EVALUATION OF BURNING AEROSOL INFLUENCE ON PERFORMANCE OF SOLAR RADIATION ASSESSED BY MODEL GL - CPTEC

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1. INTRODUCTION

Recent works showed that antropogenic aerosol not only attenuate solar flux reaching ground surface, but can seriously influence microphysical cloud characteristics. Consequent disturbances on climate are a matter of active research (Seinfeld e Pandis, 1998).

Biomass burning is one of the main global sources of atmospheric aerosols. The main component of these sub micrometric particles is organic material partially oxidized, being efficient for scattering (due to organic carbon) and absorbing radiation (due to black carbon). Particles can scatter, absorb or emit electromagnetic radiation, resulting in redistribution of short or long wave radiation; thermodynamic processes induced in local atmosphere depend on particles physico-chemical and optical properties (Penner, 1995).

Biomass burning in Amazon region is frequently used by farmers in order to clear large areas for agriculture or pasture. It occurs mainly during months of September and October, discharging aerosol concentrations of about 30 thousand particles per cubic meter (Artaxo *et al*., 1998). Aires and Kirchhoff (2001) showed that relatively clear air parcels coming from Atlantic Ocean go into Northeastern Brazil, following trajectories over regions where biomass burning occurs in Central Brazil (Tocantins, Mato Grosso, Mato Grosso do Sul) and leaving the continent over S-SE region, which is relatively free of burning areas but becomes contaminated by those parcels. Nobre *et al*. (1998) found similar results. Therefore, it can be expected that aerosol plumes in Amazonia influence surface solar budget (SRB) over a large Brazilian area. Given the large area in consideration and its geographical characteristics, SRB can be assessed using satellite-based methods. Presently, DSA/CPTEC monitors global solar radiation over Brazil using an operational algorithm applied to GOES VIS imagery (GL version 1.2).

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GL1.2 model is based on simple relations between fluxes on the top and at ground level. Based on observed VIS reflectance at top of atmosphere, it assesses cloud coverage and irradiance at UV+VIS and near infrared (NIR) spectral regions (Ceballos *et al*., 2004). Parameters used in the model include total precipitable water, CO_2 and O_3 total amount, but no aerosol. Absorption by ozone is located at the stratosphere, and attenuation by water vapor and carbon dioxide acts in NIR region, without scattering by clear atmosphere. Clouds are described as not absorbing in VIS interval. Application to GOES 8 imagery yields mean (daily) irradiances with a suggested bias of about -10 $W.m^{-2}$ and annual oscillation with amplitude of about 15 $W.m^{-2}$.

Neglecting aerosol in GL1.2 model is a matter of concern, because high deviations might be introduced during burning season, over large areas such as Amazonia. This paper communicates preliminary results concerning the analysis of the impact of aerosol presence on local deviations of GL model.

2. METHODOLOGY

Model deviations from ground truth depend on using as many daily images as possible, and also on a careful correction of GOES VIS channel for progressive degradation. Such a correction were available for GOES 8 (Ceballos et al. 2004), which was replaced by GOES 12 in April 2003. Time series of GL model were considered only for 2001-2003 (including March). Values calculated for GOES 12 were recently corrected for degradation, so that only March and September 2005 will be considered.

Modeled and observed fluxes were compared for 11 sites in Amazon and Eastern Brazil. There exists an extended network of more that hundred automatic stations (PCDs, "plataformas coletoras de dados"): see URL http://tempo.cptec.inpe.br:9080/PCD/ for data access. Among other meteorological variables, these stations provide solar irradiance. Instruments used are LiCor pyranometers. In addition the Aeronet (AErosol RObotic NETwork: Holben *et al*., 1998) and the SolRad-Net provide an important source of radiative and aerosol data. Aeronet/SolRad-Net stations have spectral photometers for aerosol monitoring of aerosol optical depth (AOD) in different wavelengths, particle size distribution, precipitable water and (where available) solar irradiance.

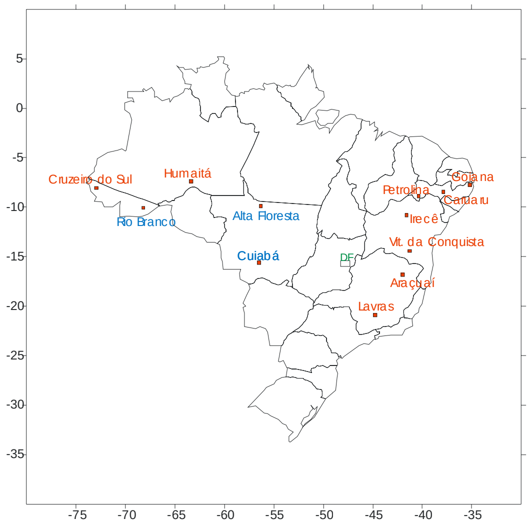

Figure 1. Geographical distribution of sites

Comparison between modeled (GL) and measured SR was performed using PCD and SolRad-Net data for the period 2001-2005. Figure 1 illustrates geographical distribution. Pyranometric data of SolRad-Net (Blue) are results of stations located in Amazon Region: Alta Floresta, Balbina, Cuiabá, Rio Branco group. PCD data (in red) correspond to stations located in regions with and without burning activity, namely the groups 1) Cruzeiro do Sul and Humaitá, and 2) Araçuaí, Lavras, Irecê, Vitória da Conquista, Caruaru and Goiana).

3. RESULTS

A first analysis refers to GL sensitivity in detecting differences between model and "ground truth" for days with aerosol presence. Table 1 shows results for period 2001 to March 2003, for annual mean, during burning season and outside it. The names of sites located in Amazon region are labeled in italics.

It can be seen that differences between modeled and observed data were lower for locals free of burning aerosol (group 3) and higher for groups 1 and 3, where aerosol of biomass burning is present. Considering only September and October (within burning season), differences were higher for Alta Floresta and Cuiabá, located below trajectory of burning aerosol plumes (Aires and Kirchhoff, 2001).

Numbers shown in Table 1 suggest that typical differences between modeled and observed data are ±10.1 for sites with aerosol-free characteristics and more than +25 W.m^{-2} in regions with burning activity. This difference represents a mean impact of 15-35 W.m^{-2} in model accuracy, or more than 8% of mean irradiance (for typical values of 250 W.m^{-2}). Nevertheless, Tarasova *et al.* (1999) reported results of aerosol effect in clear-sky conditions. They found ground irradiance attenuation as high as 70-150 W.m^{-2} during burning season.

Given an evidence of overestimation of solar irradiance by GL during burning events, the following step was to analyze relationships between model deviation and aerosol load. Amazon sites were considered during burning periods (September-October 2001 and 2002). Model deviation for each day was assessed as difference Δ between GL and pyranometric mean irradiance (in W.m^{-2}). Values Δ were stratified according to GL value.

Figure 2 illustrates results of relationship between Δ and the observed aerosol optical depth in 500 nm. It makes evident that aerosol impact on solar radiation is not linear but complex. As expected, deviation Δ may increase with increasing AOD in mainly clear-sky days (GL>250 W.m^{-2}), labeled with green and red triangles. Not negligible dispersion appears when GL is within 150-250 W.m^{-2} interval, with deviations attaining values as high as +50 W.m^{-2}.

TABLE 1. Mean difference "Model GL – PCD" (W.m^{-2}) for period 2001 to March 2003

	Araçuaí	*Alta Floresta*	Caruaru	*Cuiabá*	*Cruzeiro do Sul*	Goiana	*Humaitá*	Irecê	Lavras	*Rio Branco*	Vitória da Conquista
All Year	-0,1	5,3	-17,9	**11,7**	**5,1**	-0,7	**21,6**	-10,3	-1,9	**11,2**	5,9
Sept/Oct Only	9,5	**14,0**	-14,5	**24,7**	10,6	5,9	**26,6**	-11,1	2,3	**26,0**	-2,8
March only	-7,1	-9,0	-2,8	-0,7	-17,0	-16,2	-0,3	-15,4	-2,1	3,0	-11,8

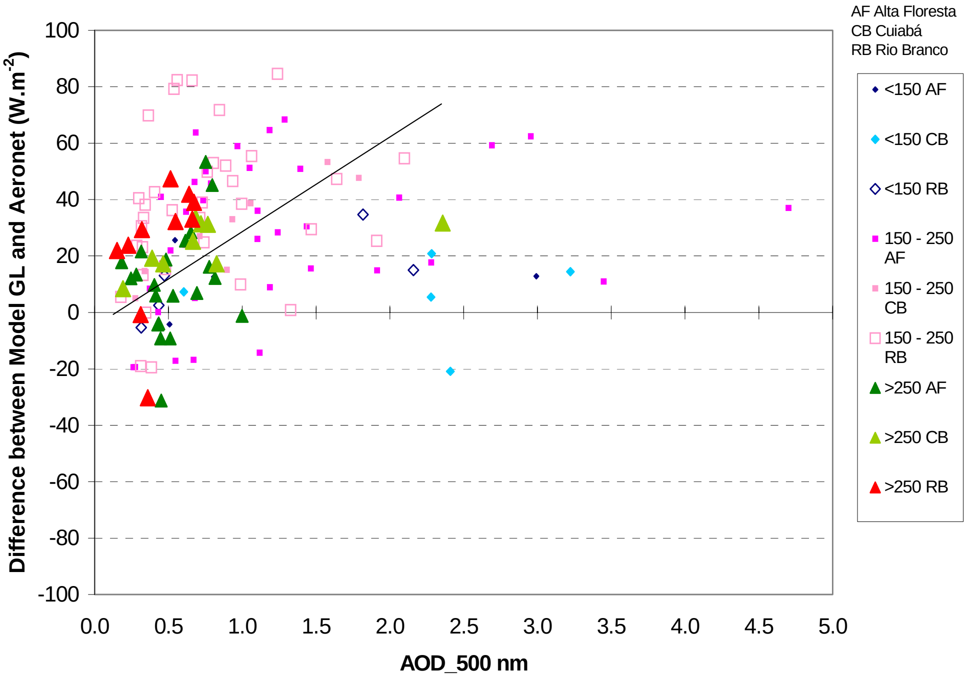

Figure 2. Relation between modeled and observed data and aerosol optical depth for September and October (2001-2002)

Noteworthy, higher aerosol loads (AOD> 2.5) exhibit lower Δ deviations. This peculiar behavior may be associated to the presence of cloud. It might be asked if higher AOD estimates are reliable or, alternatively, if the whole daily period was contaminated by cloud thus affecting quality of AOD assessment. Analysis of GOES satellite images corresponding to these sites confirmed cloud presence. In any case, it is suggested that the aerosol effect on solar irradiance at ground level is strongly affected by cloud presence (by limiting radiative flux availibilty for aerosol absorption).

These results refer to daily mean irradiance, and suggest the convenience of inspecting irradiances in shorter time intervals. Figure 3 illustrates daily cycles for aerosol and cloud contamination conditions in September 2005, 1) for Rio Branco, as measured by SolRad-Net instruments and assessed by GL model; 2) for Petrolina, Northeast Brazil, as measured by a pyranometer of CPTEC SONDA project (http://www.cptec.inpe.br/sonda/). Estimates of GL model are included as red squares. AOD available estimates of MOVAS (MODIS Online Visualization and Analysis System, internet address http://gcmd.gsfc.nasa.gov/records/GES_DAAC_MOVAS.html) provide mean values 1.6 for Rio Branco and 0.12 for Petrolina. September estimates by GL model correspond to version 1.3, which includes correction of VIS channel degradation and precipitable water field as provided by CPTEC GCM. Figures on the first column are near clear-sky cases. Latitudes are similar but precipitable water is higher in Rio Branco (yielding a slightly smaller value for maximal irradiance). Aerosol effect should be much lower in Petrolina.

It can be seen that GL model fits better to Petrolina cycle; nevertheless, differences with Rio Branco cycle are not as high as expected. A possible origin for this fact is reflectance of a dense aerosol layer, which would be interpreted as a cloud. Therefore, possible absorption by aerosol (not included in the model) is partially compensated by reflection of a “non absorbing cloud”. Figures on right column correspond to cloudy days. It can be seen that GL estimates are means well situated inside highly variable irradiance values, during hourly intervals. The general result is a not so biased assessment by GL model.

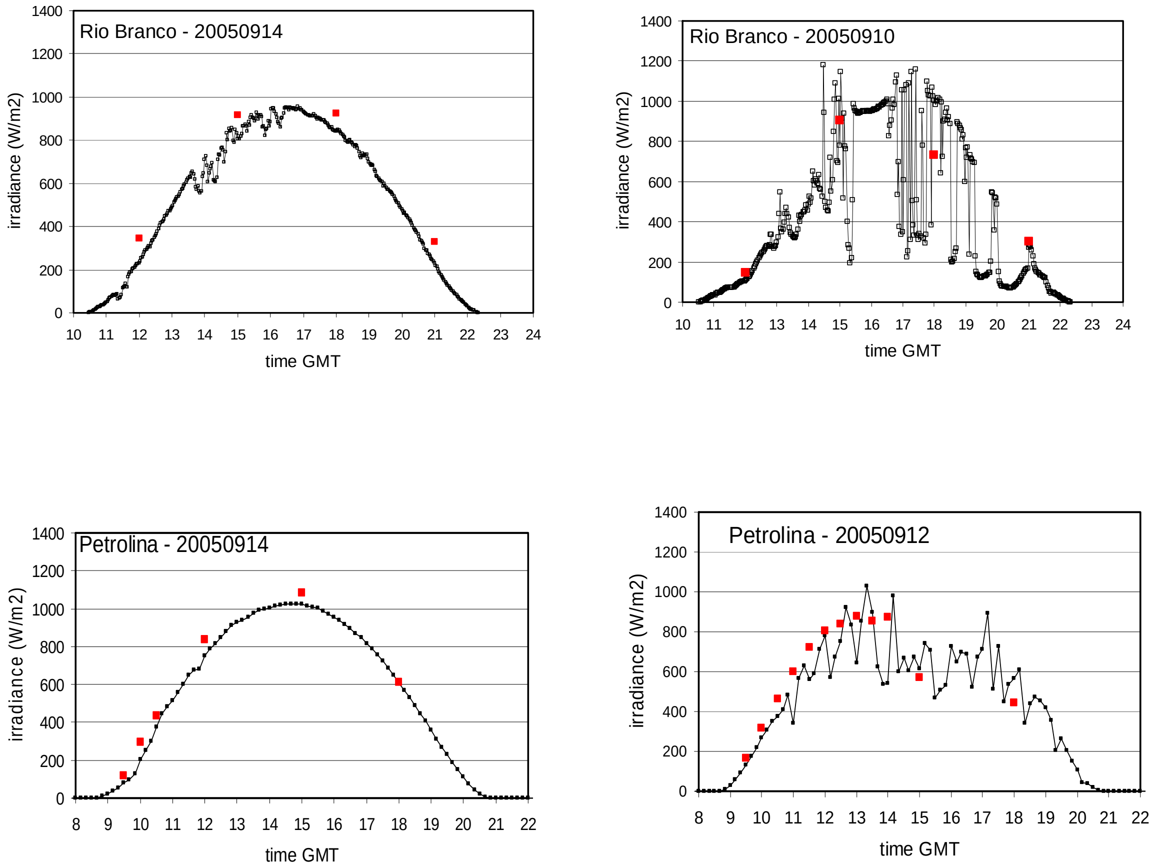

Figure 3. Daily cycles of irradiance measured by pyranometer (little black squares) and estimated by GL1.3 (red squares) in September 2005.

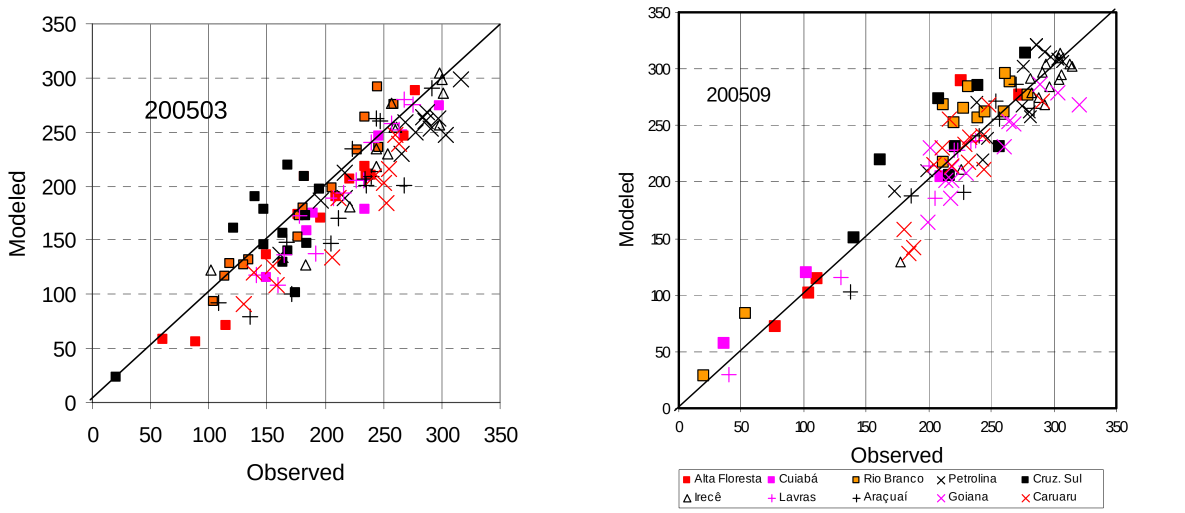

Figure 4. Daily mean irradiance for several sites in March and September 2005. March does not present burning events.

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Figure 4 presents daily mean irradiances for a set of different stations in two different months (March and September, 2005). These figures help to illustrate eventually different behavior of a smoky atmosphere in Amazon region and mostly clean situations in Northeastern Brazil. It is seen that all stations are well described by GL model in March. Cruzeiro do Sul has a somewhat different behavior, maybe associated to cloudiness assessment by GL. During September, model GL describes correctly Amazon irradiance for cloudy days (lower irradiances). Nearly clear-sky situations (highest irradiances) deviations are evident mostly for Amazonian stations. Typical deviations are about 25-30 W.m^{-2}, as shown by Table 1 for a different period (2001-2003).

4. CONCLUSIONS

The results suggest that aerosol effect on irradiance is partially accounted for, because of visual confusion between smoke plumes and clouds in VIS channel. This may happen for cloudless and smoky situations, attaining deviations of about +30 W.m^{-2} in daily means. On the other hand, cloudy days tend to prevent aerosol effects on ground level irradiance and model GL is successful in describing mean radiative flux.

Inclusion of aerosol in model GL would improve its performance, but expectedly corrections of daily means will not exceed 30 W.m^{-2} on the average.

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