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BIOMASS BURNING CONTROLLED MODULATION OF THE SOLAR RADIATION IN BRAZIL

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ABSTRACT

Atmospheric combustion products from forest fires in Brazil can affect routine satellite techniques for the assessment of solar energy resource information. The mean overestimation of solar irradiance by BRASIL-SR clear sky model was up to 2.5 times larger than that found outside the region of biomass burnings. Within the region of biomass burnings the overestimation was over 5 times larger at the peak of the burning season when compared to the rest of the year. A positive correlation between combustion products and the number of fire spots counted by satellite technique suggests a possible method for the parameterization of these effects in radiation transfer models.

BACKGROUND

Satellite radiative transfer models employed for the study of the Earth's radiative balance and for the evaluation of the solar energy resource in countries of the tropical belt must account for the influence of induced forest fires. This widely used processes of deforestation for farming and cattle growth introduces aerosols and gaseous combustion byproducts into the atmosphere. Whitlock and Tarpley (1996) have shown the influence on the Pinker radiation transfer algorithm by occurrences of forest fires in Africa between 1986 and 1987. Model overestimations of as much as 120 W/m^2 have been reported and linked to forest fires. A current estimation for the deforestation rate in the Brazilian Amazon region is 18,000 km^2/yr (http://www.inpe.br). The resulting total emission of particulate matter to the atmosphere from this source has been estimated at some 10^{14} g of particulate matter per year (Crutzen and Andreae, 1990; Ward et al., 1992). Black Carbon accounts for about 10% of this total anthropogenic release, and is of major concern for its distinctive low single scattering albedo.

THE BRASIL-SR RADIATIVE TRANSFER MODEL

The radiative transfer model BRASIL-SR was used in conjunction with ground radiation data from available sites in Brazil. The model, based on the IGMK (Stuhlmann, et al., 1990), assumes that clouds are the first order factor that modulates the solar radiation field in the atmosphere. The parameterization of the all-sky transmittance is made by the assumption that the upward flux $\varphi\uparrow$ may be split into two independent contributions: one deterministic component corresponding to the cloud free sky conditions $\varphi_{clear}\uparrow = f(\tau_a , I_o , \theta_z , \rho_s)$; and another due to overcast conditions, which is nearly isotropic, $\varphi_{cloud}\uparrow = g(I_o , \delta)$. τ_a is the atmospheric transmittance, θ_z is the solar zenith angle, I_o is the radiation flux at the top of the atmosphere, δ is the cloud optical thickness, and ρ_s is the ground albedo. This component can be estimated on the basis of a known set of input atmospheric data. The stochastic nature of the all-sky solar radiation field is included in the model by defining a fractional cloud cover index, n_{eff} such that $\varphi\uparrow$ is linearly distributed between these two extreme atmospheric conditions, $\varphi_{clear}\uparrow$ and $\varphi_{cloud}\uparrow$:

$$n_{eff} \approx (\varphi\uparrow - \varphi_{clear}\uparrow)/(\varphi_{cloud}\uparrow - \varphi_{clear}\uparrow) \qquad (1)$$

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$$n_{eff} \approx (\varphi\uparrow - \varphi_{clear}\uparrow)/(\varphi_{cloud}\uparrow - \varphi_{clear}\uparrow) \qquad (1)$$

Assuming that the broadband defined n_{eff} can be adequately represented in terms of the short band radiative fluxes from satellite sensor, Eq. (1) can be obtained directly from the satellite readings. The major assumption made by this model is the inverse correlation between the sky transmittance and the fractional cloud amount measured by n_{eff}. Therefore, the surface irradiance $\varphi\downarrow$ is given by the satellite information on fractional cloud cover index n_{eff} and two boundary values for the sky transmittance τ_{clear} and τ_{cloud} that are obtained by solving a one-dimensional radiative transfer scheme. Since the model was conceived to use readily available routine surface atmospheric data, the parameterization of the aerosol light scattering and absorption is made by employing the simple Angström approach.

ESTIMATION OF BIOMASS BURNING INTENSITY

Forest fires are detected by the AVHRR thermal channel from satellites of the NOAA-14, a technique developed by Pereira and Setzer (1993). Figure 1 shows the fire spots occurrences in three major climatic regions of Brazil as a function of the months during the period from June to November.

Previous measurements by Pereira et al. (1996) have shown that there is a good correlation between the amount of aerosol particles in a vertical column of the atmosphere, measured by an instrumented airplane, and the number of fire spots counted in a region around the site where these measurements were performed. This region will be henceforth referred to as circle of investigation. Data for CO, CH_4, and N_2O (Volker Kirchhoff, from INPE, S.J.Campos, Brazil - personal communication) obtained for the same region, also exhibit the same behavior but with much lower correlation coefficients. Table 1 displays the correlation coefficients found between these atmospheric components and the number of fire spots detected by satellite within circles of investigation of 2.5° radius.

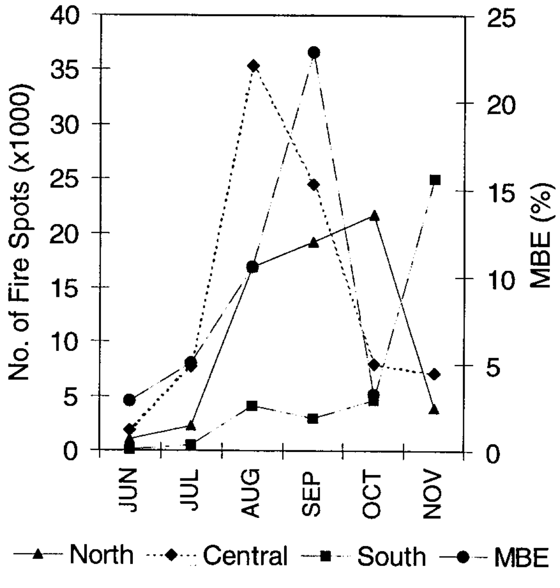

Fig. 1. Variation of the number of fire spots in three major climatic regions of Brazil. The variation of the model MBE is also shown.

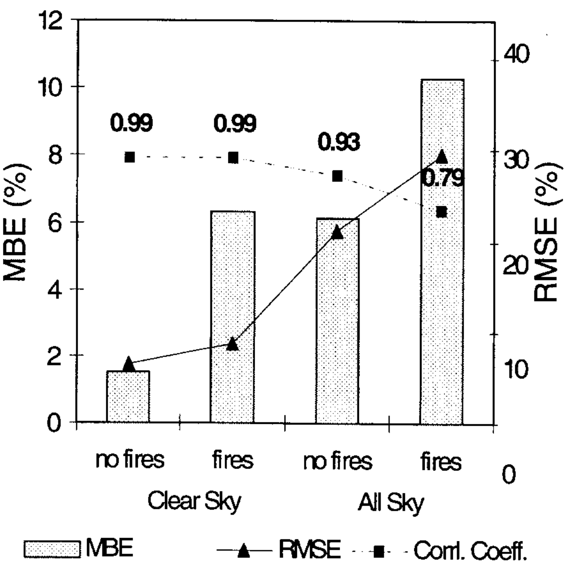

Fig. 2. Variations of relative Mean Bias Errors (MBE) and Root Mean Square Errors (RMSE) for BRASIL-SR model (see text for explanations).

GROUND RADIATION DATA

The available ground data for solar radiation obtained by pyranometers installed at 10 sites in Brazil is listed in Table 2. We selected only clear sky days for this analysis, since this study aim at the evaluation of the effects on the satellite estimations that are caused solely by changes in the atmosphere by fires. The selection of clear-sky days was based on a careful visual inspection of the GOES-8 satellite images followed by the application of the clearness index criterion. By using the above procedure it was possible to select a total of 235 clear sky days.

Table 1. Correlation Coefficients between some Forest Fire Products in the Atmosphere and the Number of Fire Spots counted by Satellite Observation

Combustion Product	***Correlation Coefficient $(R^2)^*$***	***Nº of flight profiles***	***Source***
Total aerosol mass	+0.98	5	Data from Pereira et. al. (1996)
Black Carbon	+0.97	9	„
Number of submicron particles	+0.95	5	„
CH_4	+0.90	5	Data from Kirchhoff
N_2O	+0.65	5	(personal communication, 1998)
CO	+0.45	5	„

Table 2. Average clear sky MBE and RMSE calculated at a daily basis for the each individual validation site. Sites 1 trough 8 are located within the biomass burning region; while sites 9 and 10 are located outside this region, in the South of the country.

#	**Ground Site**	**Latitude**	**Longitude**	**Altitude (m)**	**RMSE (%)**	**MBE (%)**	**Nº. of Days**
1	Potosi Mine$^{(1)}$	9.78°S	62.87°W	80	*	43,6	1
2	Jarú forest reservation$^{(2)}$	10.08°S	61.92°W	120	8,5	5,9	53
3	N.S. Aparecida farm$^{(2)}$	10.75°S	62.87°W	220	8,4	7,5	28
4	Dimona farm$^{(2)}$	2.32°S	60.32°W	120	*	*	0
5	Ducke forest reservation$^{(2)}$	2.57°S	59.95°W	80	*	9,4	1
6	Boa Sorte farm$^{(2)}$	5.17°S	48.75°W	170	6,6	6,4	8
7	Vale do Rio Doce forest reservation$^{(2)}$	5.75°S	49.17°W	150	7,2	6,4	14
8	Cuiabá$^{(1)}$	15.33°S	56.07°W	152	*	17,1	1
9	Florianópolis (BSRN)	27.60°S	48.57°W	15	6,1	1,8	121
10	Lebon Regis	26.98°S	50.71°W	1036	2,8	-0,4	8
	All Sites				7,7	2,4	235

(*) not enough data to carry out the calculation

(1) data from SCAR-B project by Thomas F. Eck, NASA/GSFC

(2) data from ABRACOS project by Carlos A. Nobre, CPTEC/INPE.

The daily basis MBE and the RMSE errors between model estimations and ground data for all the available data are presented in Figure 2 along with the respective correlation coefficients. The plots are classified according the sky condition when data were collected: clear sky and all sky. For each of these two major groupings the plots are divided into two subsets: one corresponding to sites located within the biomass burning region located in the North and West-Central region of the country *(fire)*, and another for data collected in the South of Brazil, where fire activity is small *(no fires)*. The MBE and RMSE are consistently larger for the region of intensive fire activities. Furthermore, the correlation coefficients between measured and estimated values are lower for the plots corresponding to all-sky condition owing to the added random effect of clouds.

The mean clear-sky deviations for each of the individual sites are shown in Table 2. The RMSE are all below 6% and the MBE below 2%, for the validation sites located in the South of Brazil. In the North of Brazil the results are comparatively higher for both the RMSE (up to 8.5%) and MBE (up to 44%). These last sites are all located in areas of burning of biomass, which occur during the dry season. This is the case for Potosi Mine, which data was collected during September when fire activity peaks (MBE = 44%). The site at Cuiabá, where data was collected in August also falls into this category (MBE = 17%). Data for the other northern sites were collected between June and October. They reflect the effects of a wide range of intensities of fires, covering the beginning of the dry season, with small number of fire spots, until the peak of the season in September, which may explain the relatively lower deviations.

BIOMASS BURNINGS AND SYSTEMATIC ERRORS

The clear-sky MBE for sites located within the areas of burning of biomass (sites 1 through 8) are dependent on the time of year. The maximum bias is found for September when the fire activities in this area are also high. Figure 1 depicts the time behavior of the measured MBE for these stations, together with the monthly relative increment of fire spots in selected regions of the country as a function of the time of the year. The agreement between curves corresponding to fires in the North of the country, and to a lesser extent in the Central region, suggests that these variables are indeed linked to each other. During the dry period, when fire activities are intensive, the MBE also increases for these regions. This correlation is not observed, for example, in the South of the country (also shown in the plot), and for the other regions of Brazil (not shown). During the period of maximum biomass burning activity, the model has a stronger tendency to overestimate the incoming global surface irradiation. This may be attributed to the large amounts of aerosols and gases injected into the atmosphere that are not accounted for by the simple parameterization for the aerosols adopted by this model.

The plot of the bias between the irradiation measured by ground stations and the model estimations versus the fire spot counts is shown in Figure 3. For this plot we counted the fire spots within the 2.5° circle of investigation around each of the sites from 1 through 8, and calculated the MBE for clear-sky conditions. The fire spot counting was made by a weighted integration of the last three days in order to take into account the residence time of aerosols in the atmosphere. Fire counts are shown on a logarithmic scale to account for the order of magnitude change observed for this parameter. A simple linear fit was preferred since this is only a crude evaluation for the cause-effect relationship between these two variables. Although a large scatter in the data is observed ($R = 0.6$), a positive correlation between the bias and the fire spots can be observed at the 95% confidence level. The large scattering of data can be explained by the variable emission factors related to different ground vegetation, fire intensities, and variable meteorological conditions. Thus, depending on the prevailing winds with respect to the fire spots and the kind of vegetation burning, we may have different situations where the fire spots concentrations are downwind or upwind, thus affecting the net results which is based on a 2.5° circle of investigation in this study.

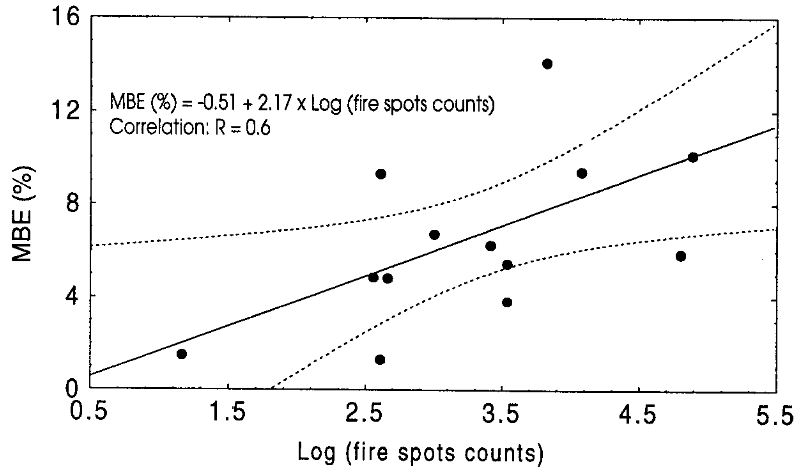

Figure. 3. Plot of the clear-sky MBE and the logarithm of the number of fire spots counted inside a 2.5° circle of investigation around the ground solar station. The doted line represents the 95% confidence level for the line fitting.

CONCLUSIONS

The combustion products injected into the atmosphere during the fire season (July through October) in Brazil may explain the systematic deviations found between the BRASILSR radiation model and radiation data from ground sites. Systematic deviations increase by a factor of 5 during the fire season. Stations located inside the humid tropical forest (4 and 5) did not present enough clear sky days to provide valuable information for this study. These stations are located inside an area strongly influenced by the ITCZ; thus clouds are frequently present during the whole year. Stations located in the South of the country presented very low MBE (-0.4% and 1.8%).

The concentration of all six atmospheric components in Table 1 increase as the fire activities in the area increase, suggesting a possible explanation for systematic model deviations. The deviations can be related to the injection of an additional load of particulate and gaseous fire products to the atmosphere. In the present model, the parameterization of the time fluctuations of the combustion products in the atmosphere is inadequate, and that suggests a possible explanation and may help to improve the parameterization of aerosols in radiation transfer models. The number of fire spots is well correlated with the observed MBE between the satellite estimations and the ground data when comparing the time series of these two variables. Both present a peak value near September, when the mean MBE reaches about 24%. This value is about 5 times larger than the MBE found just before the onset of the fire season (June).

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