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COMPARATIVE STUDY OF SATELLITE AND GROUND TECHNIQUES FOR CLOUD COVER DETERMINATION

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ABSTRACT

In this paper we compare cloud cover coefficient values derived from satellite images by using three different algorithms with cloud cover fraction obtained by automatic technique using a CCD sensor set on a ground platform. The main goal is to optimize the results obtained by each of the three satellite techniques when applied as input data for radiative transfer models. The satellite techniques are applied to generate clear and overcast composite images on the visible spectra (0.52–0.75μm), and the cloud cover coefficients are obtained from linear interpolation between clear and overcast conditions. The ground technique uses a CCD sensor adapted to a fisheye lens to derive cloud cover fraction in the visible range (0.4–0.7μm). We compared these techniques using data collected at the BSRN station of Florianópolis (27° 28'S, 48° 29'W). The study encompasses the period from January/2002 to March/2002. The radiative transfer model has underestimated the incident global solar radiation by 25-32% when derived from cloud cover fractions obtained by the CCD sensor. When supplied with the cloud cover information derived from the satellite techniques the bias decrease to 3-7%. The reason for the underestimation is attributed to the fact that cloud cover fraction derived from the ground data does not bear information on cloud optical thickness.

INTRODUCTION

Clouds are the main factor that modulates surface incident solar irradiation and they are by far the largest source of error in the estimates obtained from radiative transfer models. Clouds are responsible by a major part of atmospheric albedo - 23% of total short wave radiation (0-4μm) reaching the top of the atmosphere. In addition clouds are also able to absorb long wave radiation emitted by Earth (8-12μm). Their optical properties are a function of the cloud thickness and its water content. The combined effect albedo-absorption is called *cloud forcing*, which has strong implications on climate and on solar energy assessment for renewable energy applications (Hobbs, 1993; Pereira e Colle, 1997). However, because they have large space variability, the determination of cloud cover and cloud type is a complex issue.

The main goal of this work is to describe and to compare three techniques used to derive cloud cover information from satellite images, with data processed from images taken by a ground platform. The objective is to find a routine validation procedure for satellite assessment of the incident solar radiation. Ground data was provided by an automatic system; and the new method for cloud screening aims at providing a more consistent and time-reliable data set than the usual visual inspection performed by field observers. The visual inspection is rather subjective and thus bears intrinsic uncertainties and bias that may lead to unreliable results in the long-term. For the study of climate change and for validation of satellite methods, the cloud information generated by this visual observation method is quite questionable.

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DETERMINATION OF CLOUD COVER EFFECTIVE COEFFICIENT USING SATELLITE IMAGES

The Brazilian Institute of Space Research (INPE) and Solar Energy Laboratory of University of Santa Catarina (LABSOLAR/UFSC) are working together to develop a radiative transfer model to map the surface solar irradiation in Brazil. The BRAZIL-SR model is a physical model derived from IGMK model (Stuhlmann et al., 1990) that combines satellite and climatological data with the "two-stream" approach in order to solve the radiative transfer equation for atmosphere. Transmittances for clear (τ_{clr}) and cloudy (τ_{cld}) skies can be routinely obtained from atmospheric parameterization using easily available climatological data (temperature, relative humidity, surface albedo, visibility, cloud properties) and geographical position (latitude, longitude, altitude). The cloud cover effective coefficient, $\mathbf{C_{eff}}$, given in Eq. 1, is a weighting function for the linear relation between clear and overcast sky conditions. In spite of being a quite simple relationship, it presents very good results as demonstrated by Colle and Pereira, 1998.

$$C_{eff} = \frac{[L - L_{clr}]}{[L_{cld} - L_{clr}]}, \tag{1}$$

The $\mathbf{C_{eff}}$ value contains information on the spatial distribution and optical thickness of clouds and it is obtained from clear and overcast composite images produced by statistical analysis of satellite images. It is obtained for each pixel from radiances measured by GOES 8 visible channel-1 (0.52–0.75μm). $\mathbf{L_{clr}}$ and $\mathbf{L_{cld}}$ are the radiances measured by satellite in a clear sky and an overcast condition, respectively. The confidence and reliability of the $\mathbf{C_{eff}}$ is a chief factor in getting solar estimates with good accuracy.

In this paper, the determination of $\mathbf{C_{eff}}$ was accomplished by using 3 different algorithms: a) the "Extremes of radiance", b) the "Average of minima", and c) the "Ratio IR/VIS". The difference among these methods consists in the determination of the values used in clear sky and overcast sky composite images. The first algorithm is quite simple and it is based on the fact that surface albedo is much smaller than cloud albedo for a specific zenithal angle. The lowest value of the visible radiance measured by the satellite for each pixel is used for composition of clear sky image and the largest one is used for the overcast sky image. The time period for this calculation is made short enough to keep zenith angle changes negligible and large enough to get a reasonable statistics.

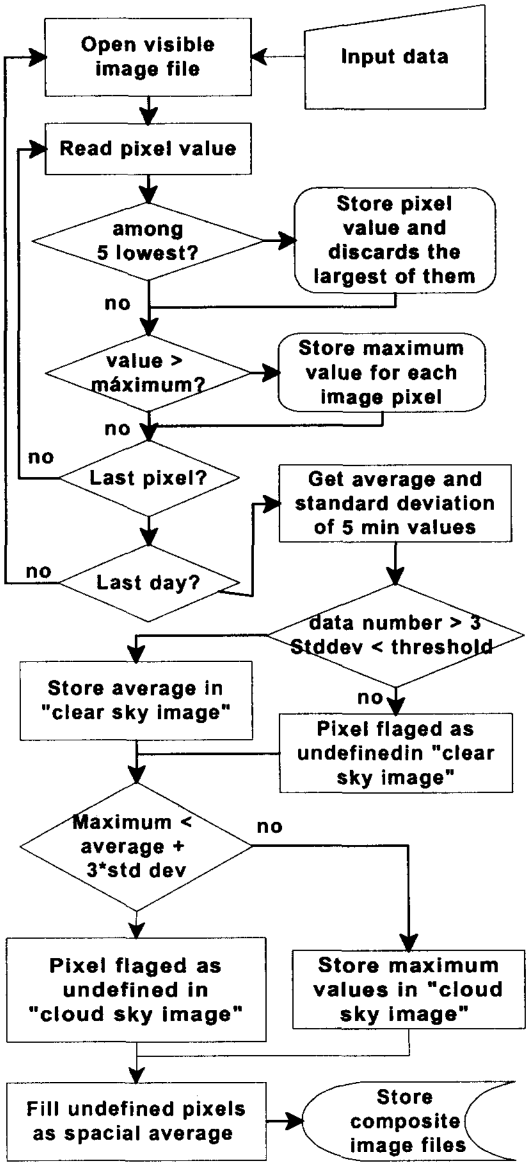
However, several factors reduce the reliability of $\mathbf{C_{eff}}$ obtained by the first algorithm. The difficulty in identifying high cirrus clouds using the visible radiance measured by satellite, and the occurrence of permanent cloudiness or clear skies are important sources of error when the first algorithm is applied. The permanent cloudiness situation may take place; for example, in the Amazon region during wet season, and clear sky all-days can occur in northeastern Brazil where the climate is very dry most of the year. Martins (2000) proposed two new algorithms in order to minimize these systematic errors and to increase the reliability of $\mathbf{C_{eff}}$.

The algorithm "Average of minima" is based on the largest variability of visible radiance measured by satellite when clouds are present (Rossow, 1989). In this algorithm, the radiance of clear sky composite image will be the average of the five smallest values of visible radiance since the standard deviation is lower than a threshold. If the threshold is exceeded, the largest of the five values is discarded and the procedure is repeated. The pixel will be flagged as undefined in clear sky composite image if three of the five lowest radiance values are discarded. The composition of overcast image uses the largest value of visible radiance if it is higher than the radiance used in clear sky composite image by more than three times its standard deviation, otherwise the pixel will be flagged as undefined. The undefined pixels in both composite images are filled with the spatial averages of the neighboring pixels or with some other default value. Figure 1(A) presents a schematic diagram for the algorithm "Average of minima".

Figure 1(B) presents a schematic diagram for algorithm "Ratio IR/VIS". This algorithm uses the ratio among the measured radiances for the satellite in the infrared and visible channels to determine values of clear sky and overcast sky in one-month period. The largest ratio values among the infrared radiances (IR) and the visible radiances (VIS) are associated with surface characteristics (in the absence of snow cover): high temperature and reduced albedo. The clear sky composite image will be filled with visible radiances that produce the largest ratio IR/VIS and are among the five lowest values selected within a one-month period. Otherwise, the pixel will be flagged as undefined condition. In a similar way, the overcast composite images are filled with visible radiances that produces lowest ratio IR/VIS and are among the five largest values of the month in study. The use of bi-spectral analysis allows for a better identification of clouds as described in Desbois *et al.* (1982). Again, the undefined pixels in both composite images are filled with the spatial average of neighboring pixels or with some other default value.

DETERMINATION OF CLOUD COVER COEFFICIENT USING CCD IMAGES

The ground technique developed to derive a cloud cover coefficient uses a digital camera "PIXERA model PCS20232". This camera has a user-friendly interface, and it can be remotely operated by software using a personal computer. The image resolution is 516(H) X 492(V) pixels. In order to prevent the direct incidence the sunbeam that could otherwise damage the CCD, a shadow disk controlled by a sun tracker was adapted for the system. A picture of a field setup is shown at the top of Figure 2.



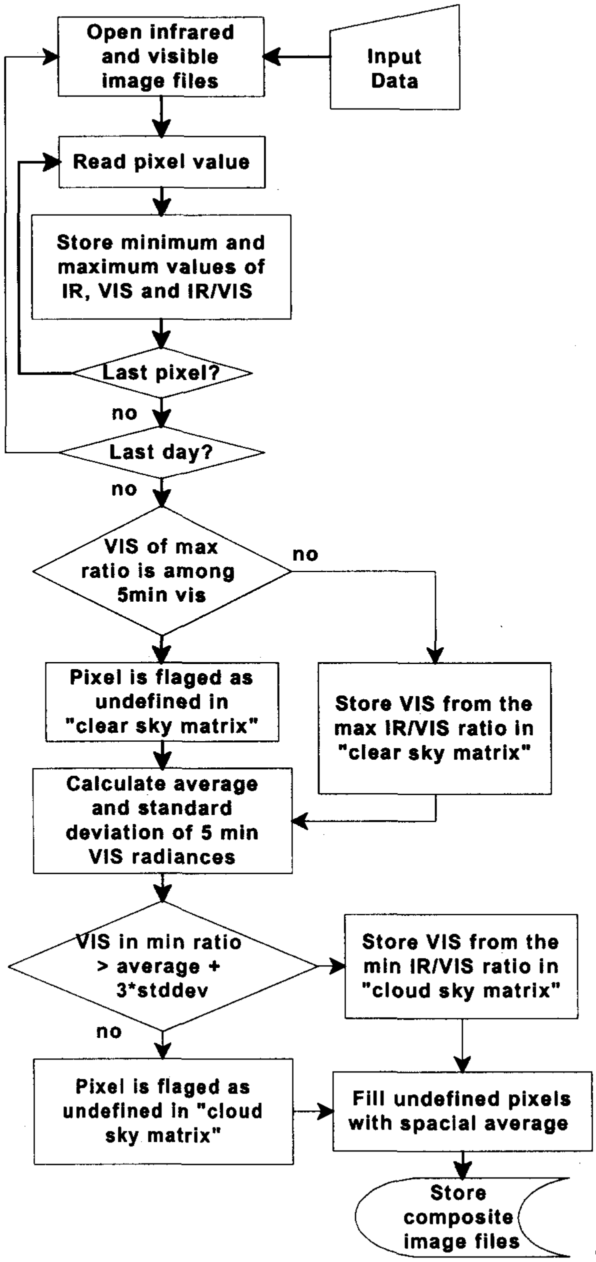


Fig. 1. Schematic diagram of algorithms to derive C_{eff}: (A) "Average of minima" and (B) "Ratio IR/VIS".

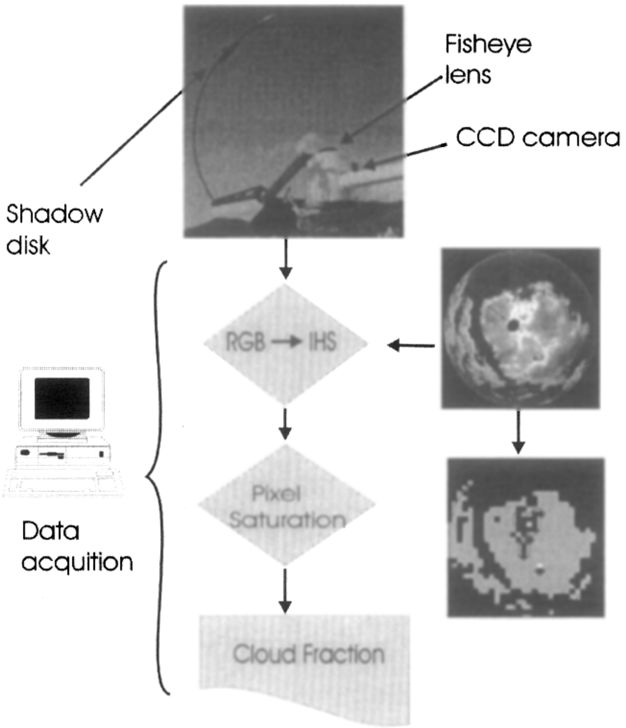


Fig. 2. Schematic diagram of automatic technique to derive cloud cover from with CCD images.

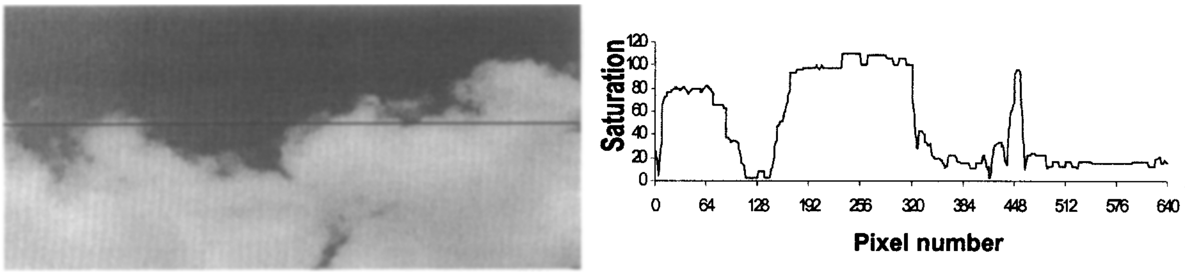


Fig. 3. CCD image (640x340) and the evolution of the saturation level for the scan line shown in the picture.

On a first approach, clouds are characterized by high reflectance a predominantly white color with hues from blue to red, characteristic of a mixture of various wavelengths. They constitute a short time-scale dynamic system of a chaotic nature. On the other hand a clear sky displays a much higher saturation of colors, and it is predominantly blue during daytime with hues from green to red. Figure 3 shows that clear skies are recognized by high values of saturation while a cloudy condition presents a mixture of various wavelengths and consequently lower color saturation values.

RESULTS

The comparative study among the three satellite algorithms and the ground technique to derive cloud cover information was performed for the city of Florianópolis in Brazil, where a BSRN (Baseline Surface Radiation Network) measurement site is operational. The time period for this study was from January to March/2002.

The model BRASIL-SR has presented similar estimates for global surface solar radiation using the three algorithms developed to get cloud cover information from satellite images. The bias error and root mean square error of estimates are presented in Figure 4. This region can be considered well behaved as far as the cloud cover is concerned and does not present permanent overcast or clear sky for the period of study. We expect that this will not be the case for other regions in Brazil, such as the Amazon region and the arid area of the northeast. There are plans to extend this research to the BSRN site located in Balbina, for a better evaluation and comparison of these algorithms.

Figure 6 presents the estimated versus measured surface solar radiation in two cases: with cloud cover information obtained from ground-based CCD method and from satellite images, both using the same methodology that was used in model BRASIL-SR for the solar radiation estimations. As seen in Figure 5(A) the use of information obtained from the CCD camera produces a rough underestimation of the incident solar radiation at surface. In contrast, the estimations derived from satellite images seen in Figure 5(B) present a good correlation (0.98) with the ground measurements. Since all three algorithms have presented similar results for this particular region the algorithm "Extremes of Radiances" is the only shown in Figure 5.

The underestimation produced by supplying the BRASIL-SR model with cloud information derived from the CCD camera can be better understood by comparing both satellite and CCD estimates with ground data obtained by the diffuse and global data from the radiometers installed at this same site. We plotted the diffuse to global ratios versus both cloud cover measurements from the satellite and from the ground set CCD camera. The plots are shown in Figure 6(A and B). Results from the satellite data are consistent with the radiation ratios obtained by the ground radiometers, notably for the extreme end values of cloud cover conditions (overcast and clear skies).

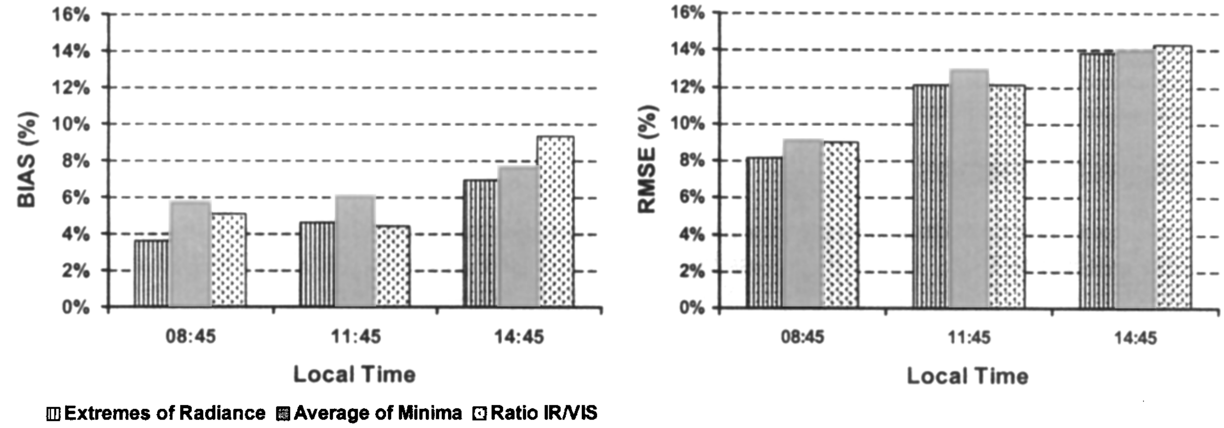


Fig.4. Deviations (BIAS) and root mean square error (RMSE) of surface solar radiation estimates obtained by model BRASIL-SR using the three techniques to derive cloud cover from satellite images.

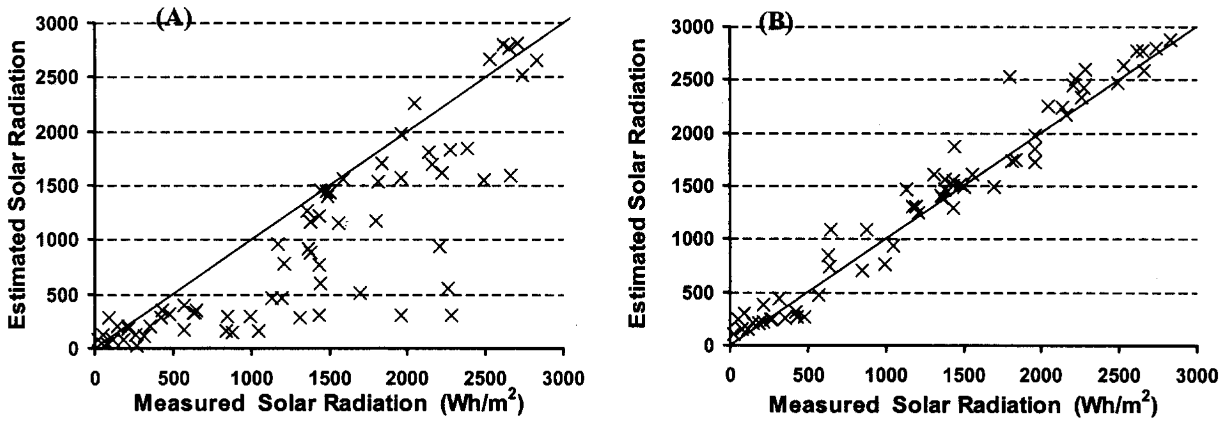


Fig. 5. Comparative analysis between estimated and measured surface solar radiation using cloud cover obtained: **(A)** from CCD images and **(B)** from satellite images using the "Extremes of radiance" algorithm.

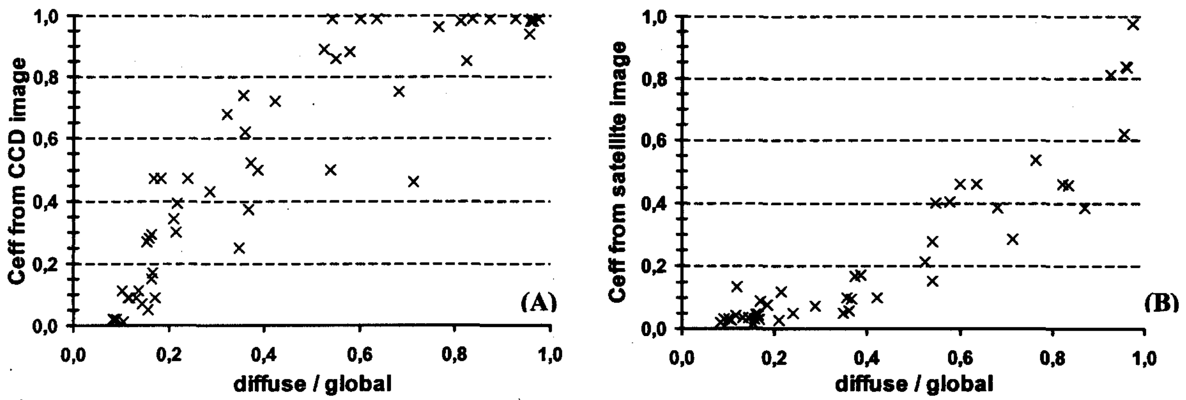


Fig. 6. Relationship between cloud cover information and diffuse to global radiation ratio measured at BSRN site in Florianópolis using: (A) CCD images and (B) satellite images with the "Extremes of radiance".

CONCLUSIONS

The radiation transfer model underestimates incident global solar radiation derived from ground data if cloud cover fraction data is used instead of the cloud cover coefficient. Cloud fraction measured by the ground technique corresponds to the fraction of the sky that is contaminated by clouds - no information on the degree of contamination is provided. Cloud cover coefficient measured by satellite techniques estimates the degree of cloud contamination, which contains information on the optical thickness of clouds.

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