Analysis of the diffuse fraction from solar radiation values measured in Argentina and Brazil sites

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Abstract

The knowledge of the spatio-temporal characteristics of the components of solar radiation is of importance to optimize its practical application, mainly for direct component, which is the one that can be concentrated. But, since most of the meteorological stations in the region only measure global radiation, the correlations between it and diffuse component are studied. In this way, from the measured values of global solar radiation, diffuse component can be estimated, and horizontal direct component can be calculated. In this paper, values of global and diffuse fractions measured in La Quiaca (Argentina) and Araripina (Brazil) are analyzed, with a recording frequency of 1 minute, adjusted according to a sigmoidal function. Qualifying data filters were applied to guarantee that invalid values cannot be used in curves adjustment. Hourly and daily partitions are analyzed, and its coefficients are obtained. Comparing the hourly curves to 5 other sites, it was noted that all curves are interlaced what indicates a quite similarity of relation behave. Daily curves were also obtained, it was verified that they are similar

Keywords: Solar radiation, Diffuse radiation, Global radiation.

1. Introduction

According to Cao et al. (2017), the knowledge of the solar resource also has its importance in diverse areas like agriculture, architecture and illumination. There is a relatively great shortage in relation to accurate and reliable information on solar radiation values, mainly for the direct component, which makes it difficult to carry out feasibility studies for the implantation of thermal solar power plants. There is a need to carry out measurements in several locations, and thus to have a database of solar radiation and, with data ownership, to make a more detailed analysis of the most promising places to carry out the projects that depend on the solar radiation.

In addition to obtaining values of direct radiation by a pyrheliometer, it is also possible to calculate the values of the direct irradiance, using the relation presented in eq. (1).

$$H_b = \frac{H_h - H_d}{\cos(\theta_z)} \qquad \text{(eq. 1)}$$

where H_h is horizontal global irradiation, H_d is horizontal diffuse irradiation, H_b is normal direct irradiation, all in Wh / m². θ_z is the solar zenith angle. All the magnitudes can be studied in the 1-minute scale, being the most common the hourly scale.

It is pointed out the importance of the study of diffuse radiation, from the use of the eq. (1) for the calculation of the direct component of solar radiation, mainly of its well-known and studied mathematical relations with the global radiation (Liu and Jordan (1963), Hay (1963), Erbs et al. (1984), Collarespereira and Rabl (1979), Perez et al. (1986)). More recent studies such as that of Ridley (Ridley et al. (2010)) and Boland (Boland et al. (2013)) used logistic functions with multiple predictors finding better results when estimating the diffuse fraction particularly in the southern hemisphere and therefore its importance for this study.

On the other hand, some applications of solar energy require to know the diffuse radiation in sub-hourly periods, for

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which reason studies have been carried out in which models were developed for a 1-minute frequency such as those of Gueymard (Gueymard and Ruiz Arias (2016), Lemos (Lemos et al. (2017)) and Engerer (Engerer (2015)).

For this study, data of two solarimetric stations located in Argentina (La Quiaca) and Brazil (Araripina) was used for adjustment and comparison to previous works. Logistic functions presented by Pedrosa Filho and Gerônimo (2018) was adjusted to both places.

2. Data collection and quality control

The database used for La Quiaca (Lat -22.10°, Long -65.6°, Alt 3460 m) corresponds to frequency of data recording = 1 minute, made from 2005 to 2007. The sensors used are two Kipp & Zonen CM11 pyranometers (one shaded by a ring to measured diffuse) and have been calibrated by the Argentinian National Meteorological Service (SMN) using a cavity pyrheliometer with traceability to the PMOD / WRC. The diffuse records obtained were corrected using the LeBaron method (LeBaron et al, 1990), which is commonly used to correct diffuse irradiance using a shadow ring (Malet-Damour et al., 2018; Li and Lam, 2007).

For Araripina station (Lat -8.37°, Long -36.68°, Alt 660 m) a 1-minute frequency of data recording is also used, measuring the direct and diffuse components as well as the global solar radiation in the horizontal plane. The data was collected between 2015 and 2019. This solarimetric station have a Kipp & Zonen CMP3 pyranometer for global radiation, a Kipp & Zonen CMP3 shaded by a ball for diffuse component and a Kipp & Zonen CHP1 pyrheliometer for the direct component.

In order to remove anomalous values from data sets and detect errors in measurements, data quality filters were applied, using the Raichijk criteria (Raichijk (2012)). It consists of a series of filters that impose lower and upper limits of acceptance of the different values intensities measured. Since this work deals only with diffuse radiation, initially focused on filters that work with this component, we have disregarded filters that use filters for K_t, focusing mainly in filters of K_d and K_t.

In this work, K_t and K_d are defined by the eq. 2 and eq. 3 respectively.

$$K_t = \frac{I_{global}}{I_{0eff}.cos(\Theta_z)} \quad \text{(eq. 2)}$$

$$K_d = \frac{I_{diffuse}}{I_{global}} \quad \text{(eq. 3)}$$

In the eq. (2) and (3), I_{global} is the global irradiance, $I_{diffuse}$ is the diffuse irradiance, I_{0eff} is the extraterrestrial irradiance corrected (all in W/m²) and θz is the zenith angle. For hourly and daily fractions, the I (irradiance) (W/m²) is changed to H (irradiation) (Wh/m²).

3. Results

As a result of the application of the quality filters and adjustment of the distribution of data points in a K_t – K_d plane, a sigmoidal function (eq. 4) was chosen to describe that relationship (Figure 1).

$$K_d = \frac{1}{1+e^{a+b.K_t}} \quad \text{(eq. 4)}$$

The software used for adjustments was SciDAVis that is a free application for Scientific Data Analysis and Visualization, which can be downloaded at (http://scidavis.sourceforge.net/).

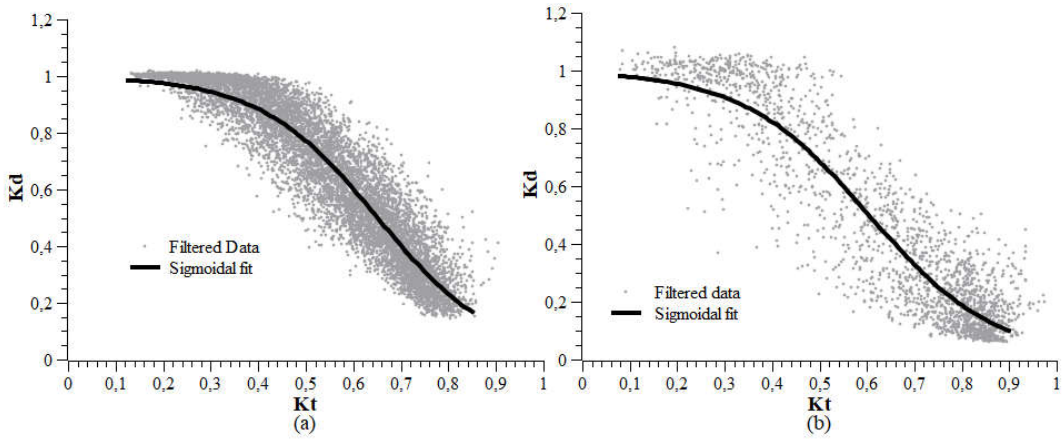

Fig. 1: Adjustment of the hourly sigmoidal function for (a) Araripina (BRA) and (b) La Quiaca (ARG).

In the Figure 1a, 9103 data points from Araripina were considered to compound the correlation. For La Quiaca, 2100 hourly data points were used (Figure 1b). This difference is because Araripina data span the period (2015-2019) meanwhile La Quiaca station just (2005-2007).

The values of coefficients *a* and *b* (see eq. 1) obtained for the study sites and of the adjustment quality indicators are shown in Table 1.

Tab. 1: Hourly coefficients of the sigmoidal function adjusted for Araripina (BRA) and La Quiaca (ARG).

Sites	a	b	R^2	χ^2
Araripina (BRA)	-4.523	7.483	0.8585	31.14
La Quiaca (ARG)	-4.132	7.088	0.8466	9.388

It is observed from the presented values that the coefficients (Table 1), using hourly data, for both sites have similar values (except χ^2). The sigmoidal function fits well to the points of K_t vs K_d since the coefficients of determination (R^2) are near the unit.

A validation to a different period of hourly measurement was done. It was considered data from march-2019 to November-2019 for Araripina (BRA). The graph of Figure 2 presents this comparison.

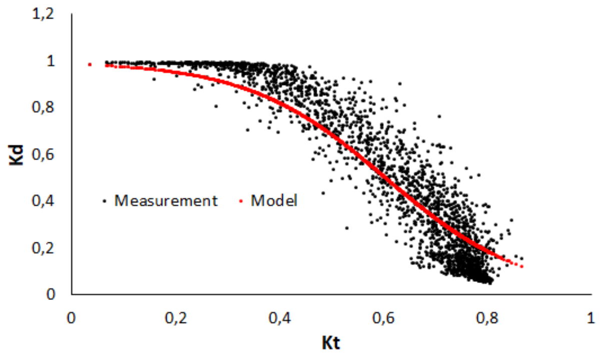

Fig. 2: Validation to a different period to Araripina (BRA) station.

It was used statistical indicators to quantify this validation as MBE (Mean Bias Error), RMSE (Root Mean Standard Error), MAPE (Mean Absolute Percentage Error) and R^2 as described in Yang and Boland (2019).

The Table 2 presents the hourly statistical validations obtained only for Araripina (BRA) site, these values were no calculated for La Quiaca (ARG) due to few amounts of data available for this work.

Tab. 2: Hourly statistical indicators for Araripina (BRA).

MBE	RMSE	MAPE	R^2
-0,0183	0,235	29,4 %	0,88

To analyze the results, the two adjusted curves were compared with other 5 curves from different locations presented by Pedrosa Filho and Gerônimo (2018). It is observed, in Figure 3, that the Araripina curve (continuous red) presents values of K_d greater from $K_t = 0.4$. La Quiaca curve is consistent with the curve of the city of Pesqueira. With this information it is expected to be able to determine, in future works, the factors that determine the relationship between the curves format shown in each curve and local weather characteristics.

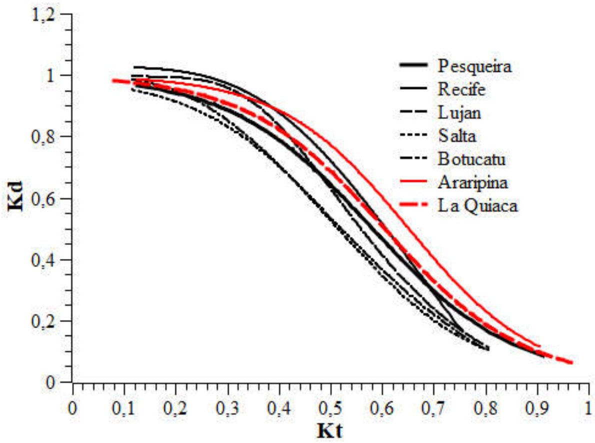

Fig. 3: K_t - K_d plan of 7 locations with their respective sigmoidal adjustment curves.

Using daily data from both sites, the Figure 4 presents the daily relations of K_d vs K_t, the eq. 2 was used for data adjustments.

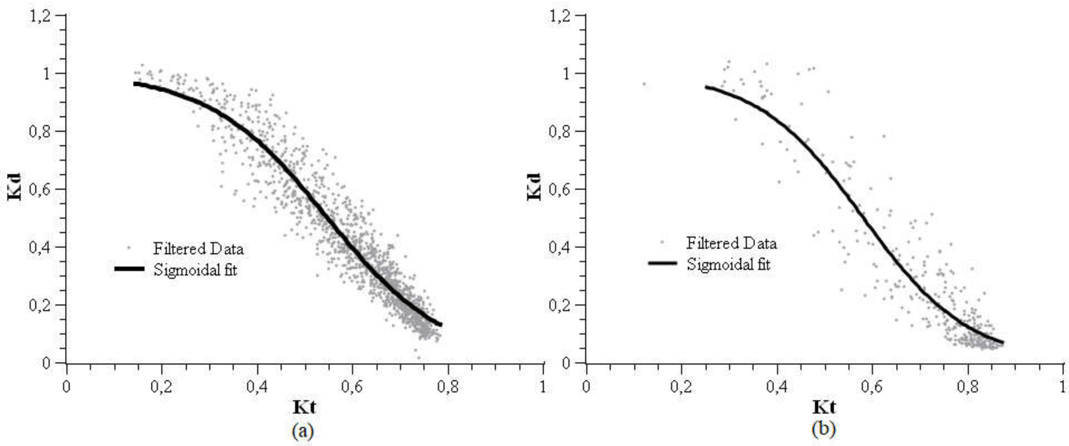

Fig. 4: Adjustment of the daily sigmoidal function for (a) Araripina (BRA) and (b) La Quiaca (ARG).

The Figure 4a shows daily data and its adjustment for Araripina station, it was used data of 1408 days. For La Quiaca, the relation used less quantity of data points, 339 days (Figure 4b). The adjustment quality indicators are presented in Table 3. The coefficient of determination (R^2) is better to Araripina than La Quiaca otherwise they are high, what shows that both adjusts are adequate.

Tab. 3: Daily coefficients of the sigmoidal function adjusted for Araripina (BRA) and La Quiaca (ARG).

Sites	a	b	R^2	χ^2
Araripina (BRA)	-4.406	8.047	0.9140	6.667
La Quiaca (ARG)	-5.216	8.969	0.8689	3.013

The Figure 5 presents a comparation of two sigmoidal curves of daily K_t vs K_d relation. La Quiaca curve is above Araripina curve due to La Quiaca “a” parameter that is higher than Araripina. It can be noted that for lower and higher values of K_t, its correspondent kd value is closed to. The curves are similar, and its higher difference is 0.08 in K_d axis correspondent to Kt = 0.45.

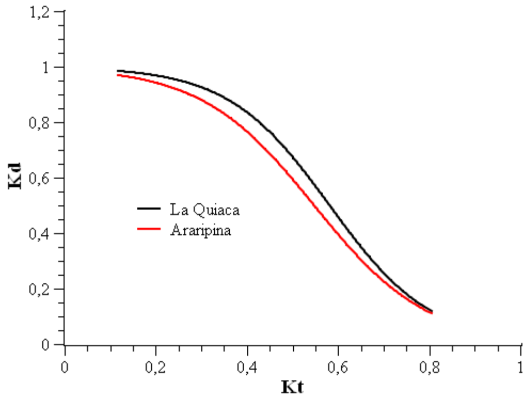

Fig. 5: Daily K_t - K_d plan of 2 locations with their respective sigmoidal adjustment curves.

4. Conclusions

In this work, sigmoidal functions have been developed to describe the relationship between hourly and daily K_t vs K_d for two different climate sites: Araripina (Brazil) and La Quiaca (Argentina). For both sites the results of R^2 are greater than 0.85, indicating a good degree of correlation. For future work, the influence of the different climates and the height differences of both sites will be analyzed.

5. Acknowledgments

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6. References

Boland, J., Huang, J., Ridley, B. 2013. Decomposing global solar radiation into its direct and diffuse components. Renewable and Sustainable Energy Reviews. 28, 749-756.

Cao, F., Li, H., Yang, T., Li, Y., Zhu, T., Zhao, L. 2017. Evaluation of diffuse solar radiation models in Northern China: New model establishment and radiation sources comparison. Renew Energ 103, 708-720.

Collarespereira, M., Rabl, A. 1979. Average Distribution of Solar-Radiation - Correlations between Diffuse and Hemispherical and between Daily and Hourly Insolation Values. Solar Energy. 22, 155-164.

Engerer, N.A. 2015. Minute resolution estimates of the diffuse fraction of global irradiance for southeastern Australia. Solar Energy. 116, 215-237.

Erbs, D.G., Klein, S.A., Duffie, J.A. 1984. Estimation os the diffuse radiation fraction for hourly, daily e monthly average global radiation. Solar Energy. 28, 293.

Gueymard, C.A., Ruiz Arias, J. 2016. Extensive worldwide validation and climate sensitivity analysis of direct irradiance predictions from 1-min global irradiance. Solar Energy. 128, 1-30.

Hay, J.E. 1963. A rational procedure for predicting the long-term average performance of flat-plate solar-energy collectors: with design data for the U.S., its outlying possessions and Canada. Solar Energy. 7, 53-74.

LeBaron, B. A., Michalsky, J. J., & Perez, R. 1990. A simple procedure for correcting shadowband data for all sky conditions. Solar Energy, 44(5), 249–256.

Lemos, L., Starke, A., Boland, J., Cardemil, J., Machado, R., Colle, S. 2017. Assessment of solar radiation components in Brazil using the BRL model. Renewable Energy: Technology and the Environment. Vols 1-5, 108, 569-580.

Li, Danny H. W., Lam, Tony N. T. 2007. Determining the Optimum Tilt Angle and Orientation for Solar Energy Collection Based on Measured Solar Radiance Data. International Journal of Photoenergy, 2007, 85402.

Liu, B.Y.H., Jordan, R.C. 1963. A Rational Procedure for Predicting the Long-Term Average Performance of Flat-Plate Solar-Energy Collectors - with Design Data for the United-States, Its Outlying Possessions and Canada. Solar Energy. 7, 53-74.

Malet-Damour, B., Guichard, S., Jean, A. P., Miranville, F., Boyer, H. 2018. SHADECO: A low-cost shadow-ring for diffuse measures: State of the art, principles, design and application. Renewable Energy, 117, 71-84.

Pedrosa Filho, M.H.O., Gerônimo, C. A. d. O., 2018. Desenvolvimento de modelos de correlação e ajuste da radiação difusa para o Agreste pernambucano. Proceedings VII Congresso Brasileiro de Energia Solar, Gramado.

Perez, R., Stewart, R., Arbogast, C., Seals, R., Scott, J. 1986. An anisotropic hourly diffuse radiation model for sloping surfaces: description, performance validation, site dependency evaluation. Solar Energy. 36, 481-497.

Raichijk, C. 2012. Control de calidad de mediciones de radiación solar. Avances en Energía Renovables y Medio Ambiente. 16.

Ridley, B., Boland, J., Lauret, P. 2010. Modelling of diffuse solar fraction with multiple predictor. Renewable Energy. 35, 478-483.

Yang, Dazhi, Boland, J. 2019. Satellite-augmented diffuse solar radiation separation models. Journal of Renewable and Sustainable Energy, 11, 2.