ANISOTROPIC CORRECTIONS AS A FUNTION OF THE CLEARNESS INDEX KT FOR THE DIFFUSE SOLAR IRRADIANCE MEASURED BY THE MELO-ESCOBEDO SHADOWRING METHOD

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Abstract. The present paper deals with anisotropic corrections factors proposed as a function of the clearness index in order to correct the diffuse solar irradiance measured with the Melo-Escobedo Shadowring Measuring Method (ME shadowring). The global irradiance was measured by an Eppley - PSP pyranometer ; direct normal irradiance by an Eppley-NIP pyrheliometer fitted to a ST-3 sun tracking device and the diffuse irradiance by an Eppley-PSP pyranometer fitted to a ME shadowring. The validations were performed by the MBE and RMSE statistical indicators. The results showed that the anisotropic correction factors were appropriate to correct the diffuse irradiance.

Keywords. Shadowring. Clearness index. Diffuse solar irradiance. Measuring methods. Anisotropy.

1. Introduction

Among the solar radiation components used in meteorological stations observed in the world, global radiation on horizontal surface is the most extensively quantity measured. However, measurements of diffuse and direct radiations are less common. A monitoring station typically measures only two of the insolation components and calculates the other. The global and diffuse components are often measured. The direct irradiation is calculated through the Eq. (1) (global I_G radiation is the sum of the diffuse I_{DF} and direct I_{DH} radiations) due to the expensive maintenance , associated with solar tracking for the direct normal measurement.

$$I_G = I_{DF} + I_{DH} \qquad (1)$$

The shadowing method is adopted in the measurement of diffuse radiation. In this method, which presents low costs, easy maintenance and optimal operation, the ring is oriented perpendicularly to the polar axis and at an angle equal to the local latitude. It shades the bands center point from sunrise to sunset. An instrument is placed at this point and it permits the measurement of diffuse radiation for extended periods of time.

Drummond (Drummond, 1956) and Robinson (Robinson and Stoch, 1964) (Fig. 1) are two well-known shading setups. In Drummond´s setup, the pyranometer is fixed and the shadowring is translated parallelly to the polar axis which acts to compensate the solar declination. This means that periodical mechanical adjustments are necessary. In this setup, the shadowring, as seen from the pyranometer, varies its width and distance with the solar declination. In Robinson´s setup, the pyranometer is fixed in the center of the shadowring and the shadowring is rotated around its center to compensate the solar declination. The width and the distance do not change in this setup.

An alternative shadowring setup was proposed by Melo & Escobedo (1994) - ME shadowring (Fig. 1). In this setup , mechanical operation is inverse to Drummond's setup. In the ME setup, the shadowring is fixed and the pyranometer is translated parallelly to the local horizon plan in a mobile base to compensate the solar declination.

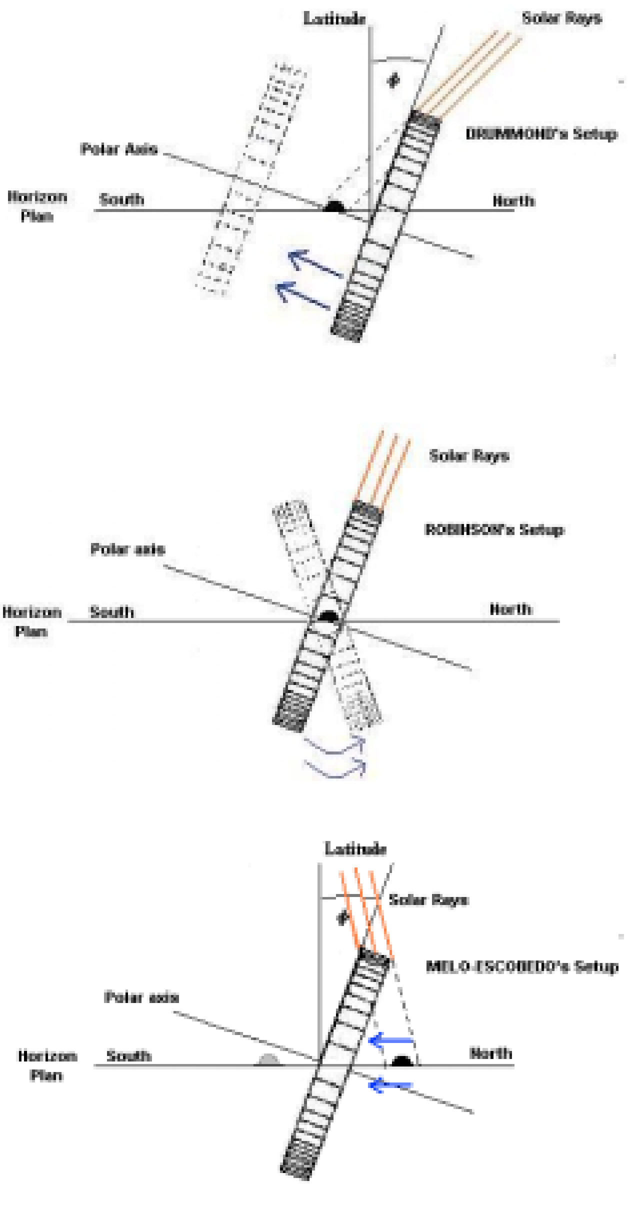

Figure 1 – Shadowring setups: Drummond, Robinson-Stoch and Melo-Escobedo.

A drawback of the shadowring method is the use of correction factors (FC) to compensate the diffuse irradiance blocked by the shadowring (Drummond, 1956; Kasten et al, 1983; Dehne, 1984; Stanhill, 1985) given by the Eq. (2). The loss fraction (Fp) is based on the isotropy of the radiation, which is considered a geometric function (the ring length and width) and geographical factors(latitude and solar declination). Oliveira et al (2002) calculated the loss fraction for the ME shadowring (Eq. (3)).

$$FC = \frac{1}{1 - F_P} \tag{2}$$

$$F_P = \left(\frac{2b}{\pi R}\right) \cos(\delta) . \left[\frac{\cos(\phi + \delta)}{\cos(\phi)}\right]^2 . \int_0^{w_S} \cos(\theta_Z) dw \tag{3}$$

where b is the ring width, R the ray, δ the solar declination, ϕ the latitude, ω the hourly angle and θ_Z the zenital angle.

The use of the isotropic correction doesn't take into account the atmospheric effects (turbidity, cloudiness, pollution, water vapor) that are responsible for the anisotropy of the diffuse radiation. Kasten et al. (1983) and Pollard and Langevine (1988) introduced corrections based on anisotropic parameters such as clearness index K_T (ratio of global to extraterrestrial radiation), zenital angle and turbidity atmospheric to improve the precision of the shadowring diffuse irradiance. Dehne (1984) observed that the anisotropic corrections are local dependent, while Painter (1981) and

Stanhill (1985) verified that the anisotropic seasonal corrections are dependent due to the different sizes and levels of the aerosol concentration in the atmosphere. LeBaron et al (1990) combined one isotropic (geographical) and three anisotropic parameters (zenital angle, clearness index and brightness) to develop anisotropic corrections for the shadowring diffuse irradiance. They concluded that the clearness index is the best representative parameter of the anisotropic conditions of the sky. In that direction, Iqbal (1983) recommends different anisotropic corrections as a function of the clearness index: 3% for $0 < K_T < 0{,}30$, 5% $0{,}30 < K_T < 0{,}65$ and 7% for $0{,}65 < K_T < 1$. Battles et al (1995) used the same parameters of LeBaron. These authors developed two correction equations: the first is used for all parameters in an unique equation, while the second is used on geometric, zenital angle and brightness parameters as a function of four clearness index intervals.

2. Methodology

The global, direct and diffuse irradiances were recorded at Botucatu/SP/Brazil by the Solar Radiometric Laboratory – FCA/UNESP (latitude 22,85º S, longitude 48,45º W, elevation 785m) in the period of 1996-2002 (5 years for modeling; 2 years for validation purposes).

The global irradiance I_G was measured by an Eppley - PSP pyranometer (K = 8,13 Vm²/W); the direct normal irradiance I_{DN} by an Eppley-NIP pyrheliometer (K = 7,73 Vm²/W) fitted to a ST-3 sun tracking device; and the diffuse irradiance I_{DF} by an Eppley-PSP pyranometer (K = 8,17 V/Wm-2) fitted to a ME shadowring (radius of 0,40m and width of 0,10m).

The diffuse irradiance data were correct isotropically by the Eq. (2) and (3). The reference diffuse irradiance I_{DFref} was calculated by the Eq. (1) (difference among the global I_G and horizontal direct I_{DH} irradiances). The horizontal direct irradiance I_{DH} was calculated by means of the multiplication of the direct normal I_{DN} irradiance by the zenital angle cosine. The extraterrestrial I_O irradiance was calculated by means of the multiplication of the solar constant I_{CS} = 1367 W/m² by zenital angle cosine.

The instruments were connected to a rechargeable battery powered datalogger (Campbell Scientific Inc, model 21X) which scans the inputs every 5 seconds and records average at 5 minute intervals.

The validation of the anisotropic corrections in a 5minute interval was performed by MBE and RMSE statistical indicators (Stone, 1993):

$$MBE(\%) = 100 \frac{\left(\sum_{i}^{N} (y_i - x_i) \Big/ N \right)}{\overline{X}} \tag{4}$$

$$RMSE(\%) = 100 \frac{\left(\sum_{i}^{N} (y_i - x_i)^2 \Big/ N \right)^{1/2}}{\overline{X}} \tag{5}$$

where y_i is the correct values, x_i the measured values, N the number of observations and $\overline{X}$ is the average measured value.

The MBE (Mean Bias Error) provide information on the long-term performance of a model. A drawback of this indicator is that over-estimation of an individual observation will cancel under-estimation in a separate observation. The RMSE (Root Mean Square Error) provide information on the short-term performance of a model by allowing a term by term comparison of the actual difference between the estimated value and the measured value. A drawback of this indicator is that a few large errors in the sum can produce a significant increase in RMSE.

3. Results And Discussions

3.1 Anisotropic Correction Factors

In the developing of the anisotropic correction model, the shadowring diffuse irradiance database was separated and grouped as a function of the clearness index K_T, according to the Liu and Jordan (1960) classification: cloudy ($0 < K_T < 0{,}30$), partially cloudy ($0{,}30 < K_T < 0{,}65$) and clear ($0{,}65 < K_T < 1$). Then, the reference and measured diffuse irradiances were compared. The Fig 2 (a), (b) and (c) shows the correlation between the reference and measured diffuse irradiances for the cloudy, partially cloudy and clear sky conditions. The equations and the determination coefficients R^2 are shown in Tab. 1:

Table 1. Anisotropic corrections as a function of the clearness index K_T intervals.

Sky covering	Anisotropic Correction Equation	R²
Cloudy	$I_{DFani} = 0{,}973 I_{DFisoME}$	0,994
Partially cloudy	$I_{DFani} = 1{,}045 I_{DFisoME}$	0,989
Clear	$I_{DFani} = 1{,}125 I_{DFisoME}$	0,984

The linear regressions for cloudy, partially cloudy and clear skies and the 45º line are compared, showing the different effect of the anisotropy for each sky covering. For cloudy sky, the anisotropic correction factor was smaller than one due to the low condition of the anisotropy (homogeneous cloud distribution). This is possible because the anisotropic correction compensates the isotropic correction unnecessary in this covering. Thus, it is necessary to apply the factor 0,973 to correct the shadowring diffuse irradiance.

For partially cloudy sky, the anisotropic conditions are dynamic due to the fast change in the cloud distribution in the atmosphere. The shadowring diffuse irradiance was underestimated in 4,5%, demanding a numeric correction of 1,045.

The clear sky shows permanent and high condition of anisotropy and the shadowring method underestimates the reference method in 12,5%, with numeric correction of 1,125. The value 12,5% represents an average value over a 7 years time. In this time, the correction varied annually among 7% to 19%, showing that the anisotropy of the radiation depends on the local climate and presents seasonal variation. The place of the measurements is located in a rural area, practically free from the urban pollution. However, in the winter period it is frequent the sugar-cane burned. Because of that, the atmosphere receives great amounts of aerosols that increase the circunsolar radiation and, consequently, increase the effect of the anisotropy.

The validation of the anisotropic correction model was performed by correcting the shadowring diffuse irradiance with the factors: 0,973 for cloudy (0 < K_T < 0,30), 1,045 for partially cloudy (0,30 < K_T < 0,65) and 1,125 for clear skies (0,65 < K_T < 1). The results were compared with respect to the reference values. The Fig. 3 (a), (b), (c) shows the correlation between the reference and anisotropic corrected diffuse irradiances for cloudy, partially cloudy and clear skies, respectively. The angular coefficients for cloudy (0,996 – Fig. 3a), partially cloud (0,999 – Fig. 3b) and clear (0,986 – Fig. 3c) skies show good correlation between the reference and anisotropic corrected diffuse irradiance. The Tab. 2 presents the statistical indicators MBE (%) and RMSE (%) obtained from the comparison between the reference and anisotropic corrected diffuse irradiances for the three sky coverings.

Table 2. Statistical indicators MBE (%) and RMSE (%) obtained from the comparison between the reference and anisotropic corrected diffuse irradiances for cloudy, partially cloudy and clear skies.

Sky Covering	MBE (%)	RMSE (%)
Cloudy	0,25	5,78
Partially Cloudy	0,51	9,83
Clear	-0,38	12,93

The statistical indicator MBE (%) shows that the anisotropic corrections were efficient, overestimating in just 0,25% the measured diffuse irradiance for cloudy and 0,50% for partially cloudy skies and underestimating in 0,38% for clear sky. The RMSE (%) shows an increase of the scattering with respect to the increase of the clearness index K_T, with 5,78% for cloudy, 9,83% for partially cloudy and 12,93% for clear skies.

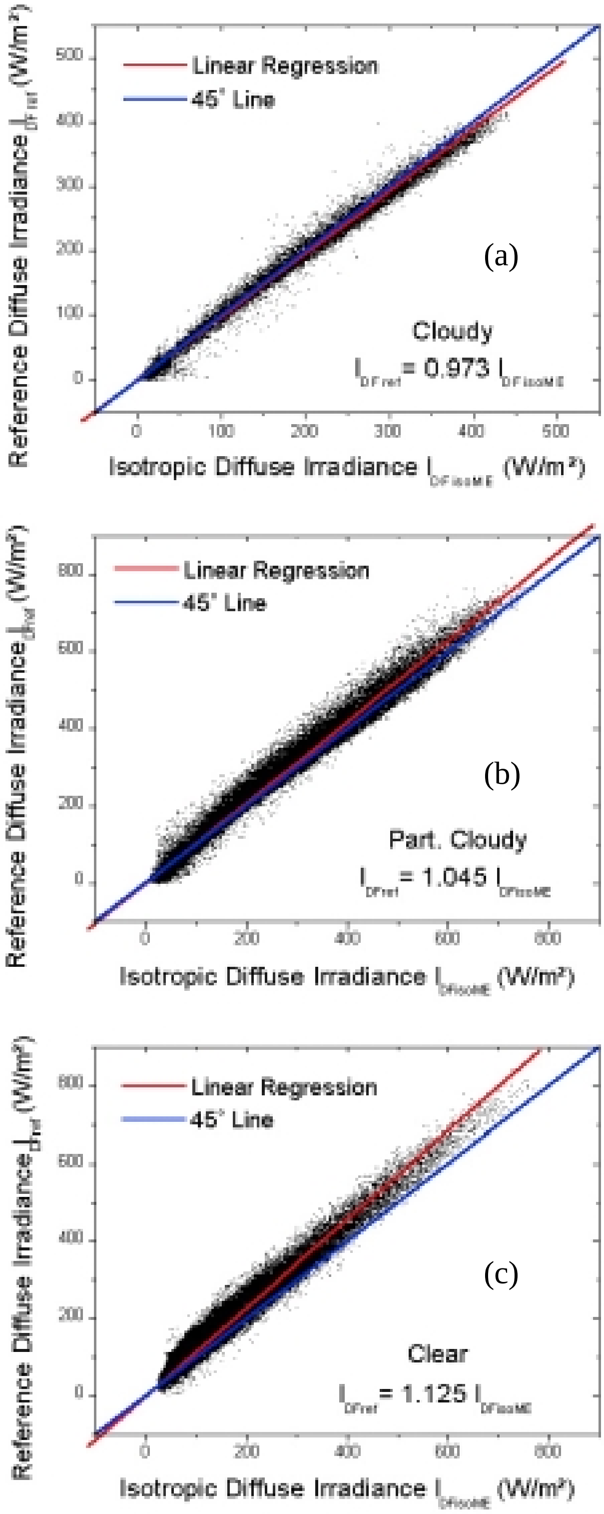

Figure 2. Anisotropic corrections as a function of the clearness index. a) Cloudy. b) Partially cloudy. c) Clear.

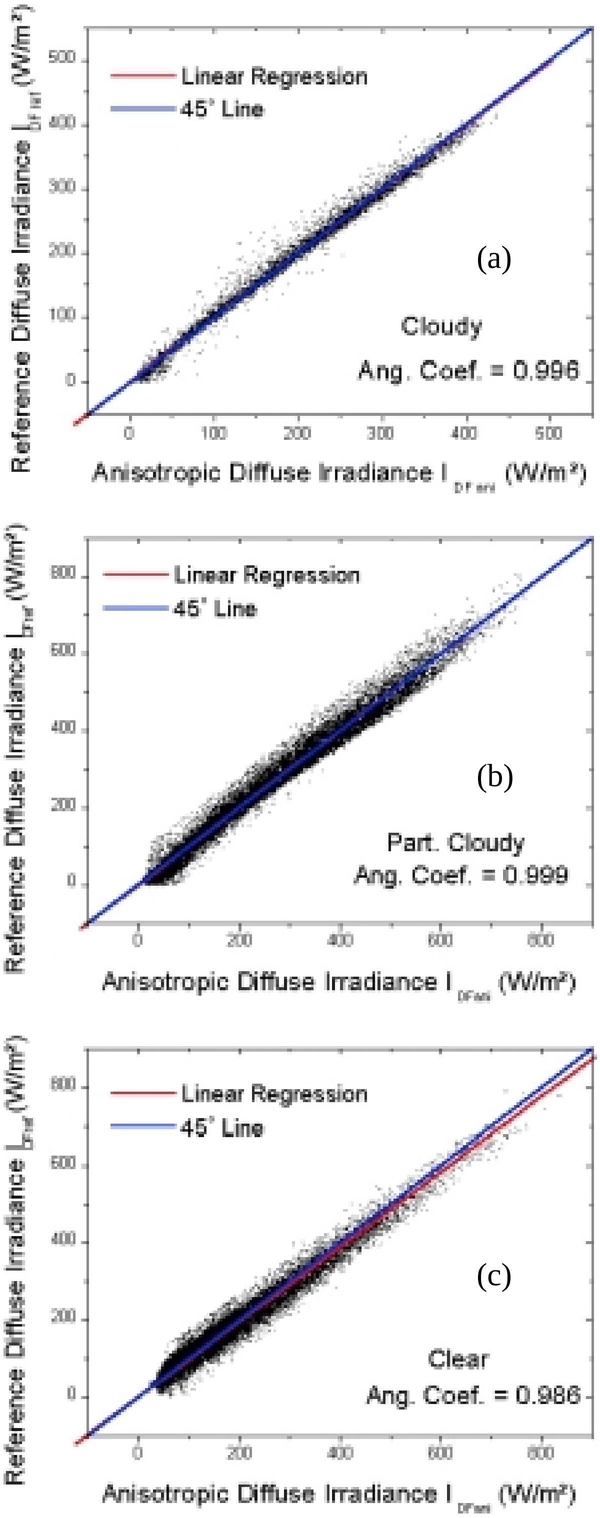

Figure 3. Correlation between the reference and anisotropic corrected diffuse irradiances. a) Cloudy. b) Partially cloudy. c) Clear

4. Conclusion

The ME shadowring anisotropic corrections proposed as a function of the sky covering (clearness index) were efficient to correct the isotropic diffuse irradiance, approaching the measured and reference diffuse irradiance less than 1%. The results showed that the anisotropic corrections improve the ME shadowring method, allowing the generation of a reliable global, direct and diffuse radiation database without high financial investments.

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6. Responsability notice

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