the Model B performed better than Model A, with RMSE values lower than 11%. The Model A had low deviations, but the correlation factor obtained pointed out that it cannot represent the radiative processes occurring in the atmosphere in clear sky conditions. However, there was significant improvement in the estimates provided by Model B, using as input variables the transmittances associated with atmospheric aerosols and Rayleigh scattering, and the absorptivity by water vapor. The Model B overestimated the radiation incident on the surface in Kt values below 0.75. It is believed that this overestimation is due to the presence of cloud near the horizon, hardly identified by the criteria used in the study.

The development of more accurate mathematical models to estimate index Kt will be matter of future work. The main idea is to include other meteorological variables as input data and, in particular, to get forecast for all sky conditions.

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