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AN ASSESSMENT OF THE DIFFUSE RADIATION MODELS FOR PREDICTION ON HOURLY GLOBAL RADIATION IN TILTED SURFACE

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ABSTRACT: The total solar irradiation incident on a tilted surface consists in three components including: direct, diffuse and reflected from the ground. The reflected radiation has a small effect and the direct radiation can be calculated with an isotropic model. The most difficulty depends on diffuse radiation by circumsolar variations, horizontal brightness, isotropic and anisotropic subcomponents. This study evaluated the influence of diffuse radiation estimate by different models for obtaining the incident global radiation on tilted surfaces at 12.85, 22.85and 32.85° facing to North, in hourly temporal partition, under different cloudiness sky conditions, in Botucatu, São Paulo State, Brazil (22°53′ S, 48°26′ W and 786 m above sea level). The following models were: Circumsolar [CIR], Badescu [Ba], Hay [Ha] and Ma and Iqbal [MI], that are indicated as the best models for estimating the diffuse radiation in the geographic and climatic local conditions. The increase of the inclination angle provides increased scattering between measured and estimated. The largest variations in the statistical residues were found for atmospheric transmissivity coefficients less than 0.15 and the best estimates occurred of cloudy skies due the low energy levels.
Keywords: atmospheric transmissivity, statistical index, parameterized models.

AVALIAÇÃO DE MODELOS DE ESTIMATIVA DA RADIAÇÃO DIFUSA NA OBTENÇÃO DA RADIAÇÃO GLOBAL HORÁRIA EM SUPERFÍCIES INCLINADAS

RESUMO: *A radiação solar incidente em planos inclinados é composta por três componentes: direta, difusa e refletida do solo. A radiação refletida apresenta um efeito pequeno e a radiação direta pode ser obtida por modelos isotrópicos. Em geral, as maiores limitações dependem da radiação difusa por variações nas subcomponentes circunsolar, brilho horizontal, isotrópicos e anisotrópicos. Este trabalho avaliou a influência do modelo de estimativa da radiação difusa na obtenção da radiação global incidente em superfícies inclinadas a 12.85º, 22,85º e 32,85° para o Norte, na partição horária, sob diferentes condições de nebulosidade, em Botucatu, SP (22° 53′ S, 48° 26′ W e 786 m de altitude). Foram avaliados os seguintes modelos: Circunsolar [CIR], Badescu [Ba], Hay [Ha] e Ma e Iqbal [MI], indicados como os melhores modelos para estimativa da radiação difusa nas condições geográficas e climáticas locais. O aumento da inclinação proporcionou maiores dispersões entre valores medidos e estimados da radiação global. As maiores variações nos resíduos estatísticos foram encontrados para coeficientes de transmissividade atmosférica inferiores a 0,15 e em condições de céu nublado ocorreram melhores estimativa em função dos baixos níveis energéticos.*
Palavras-chave: *transmissividade atmosférica, indicativos estatísticos, modelos parametrizados.*

1. INTRODUCTION

In Brazil, the routine monitoring of solar radiation are linked to universities and research institutes, and they are usually performed for the global radiation on horizontal planes. This is due to the costs involved in the acquisition and maintenance of specific instruments for measuring of attenuation and/or spectral components, thus justifying the existence of few solar radiometry stations installed in Brazil (CODATO et al., 2008; ESCOBEDO et al., 2009; VIANA et al., 2011; FURLAN et al., 2012).

The incident solar radiation on a tilted surface must be determined by converting the solar radiation intensities measured on a horizontal surface to that incident on the tilted surface of interest in order to design the system size and estimate its productivity (EVSEEV; KUDISH, 2009). The global solar radiation incident on a horizontal surface is composed of direct and diffuse radiation, whereas on tilted surfaces consist of three components: direct radiation, diffuse radiation and ground reflected radiation. For this case, the direct radiation on a tilted surface can be computed by the relatively simple geometrical relationship between the horizontal and tilted surfaces. The ground reflected radiation can be estimated with good accuracy with an isotropic model using a simple algorithm (PANDEY; KATIYAR, 2011).

This is not the case regarding the diffuse component, it requires isotropic and anisotropic corrections, it is dependent on atmospheric change. Those corrections include the astronomical, geographical, climatic and geometric variations (NOTTON et al., 2006; NOORIAN et al., 2008; EL-SEBAII et al., 2010). Recently a large number of models were developed for estimating the incident diffuse radiation on tilted surface and this abundance of models attests to the complexity of measures and estimates (KAMALI et al., 2006; LOUTZENHISER et al., 2007; BOLAND et al., 2008; PANDEY; KATIYAR, 2009; CHWIEDUK, 2009; RAKOVEC; ZAKŠEK, 2012).

In usual measures for diffuse or direct radiation estimates is applied the statistical or parametric estimation models in different atmospheric conditions and tilt angles (SOUZA et al., 2011; SOUZA; ESCOBEDO, 2013). However, the Brazilian's studies conditions have few meteorological stations with measured diffuse radiation and it has two possibilities to obtain this component: i) the difference method (global - direct - reflected), and ii) estimates were calculated as functions of optical air mass, turbidity, sky conditions, isotropy and anisotropy. These methods have few correlations when apply the reverse process and evaluate the effect of diffuse radiation estimated by the incident global radiation on tilted planes. According to El-Sebaii et al. (2010), in most cases, the method of subtracting the diffuse radiation from the total radiation does not give accurate results. Therefore, it has become increasingly important to accurately estimate on the monthly average amount of available daily diffuse solar radiation in a given region for feasibility study and successful implementation of concentrating solar energy systems. This paper discusses a statistical performance of twenty parameterized models to estimate hourly incident diffuse radiation on tilted surfaces to 12.85º, 22.85º and 32.85° facing to North, in different sky conditions (cloudiness).

2. MATERIAL AND METHODS

2.1. Site and measurements

The data of global, direct and diffuse radiation used in this study was measured at the radiometric station, at latitude of 22°53′S and longitude of 48°26′W , located in the rural area of Botucatu city, São Paulo State, Brazil. Botucatu is a city with 127.328 habitants, it is located in the countryside of Brazil, at 786 m above the mean sea level, and this is approximately 221 km far from the Atlantic Ocean. According to the Köppen climate classification, this climate type is Cwa, characterized as temperate, with dry winter and humid summer (ESCOBEDO et al., 2009; SOUZA; ESCOBEDO, 2013).

The evaluations were conducted on three inclinations, with slopes of 12.85° (latitude - 10°), 22.85° (latitude) and 32.85° (latitude + 10°) and this occurred in different periods: between 09/2001 to 02/2003 at 12.85°; 04/1998 to 08/2001 at 22.85°; 03/2004 to 12/2007 at 32.85°. The measurements were independently and concomitant with the measures on horizontal surface. There was an analyze of consistency on databases and outliers (derived from reading errors or malfunction of the sensors and system data acquisition) were removed.

Measurements were considered instant values when obtained by average of five minutes (300 readings). The acquisition system employed was the Microlloger CR23X, which operating at a 1Hz of frequency and a SM192 interface memory module with a SC532 microcomputer operated by PC 208W software, both of Campbell Scientific, Inc. The instant global horizontal irradiation (I_{GH}) was measured by an Eppley pyranometer - PSP with calibration factor of 7.45 μV W^{-1} m^{-2} and linearity of ± 0.5% (0-2800 W m^{-2}). For instant global tilted radiation ($I_{G\beta}$) was used a CM3 pyranometer from Kipp & Zonen, who owns the sensitivity response of ± 10-35 μV W^{-1} m^{-2}, the response time of 18s, the temperature response of ± 1.0% for the range of -40° C to 80° C and deviations for the cosine effect of ± 2% ($0 < z < 80°$). The instantaneous incidence direct radiation (I_{BN}) was obtained by a pireliometer Eppley NIP-coupled to solar tracker ST3 Eppley with calibration factor of 7.59 μV W^{-1} m^{-2} and linearity of ±0.5% (0-1400 W m^{-2}).

2.2. Data Processing

The hourly diffuse radiation on horizontal [H^h_{DH}] and tilted surfaces [$H^h_{D\beta}$] were obtained by the difference method (Eq. 1 and 2). Assessments were given the seasonality by obtaining of annual average and monthly schedules of energy levels.

$$H^h_{DH} = H^h_{GH} - H^h_{BH} \quad (1)$$

$$H^h_{D\beta} = H^h_{G\beta} - H^h_{B\beta} - H^h_{R\beta} \quad (2)$$

Therefore, the hourly global radiation was obtained by integrating of instantaneous values. The projection of hourly direct radiation also was obtained by integrating the instantaneous values. On the horizontal surface [$H^h_{D\beta}$] it was given by the product between the direct radiation measure on incidence and zenital angle by horizontal surface.

$$H^h_{BH} = H^h_{BN} \cos Z_H \quad (3)$$

The projection of direct radiation to hourly inclined planes [$H^h_{D\beta}$] was given by the geometrical relationship between the extraterrestrial radiation to a tilted surface and a horizontal surface or the ratio of the cosine of the inclined zenith angles (Z_β) and horizontal (Z_H) (EL-SEBAII et al., 2010; RAKOVEC; ZAKŠEK, 2012).

$$R_B = H^h_{0\beta} / H^h_{0H} \quad (4)$$

In which: H^h_{0H} and $H^h_{0\beta}$ is extraterrestrial radiation to horizontal and the inclined surfaces respectively, obtained by equations 5 and 6 described by Iqbal (1983).

$$H^h_{0H} = H_{SC}\, E_0\, [(\sin\delta \sin\varphi) + (\cos\delta \cos\varphi \sin \omega_s)] \quad (5)$$

$$H^h_{0\beta} = H_{SC}\, E_0\, [\sin\delta \sin(\varphi\pm\beta) + \cos\delta \cos(\varphi\pm\beta) \sin \omega'_s] \quad (6)$$

In which: H_{SC} is the solar constant (4921 KJ m^{-2} h^{-1}); φ is the local latitude; δ is the hourly solar declination (Eq. 7), dependent of the season (DJ – Julian day); E_0 is the correction factor of the eccentricity of Earth's orbit (Eq. 8); ω_s and ω'_s are the hourly angle by horizontal and tilted surfaces, respectively (Eq. 10 and 11).

$$\delta = 23.45 \sin [(360/365)*(DJ+284)] \quad (7)$$

$$E_0 = 1.00011 + 0.034221\cos\Gamma + 0.00128\sin\Gamma + 0.000719\cos2\Gamma + 0.000077\sin2\Gamma \quad (8)$$

$$\Gamma = 2\pi\, [(DJ - 1)/365] \quad (9)$$

$$\omega_s = \cos^{-1} (- \tan\delta \tan\varphi) \quad (10)$$

$$\omega'_s = \min \{\cos^{-1} (- \tan\delta \tan\varphi) \,;\, \cos^{-1} [-\tan\delta \tan(\varphi\pm\beta)]\} \quad (11)$$

The hourly reflected component $[H^h_{R\beta}]$ incident on tilted surfaces may have isotropic and anisotropic behavior, however, the anisotropy should be applied only for days with clear skies. Due to the variability of sky cover conditions in Botucatu was considered only the isotropic behaviour given by equation 12 (CHWIEDUK, 2009; ESCOBEDO et al., 2009; FURLAN et al., 2012;), which in turn is dependent on surface albedo (α) considered as 0.23 for reference crop.

$$H^h_{R\beta} = 0.50\, H^h_{GH}\, \alpha\, (1 - \cos\beta) \quad (12)$$

2.3. Estimative models of hourly diffuse radiation

Twenty models for estimating the hourly diffuse radiation incident on tilted surfaces were evaluated, distributed in circumsolar theory (1), isotropic and anisotropic, described below:

2.3.1. Circumsolar (geometric) – CIR model

$$H^h_{D\beta} = H^h_{DH}\, (\cos Z_\beta / \cos Z_H) \quad (13)$$

In which: $H^h_{D\beta}$ - hourly diffuse radiation on tilted surface (MJ m^{-2} h^{-1}); β - angle of inclination; H^h_{DH} - hourly diffuse radiation on horizontal surface (MJ m^{-2} h^{-1}); Z_H - horizontal zenith angle; Z_β - tilted zenith angle.

2.3.2. Badescu (2002) – BA model (isotropic)

$$H^h_{D\beta} = H^h_{DH}\, [(3 + \cos 2\beta)/4] \quad (14)$$

2.3.3 Hay (1979)

HA model (anisotropic): this is considered to be the addition of the circumsolar component coming from the direction near the solar disk and a diffuse component isotropically distributed from the rest of the sky. These two components are weighted according to an index of anisotropy, which represents transmittance through the atmosphere of direct irradiance:

$$H^h_{D\beta} = H^h_{DH}[F\, (\cos Z_\beta / \cos Z_H) + (1-F_H)\, ((1+\cos\beta)/2)] \quad (15)$$

$$F_H = H^h_{BH} / H^h_{0H} \quad (16)$$

In which: H^h_{BH} - hourly direct (emitted) radiation projected on horizontal (MJ m^{-2} h^{-1}); H^h_{DH} - hourly extraterrestrial radiation on horizontal (MJ m^{-2} h^{-1});

On cloudy days, the global radiation is composed only by the diffuse component, while the anisotropic factor (F_{HAY}) tends to nullity and HA model introduces only isotropic characteristics.

2.3.4. Ma and Iqbal (1983)

MA model (anisotropic): consider the coefficient of atmospheric transmissivity on horizontal (K_{TH}) obtained by the ratio between the global and extraterrestrial radiation.

$$H^h_{D\beta} = H^h_{DH}\, [(K^h_{TH} R_B) + (1-K^h_{TH}) \cos^2 (\beta/2)] \quad (17)$$

2.4. Sky conditions classification

The evaluation of cloudiness classification (sky conditions) was performed considering the methodology when ranked the sky conditions into 4 types according to coefficient of atmospheric transmissivity of global radiation $[K^h_T]$ (ratio between global radiation and extraterrestrial radiation) (ESCOBEDO et al., 2009; SOUZA; ESCOBEDO, 2013). This methodology avoids the use of data from direct and diffuse radiation, which are measured routinely in few Brazilian's meteorological stations and consider the following sky condition: i) cloudy sky: $[K^h_T] \le 0.35$; ii) partially cloudy sky: $0.35 < [K^h_T] \le 0.55$; iii) partially clear sky: $0.55 < [K^h_T] \le 0.65$; and iv) clear sky: $[K^h_T] > 0.65$.

2.5. Statistical indexes

To evaluate the performance of hourly estimation by tilted and horizontal surfaces were applied the statistical indexes: mean bias error (MBE), root mean square error (RMSE) and adjustment index (d) of Willmott (1981), described by:

$$MBE = \frac{\sum_{i=1}^{N} (Pi - Oi)}{N} \quad (18)$$

$$RMSE = \left[\frac{\sum_{i=1}^{N} (Pi - Oi)^2}{N} \right]^{\frac{1}{2}} \quad (19)$$

$$d = 1 - \frac{\sum_{i=1}^{N} (Pi - Oi)^2}{\sum_{i=1}^{N} (|P'i| + |O'i|)^2} \quad (20)$$

In which: P_i – estimated values; Oi- measured values; N – number of observations; $|P'i|$ - absolute values of difference $Pi - \overline{Oi}$; $|O'i|$ - absolute values of difference $Oi - \overline{Oi}$.

The MBE indicative represents the deviation of averages and negative or positive values indicate underestimation and overestimation, respectively. The RMSE indicative informs about the actual value of error produced by model, however, some proportion errors can sums significant increases in RMSE and doesn't have differentiate in overestimate or underestimate. The adjustment index "d" ranges from 0 to 1, representing how the estimated values fit with the measured values. The smaller absolute value of MBE and RMSE and higher values of the "d" index show the best performance of tested model (WILLMOTT, 1981; SOUZA et al., 2011).

3. RESULTS AND DISCUSSION

The high levels of hourly diffuse radiation occurred in lower values of zenith angle and they were dependents of the atmospheric transmissivity of solar radiation. The models for estimate the total radiation on a tilted surface, in the literature, discuss the direct and reflected components based only on geometric aspects.

For the assessment of the percentage contribution of diffuse radiation in the global radiation that reaches the three inclined surfaces and in different sky coverage were selected two best anisotropic models: Ma and Iqbal (1983) and Hay (1979); the best isotropic models: Badescu (2002) and Circumsolar model. In this case, the global radiation incident on tilted surface was given by the sum of the components of direct, reflected (equation 12) and diffuse (estimated by four models). In Figure 1, note that the filtering performed on the database allowed to diffuse radiation was less than the global radiation in the hourly partition.

When the models were used to estimate the diffuse and this add with the others components to obtain the global radiation, was observed that the anisotropic models of Hay (1979) and isotropic Badescu (2002) enabled the global component estimated to be lower the reference diffuse radiation, regardless of the sky coverage (Figure 2). The models Circumsolar and Ma and Iqbal (1981) showed this trend only for conditions of atmospheric transmissivity less than 0.65. This fact is justified, with the exception of the Circumsolar model, the other underestimates the diffuse radiation to atmospheric transmissivity less than 0.35 (cloudy conditions).

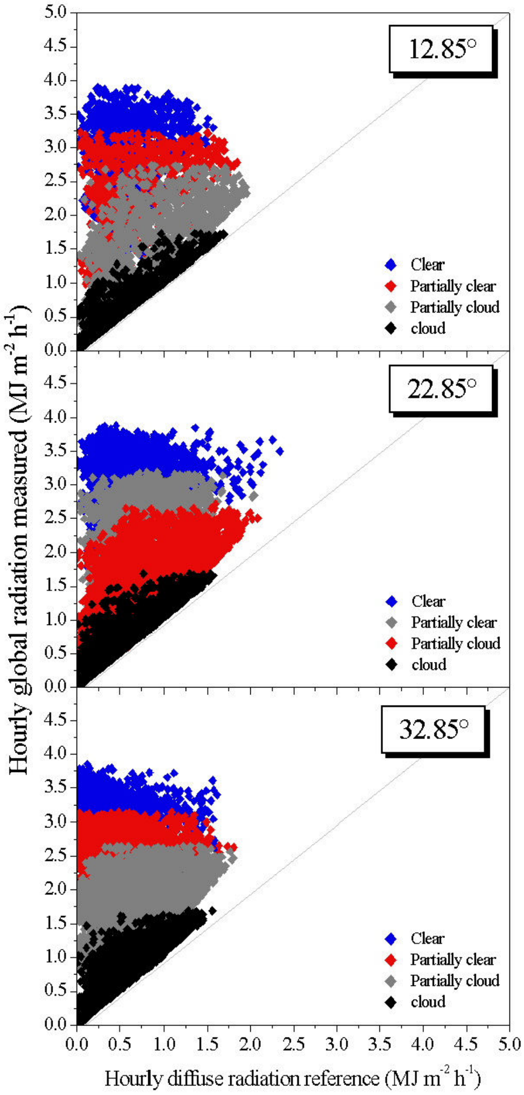

Figure 1. Relationship between hourly global radiation measured and hourly diffuse radiation reference (by difference method) for three tilted surfaces and grouped in different sky conditions.

Note that the Ma and Iqbal model (1983) allows better adjustments when the values $K_{T\beta}^{h}$ are less than 0.55 (cloudy and partly cloudy) for the three tilted surfaces. Already in clear sky conditions, the smallest dispersions are given by the Circumsolar model mainly in inclination of 32.85° (Figure 3).

Scolar et al. (2003) evaluated the possibility of modifying models to estimate the diffuse radiation by the sum of three components. In this case, the applied of conceptual quotient with global horizontal radiation on equations and found that visual analysis of scatter diagrams not occurred differences between the two methodologies of obtaining the total daily incident radiation.

However, the Perez et al. (1990) model showed better adjustment when compared with the models of Liu and Jordan (1962), Hay (1979) and Reindl et al. (1990).

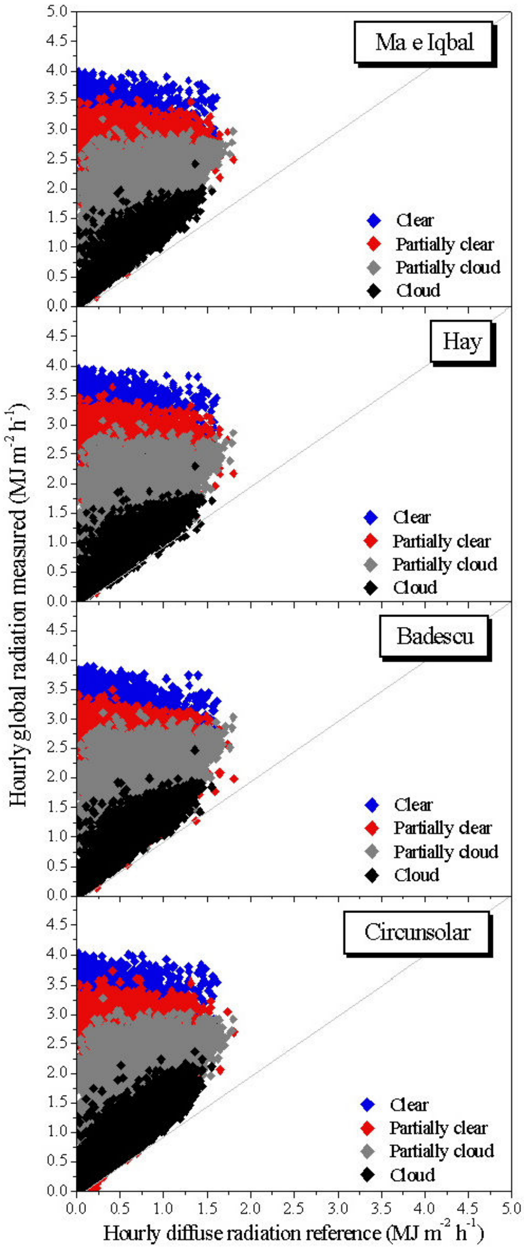

Figure 2. Relationship between hourly global radiation estimated by different models and hourly diffuse radiation reference (by difference method) for three tilted surfaces and grouped in different sky conditions**.**

Evseev; Kudish (2009) estimates the hourly global radiation on slope of 40° facing to South and noted that the Ma and Iqbal (1983) model showed linear regression of 0.9910 and 0.9834, with correlation coefficients of 0.9834 and 0.9602 for grouping all coverage sky and overcast skies, respectively, when correlated with the diffuse radiation measured and corrected by Muneer; Zhang (2002) proposed model. However, when correlated with corrections proposed by Battles et al. (1995) were found slopes of linear regression of 0.9953 and 0.9676 with decreased of determination coefficient (R^2) to 0.9646 and 0.9602, respectively.

In Figures 4 and 6 shows the percentage of deviations occurrence of hourly global radiation measured and estimated (considering four models to estimate the diffuse component). There is a normal distribution in all sky conditions to 12.85°.

The increase of the inclination angle increases the dispersion and therefore the deviations to $K_{T\beta}^{h}$ less than 0.35 (cloudy). In this sky condition, about 99.05, 93.35 and 73.74% of deviations obtained by Ma and Iqbal (1983) model are between -0.10 and 0.10 MJ m^{-2} h^{-1} to 12.85º, 22.85º and 32.85°, respectively. In the clear conditions, this fact becomes even more evident, since the same intervals deviations above, considering the Circumsolar model, there is 80.45, 52.70 and 20.79% of occurrence for the same inclinations.

In the partially cloudy sky conditions and/or partially clear sky there is a great variability of the deviations generated by each model, however, it continues the tendency of increasing the frequency amplitude with increasing the tilt angle. Around 99% of the values occurred between -0.34 and 0.30; 0.40 and -0.40; -0.65 and 0.65 MJ m^{-2} h^{-1} to partially cloudy sky -0.60 and 0.45; -0.40 to 0.65; -0.70 to 0.60 MJ m^{-2} h^{-1} for partially clear sky, the slopes of 12.85º, 22.85º and 32.85°, respectively.

All models showed the same statistical indicative values (MBE, RMSE and adjustment index) validations in the estimation of global radiation (Table 1) when compared with the values found in the validation of the diffuse radiation estimation. The only exception was the group data amount (assuming all coverage) with increasing scattering (less than 0.19 MJ m^{-2} h^{-1}) and decreased adjustments (more than 0.99).

These results for global radiation estimates are higher than those in the literature. Bilbao et al. (2003) find for 13 Spanish localities MBE values equal to 3.09% for isotropic models and 12.01% for the Temps and Coulson model (1977), with RMSE occurring between 10.05 and 11.97%, indicating that the Perez et al. (1990) model showed the best estimates of the overall time for the inclination of 42° facing to South.

From Figure 4 to 6, it is observed that the four models evaluated are similar behavior as for relative deviations of energy. The largest variations in residual statistical percentage of global radiation measured and estimated found were for $K_{T\beta}^{h}$ values less than 0.15 (cloudy), indicating isotropy conditions, justifying the positive residues found with the Badescu model (2002).

Increasing the angle of inclination provides a tendency for the negative residues originating anisotropic models. However, the reduction of residue by increasing the atmospheric transmissivity can be explained by the increased contribution of subcomponents and anisotropic circumsolar, seen that, among the four models evaluated, only one is considered isotropic (BADESCU et al., 2012).

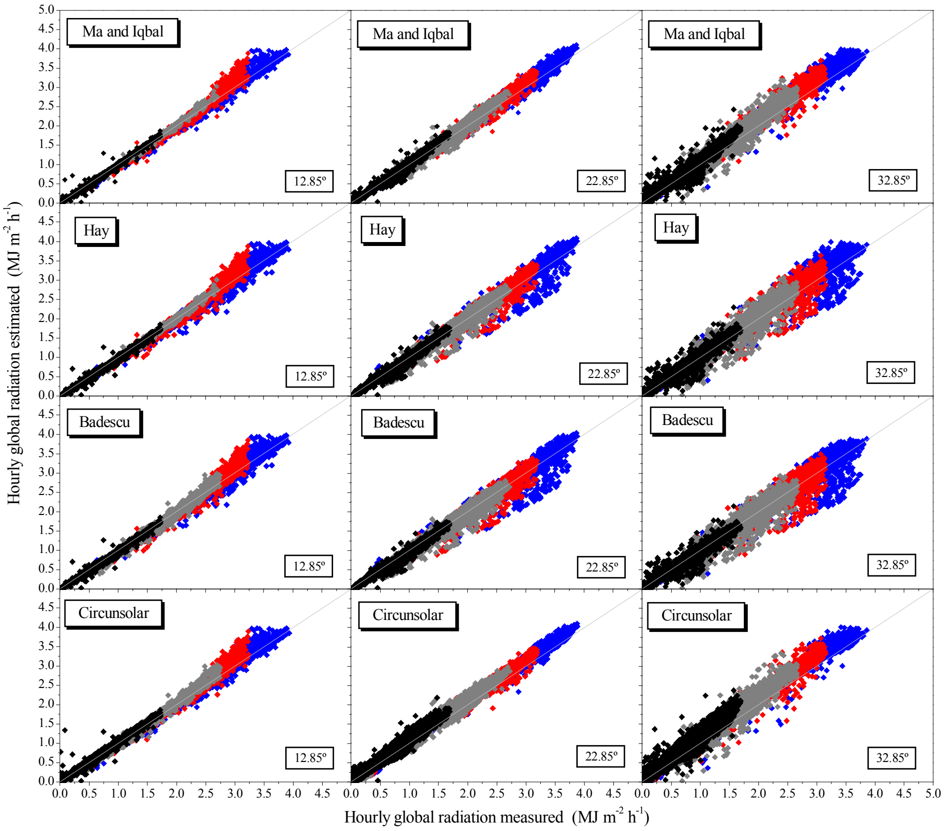

Figure 3. Correlations between measured and estimated hourly global radiation (with models to estimate the diffuse radiation) in different sky conditions and inclinations facing to North.

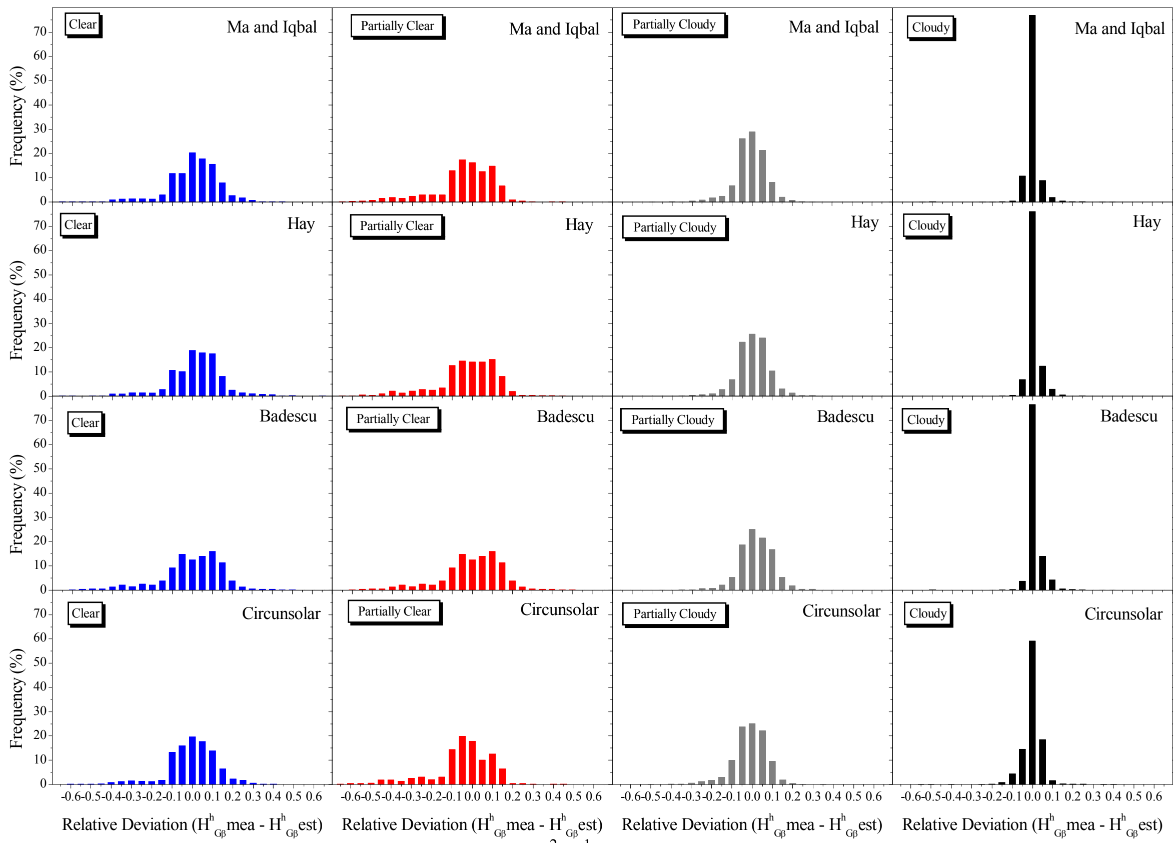

Figure 4. Frequency of energy relative deviations (in MJ m^{-2} h^{-1}) of hourly global radiation measured (reference) and estimated at different sky conditions for inclination of 12.85° facing to North.

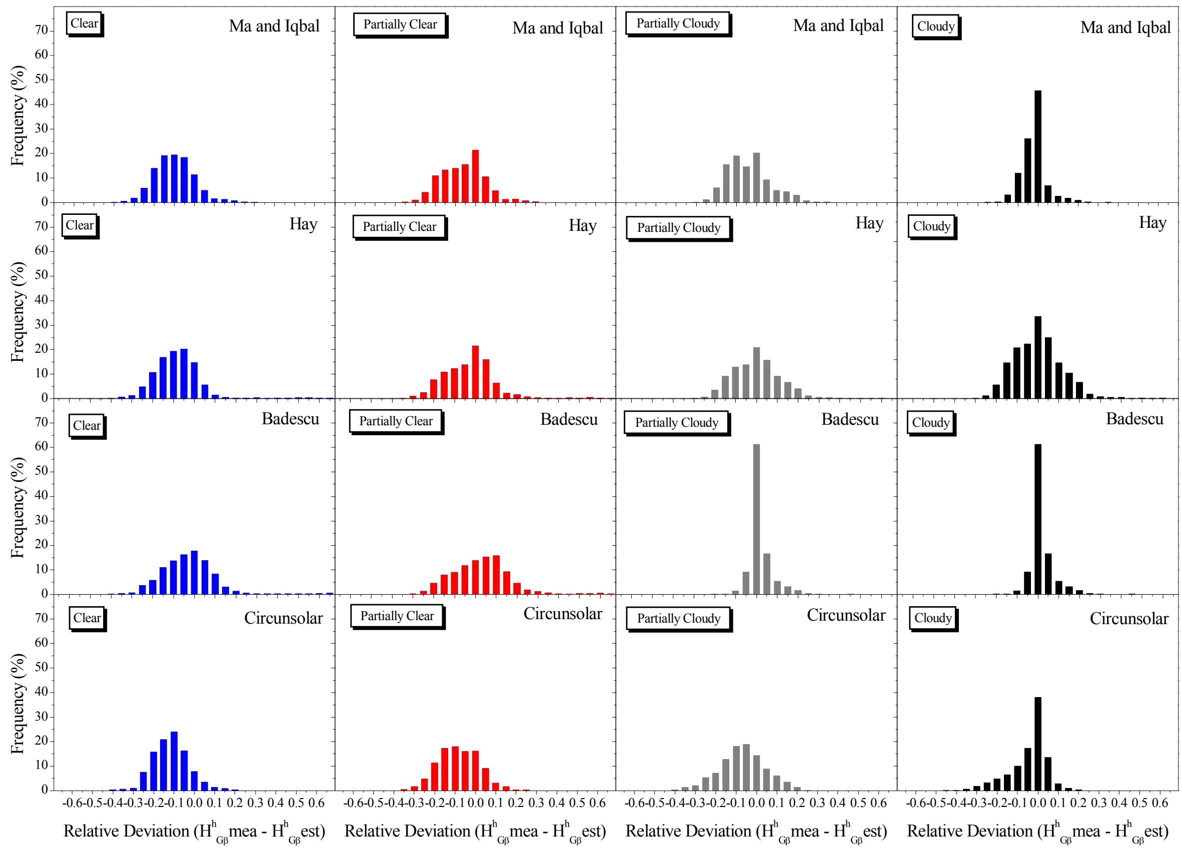

Figure 5. Frequency of energy relative deviations (in MJ m^{-2} h^{-1}) of hourly global radiation measured (reference) and estimated at different sky conditions for inclination of 22.85° facing to North.

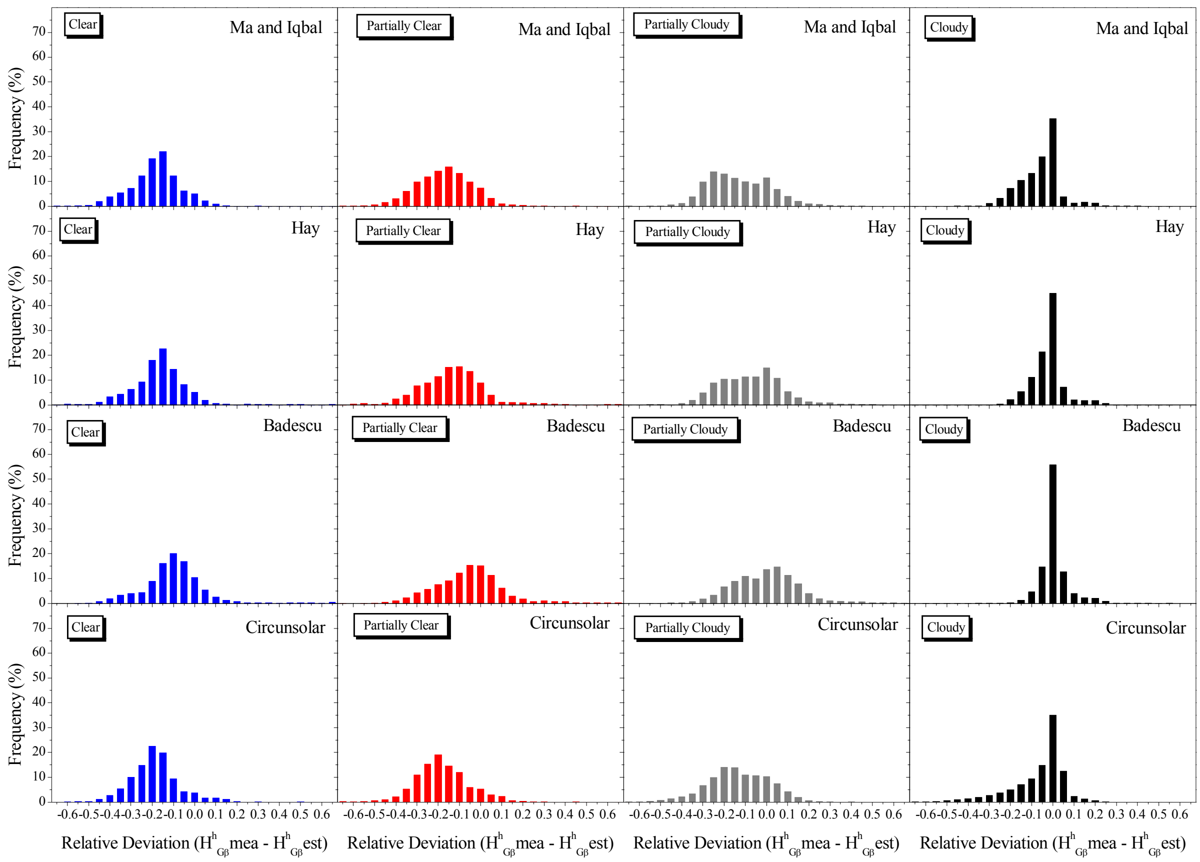

Figure 6. Frequency of energy relative deviations (in MJ m^{-2} h^{-1}) of hourly global radiation measured (reference) and estimated at different sky conditions for inclination of 32.85° facing to North.

Table 1. Statistical indexes by application of four models to estimate the diffuse component for obtaining the hourly global radiation, in different sky conditions, for inclination of 12.85, 22.85 and 32.85° facing to North.

Inclination	Model	Statistical indexes	Sky conditions				
			All	Clear	Partially clear	Partially cloudy	Cloudy
12.85°	Ma and Iqbal	MBE[2]	0.0102	-0.0061	0.0394	0.0081	-0.0017
		RMSE[2]	0.1093	0.1254	0.1566	0.0782	0.0362
		d	0.9960	0.9903	0.9881	0.9964	0.9982
	Hay	MBE	-0.0015	-0.0175	0.0257	-0.0031	-0.0070
		RMSE	0.1147	0.1365	0.1579	0.0825	0.0360
		d	0.9956	0.9885	0.9878	0.9960	0.9982
	Badescu	MBE	-0.0201	-0.0396	0.0033	-0.0189	-0.0119
		RMSE	0.1175	0.1419	0.1570	0.0850	0.0378
		d	0.9954	0.98746	0.9878	0.9956	0.9980
	Circunsolar	MBE	0.0154	-0.0008	0.0475	0.0116	0.0010
		RMSE	0.1111	0.1244	0.1577	0.0826	0.0545
		d	0.9959	0.9905	0.9880	0.9961	0.9960
22.85°	Ma and Iqbal	MBE	0.0502	0.0994	0.0601	0.0391	0.0198
		RMSE	0.1089	0.1402	0.1249	0.1148	0.0656
		d	0.9978	0.9897	0.9919	0.9912	0.9941
	Hay	MBE	0.0189	0.0659	0.0252	-0.0024	-0.0024
		RMSE	0.1224	0.1752	0.1389	0.1186	0.0566
		d	0.9972	0.9838	0.9899	0.9903	0.9954
	Badescu	MBE	-0.0198	0.0093	-0.0313	-0.0473	-0.0182
		RMSE	0.1302	0.1802	0.1525	0.1336	0.0585
		d	0.9967	0.9824	0.9875	0.0873	0.9949
	Circunsolar	MBE	0.0722	0.1150	0.0817	0.0670	0.0428
		RMSE	0.1255	0.1453	0.1306	0.1324	0.1029
		d	0.9970	0.9892	0.9914	0.9885	0.9860
32.85°	Ma and Iqbal	MBE	0.1166	0.1826	0.1708	0.1268	0.0576
		RMSE	0.1796	0.2206	0.2198	0.2003	0.1154
		d	0.9937	0.9776	0.9726	0.9728	0.9834
	Hay	MBE	0.0748	0.1480	0.1251	0.0702	0.0227
		RMSE	0.1708	0.2363	0.2162	0.1798	0.0871
		d	0.9942	0.9737	0.9727	0.9770	0.9898
	Badescu	MBE	0.0183	0.0772	0.0430	-0.0021	-0.0061
		RMSE	0.1533	0.2169	0.1925	0.1642	0.0750
		d	0.9953	0.9770	0.9773	0.9799	0.9920
	Circunsolar	MBE	0.1211	0.1863	0.1789	0.1311	0.0639
		RMSE	0.1901	0.2246	0.2256	0.2047	0.1440
		d	0.9931	0.9775	0.9720	0.9723	0.9748

4. CONCLUSIONS

The variations in cloudiness sky as a function of atmospheric transmissivity of global radiation must be employed to assess the behavior of circumsolar, isotropic and anisotropic diffuse radiation components.

The four estimate models of the diffuse component allow good estimates of hourly global radiation in the absence of measures on tilted surfaces for all cloud conditions. The increment of the inclination angle and atmospheric transmissivity decrease the statistical models performance by increased scattering.

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