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STATISTICAL CORRELATIONS BETWEEN SOLAR RADIATION PARAMETERS AND CLOUDINESS FRACTIONS AT THE BRAZILIAN SOUTHERN SPACE OBSERVATORY

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ABSTRACT: In Brazil, the SONDA project have installed a ground data acquisition network in order to provide reliable ground data to develop and improve numerical models to assess the energy resource in Brazilian territory. One of SONDA measurement site is located at the Southern Space Observatory – SSO/CRS/CIE/INPE–MCT, in São Martinho da Serra, South of Brazil. It has two *Pyrhanometers Kipp & Zonen CM21* and *CM22* for global and diffuse solar irradiation measurement, a *Pyrheliometer Eppley NIP* to acquire direct beam solar irradiation data and a *Total Sky Imager TSI-440* to evaluate the opaque and thin cloudiness fractions The cloudiness is the main impact factor on solar irradiation at the surface, and the major cause of deviations on estimates provided by numerical models. These work aims at studying the cloud cover influence on five radiation parameters based on direct-beam, diffuse, and global solar radiation ratios. It was analyzed data collected for zenithal solar angle (SZA) lesser than 75deg. between September/2005 to September/2007. It was observed the solar radiation behavior as function of total, opaque and thin cloudiness fractions. Empirical models were developed, using part of the data, to estimate the radiation parameters in function of ground data for cloudiness fractions by using polynomial functions and multiple linear regressions (RLM). It was observed that opaque cloudiness fraction showed more influence on radiation parameters than thin cloudiness fraction. The Root Mean Square Error (RMSE), roughly 22-35%, and Mean Bias Error (MBE), around 1%, were obtained using the remaining data. The correlation factor among solar parameters and cloud fractions were around 0.90, however, it was observed larger correlations in some SZA intervals. The results are important for a better knowledge of the influence that different cloudy thickness can offer on surface solar irradiation and to improve radiative transfer models.

INTRODUCTION

- The study and forecasting of the solar radiation energy resources is required for the best use of this clean and renewable energy source.
- The solar radiation that reaches the top of atmosphere go through absorption and scattering processes caused by aerosols, atmospheric gases and clouds until reach the surface.
- These interactions between clouds and solar radiation are complex, and depends on the clouds characteristics such optical depth, cloud type, amount and height.
- This paper aims at studying the influence of cloudiness on the fraction of solar radiation components that reaches the ground
- Another goal is to develop empirical models to estimates solar radiation values from cloudiness index measured at SONDA measurement site at Southern Spatial Observatory – SSO/CRS/CIE/INPE – MCT.

METHODOLOGY

- The SONDA project installed and has been operating a ground station network in Brazil in order to provide reliable ground data to be used in validation of numeric models and in energy resource assessment.
- The Southern Space Observatory – SSO/CRS/CIE/INPE–MCT (COLOCAR LAT LON) is one of these reference ground sites. It has a CM21 and CM22 Pyrhanometers (Kipp & Zonen) to global and diffuse solar irradiation measurement and a Pyrheliometer NIP (Eppley Laboratory,Inc) to direct beam solar irradiation measurement.
- The opaque and thin cloudiness fractions are acquired by a *Total Sky Imager TSI-440 (YES, Inc)*. It has a colored camera to capture sky image each 15 minutes. The pixels are evaluated by the *TSI Manager Software* and classified as thin and opaque clouds.
- It was calculated 15 minutes – irradiation – means related to each one of the 7500 cloud fractions data collected for zenithal solar angle (SZA) lesser than 75deg. between September/2005 to September/2007.

Figure 1 - SONDA reference station installed at the Southern Space Observatory – SSO/CRS/CIE/INPE – MCT.

- The radiation parameters analyzed, are presented in the Table 1, where TOA is the global solar radiation at the top of the atmosphere.

Table 1 – Radiation Parameters analyzed in this paper.

Parameter	Ratio
K_T	Global by TOA Solar Radiation
K_D	Diffuse by TOA Solar Radiation
K	Diffuse by Global Solar Radiation
DDB	Diffuse by Direct-Beam Solar Radiation
DB-TOA	Direct-Beam by TOA Solar Radiation

- The solar parameters behavior were analyzed as function of thin (X_{TH}), opaque (X_{OP}), and total (X_T) cloudiness fractions, evaluating the correlation factors among them.
- The ground data was split in two groups: one for development of empirical models and other for statistic validation of models results.
- The empirical models were developed by polynomial functions (Eq.1) and multiple linear regression (Eq.2). Their performance was evaluated by calculating the Mean Bias Error (MBE) and Roots Mean Square Error (RMSE) statistic deviation.

$$P = A + B \cdot X_T + C \cdot X_T^2 + D \cdot X_T^3 \quad (1)$$

$$P = A + B \cdot X_{OP} + C \cdot X_{TH} \quad (2)$$

where: A, B, C, D are equation coefficients and P are one of the parameters from Table 1.

RESULTS

- The correlation factor between the solar radiation parameters and total, opaque and thin cloudiness fractions are showed in the Table 2.
- The highest correlations between cloudiness and radiation data were found for K_T, K and DB-TOA parameters.
- It can be notice in the Figures 2 and 3 that K increase and DB-TOA decrease when cloud cover grows due to scattering processes in the atmosphere.

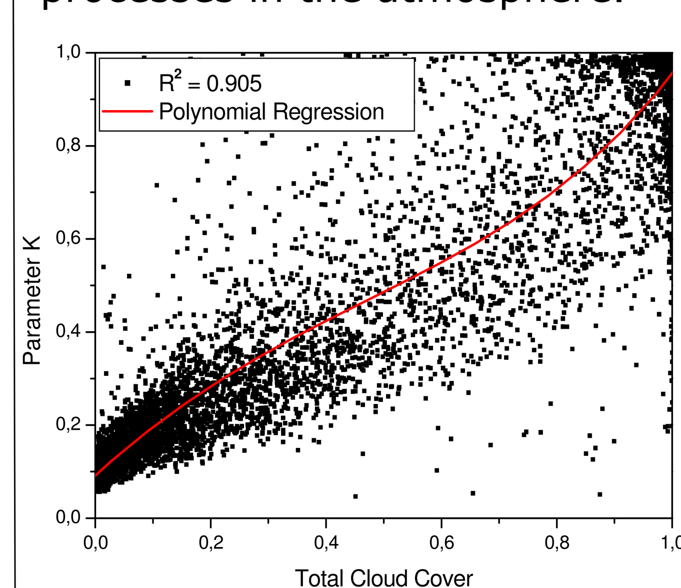

Figure 2 – Measured K as function of total cloud cover fraction measured at the Southern Space Observatory

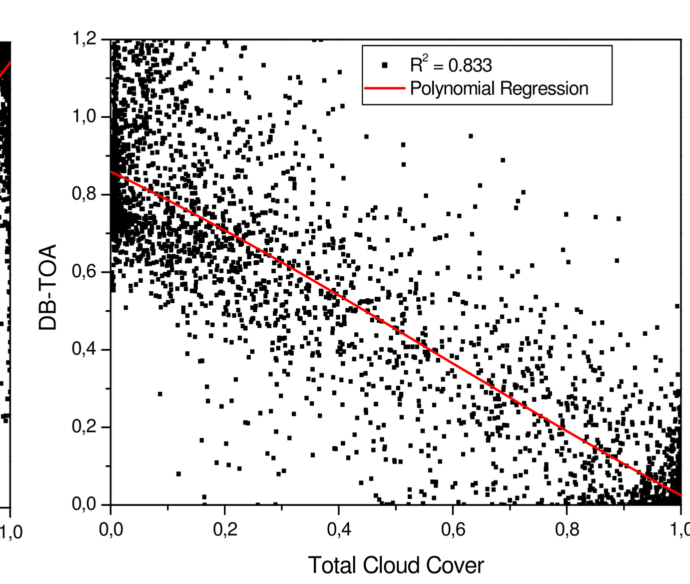

Figure 3 – Measured DB-TOA ratio as function of total cloud cover fraction measured at the Southern Space Observatory.

Table 2 - Correlation factors between radiation parameters and cloudiness fractions.

Cloud Fraction	K_T	K_D	K	DB-TOA	DDB
Thin	-0,349	0,192	0,352	- 0,352	0,134
Opaque	-0,791	0,511	0,92	-0,877	0,616
Total	-0,835	0,529	0,951	-0,909	0,596

- The empirical models developed by polynomial regression have its coefficients and statistic information showed in the Table 3.

Table 3 – Coefficients and statistical information about empirical models developed by polynomial regression.

Model	A	B	C	R^2	MBE	RMSE
K_T	-x,xxx	-x,xxx	-x,xxx	0,xxx	-x,xxx%	XX,XX%
K						
DB-TOA						

- Additionally, the Table 4 presents the coefficients from Eq. 2 for empirical models developed by MLR Regression, besides of their correlations factors and statistical deviations.

Table 4 – Coefficients and statistical information about empirical models developed by multiple linear regression.

Model	A	B	C	D	R^2	MBE(%)	RMSE(%)
K_T	-x,xxx	-x,xxx	-x,xxx	-x,xxx	0,698	0,665	26,63
K							
DB-TOA							

CONCLUSION

- Analyzing the data dispersion it is possible to confirm the difficulty to get best correlations between solar irradiation measurements and the available cloudiness data.
- Although the opaque cloudiness fraction showed more influence in solar irradiation than thin cloudiness fraction, the best results were obtained with the total cloudiness.
- In the other hand, the cloud classification between thin and opaque fraction didn't bring a modeling advantage judging by the similar correlations and statistic deviations for polynomial and MLR models.
- A longer temporal data series is necessary to get more reliable empirical models and contribute to energetic models improvements.

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