COHERENCE OF SOLAR IRRADIATION ASSESSED WITH A SIMPLIFIED PHYSICAL MODEL USING GOES AND MSG2 VIS IMAGERY

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Abstract. It is shown that model GL for solar radiation assessment (running at CPTEC/INPE, Brazil) yields accurate estimates of daily irradiation over Brazil when using GOES 12 VIS imagery and the same is true when using MSG SEVIRI VIS channel (over an extended region of that country). Comparison of modeled daily mean irradiance with data from seven meteorological stations along 2700 km shows correlation coefficients higher than 0.97, monthly mean deviations lower than 20 $W.m^{-2}$ and standard deviation ranging 6-16 $W.m^{-2}$ for GOES- and MSG-based estimates. Model GL is based on observed reflectance in VIS interval and simple but physical local parameters (surface albedo and water vapor column) so that no special adaptation is needed for using GOES Imager or SEVIRI in model GL, except the proper monitoring of sensor calibration. These facts suggest the ability of SEVIRI-based GL model estimates as an alternative for monitoring solar radiation not only over Northeastern part of South America, but also over tropical Atlantic Ocean and African continent.

1. INTRODUCTION

Surface solar radiation monitoring is indeed an important tool for energy balance studies in agrometeorology, environmental diagnosis and climatology. South America and Africa are served by sparse solarimetric networks and many stations have only sunshine recorders, whose burned strips can be roughly calibrated against pyranometer networks. Careful processing of these data provided information for building Solar Radiation Atlases in Argentina, Peru and Brasil (see references at end of paper). During the last decade an important effort was developed for installation of automatic networks in Brazil, providing easy access of hourly and daily values through internet (see http://www.inmet.gov.br/html/rede_obs.php, http://sonda.cptec.inpe.br/, http://satelite.cptec.inpe.br/PCD/, accessed in September 2010, for more than 700 stations).

Nevertheless, modeling of solar radiation based on VIS band data from geostationary satellites seems to be a more efficient method for monitoring extended regions with high temporal and spatial resolution, with ground information as valuable reference for validation of satellite estimates. Many physical and statistical schemes can be found in 1980-2010 scientific literature (see e.g. Pinker et al. 1995, Rigollier et al. 2004). In some cases the same model (Pinker & Laszlo, 1992) was used for estimation of solar radiation throughout the world, using data of several satellites (see http://eosweb.larc.nasa.gov/PRODOCS/srb/table_srb.html for SRB_REL3.0 shortwave documentation). Also, IGMK model used Meteosat imagery for solar radiation assessment over Africa (Stuhlmann et al 1990) and Brazil (Pereira et al. 1996). An adaptation of IGMK lead to Brasil SR model used with GOES imagery for generating a Solar Radiation Atlas (see reference at end of paper).

Model GL/CPTEC (Ceballos et al. 2004), based on GOES Imager VIS imagery, currently runs at CPTEC generating solar radiation fields over South American area north from 50°S and east from 100°W (see Figure 1, left). Model resolution is 0.04°. Contemporarily, MSG2 allows for observation of a large area of South America, as shown in Figure 1 (right), with similar resolution. Since Northeastern Brazil looks towards satellites GOES 12 (over 75°W) and Meteosat 9 (over 0°W) with similar zenith angles, it might be expected that both satellites yield similar values for solar radiation estimates over the region when using the same physically based model. This paper shows some results which lead to validate this assumption at least for model GL.

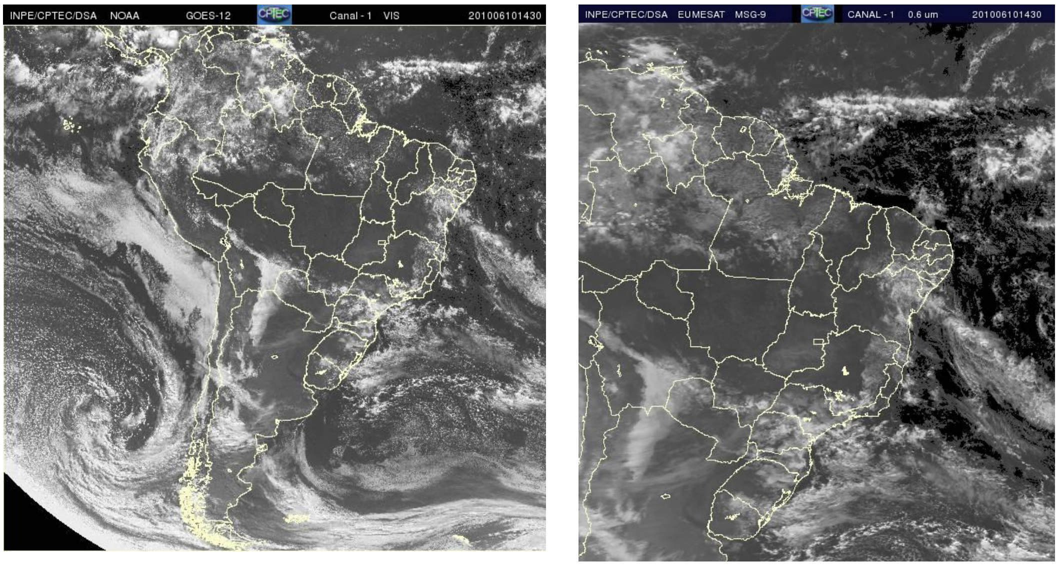


Figure 1. Contemporary images GOES 12 (left) and MSG2 (right), channel 1, day 20100610, 1430 UTC. Regular projection (linear in lat,lon). Source: DSA/CPTEC/INPE (http://satelite.cptec.inpe.br → Collection BDI)

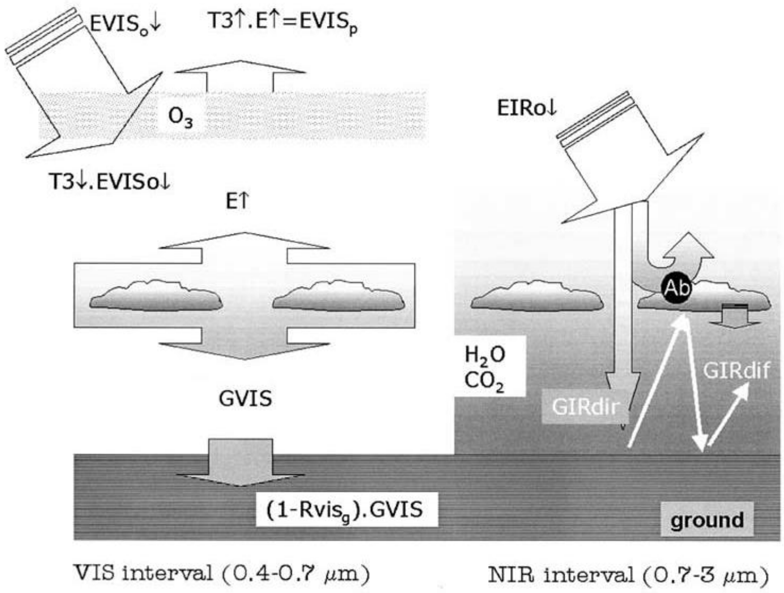


Figure 2. Physical scheme for solar irradiance estimation by model GL. T3 refers to ozone transmittance, Gvis= VIS irradiance, GIRdir= NIR direct irradiance (source: Ceballos et al., 2004).

2. STRUCTURE OF CPTEC'S MODEL GL

GL model provides an approximate but physically sound estimate of global irradiance; a detailed description is found in Ceballos et al. (2004). The basic idea is a partition in three wide spectral bands: ultraviolet UV (0.2-0.4 μm), visible VIS (0.4-0.7 μm) and near-infrared NIR (0.7-3 μm), which exhibit different dispersion/absorption behaviours. Figure 2 illustrates the energy balance for solar radiation. Firstly atmosphere is weakly absorbent in VIS interval so that, no matter the complexity in radiative transfer processes, global irradiance at ground level will be mainly described by a simple radiative balance: solar flux is either reflected back to space with weak O3 Chappuis-band absorption throughout stratosphere (upwelling radiance being observed by satellite), or absorbed within ground (so that surface reflectance is an important parameter). Absorption of UV fluxes operates mainly within stratosphere, so that their behaviour within troposphere (say, below 18 km) follows the same philosophy of VIS flux and can be jointly described. NIR flux is weakly influenced by atmospheric Rayleigh and Mie scattering, so that irradiance reaching the ground is likely to be direct flux attenuated by gaseous H2O and CO2 absorption (water column becomes an important parameter). The presence of cloud simply should block NIR flux, because of strong absorption in H2O bands combined with high reflectance. This simplifying hypothesis is supported by radiation transfer codes, whose estimates show very low NIR transmittance even for somewhat poorly developed clouds. Therefore, the very points in the model are satellite estimates of outgoing VIS irradiance and cloud cover (anyway, it is worth to note that clear day conditions should yield lower errors).

Concerning estimation of cloud cover, Model GL follows the usual hypothesis about patchy-cloud pixels: radiance L in VIS band would be composed by energy associated to cloud top reflexion Lc, weighted with fractional cloud cover C, plus ground+atmosphere reflexion Lga, weighted with clear fraction 1-C, which leads to the simple estimate

$$C = (L – Lga)/(Lc – Lg) = (R – Rga)/(Rc – Rga). \quad (1)$$

Here, R describes reflectance estimated from L and solar zenith angle Zo. It must be pointed out that Rc *does not* represent the highest-valued reflectance in image sets neither the mode (most frequent) value. Cloud classification makes evident that a rather well defined value R*≅ 0.46 separates cumulus cover from other types (St, Cb) which should be labeled as full-pixel clouds with C=1. Therefore, Rga values may become important parameters in bright scenes as desert or semiarid regions. Typical values are 0.09 over continent and 0,04 over ocean. Version 1.2 of model GL assumes the simplifying hypotheses of homogeneous value Rga= 0.09 and water column content constant over large areas (north and south from 20°S, changing seasonally twice in a year). Of course, Amazonian and Northeastern regions may present rather different precipitable water, and Andes mountains may exhibit albedo values rather higher than those of forest or agricultural surfaces. Version 1.4 (presently being tested) will include geographical distributions of albedo and water vapour column.

3. COMPARISON OF GL ESTIMATES BASED ON GOES 12 IMAGER AND MSG2 SEVIRI

Version GL 1.2 was used for radiation estimates. In order to illustrate ground validation, seven meteorological stations were chosen along Eastern Brazil along latitudes ranging from 5°S to 30°S (about 2700 km). Table 1 shows two statistical parameters for April and July 2010: a) monthly mean deviations of GOES- and MSG-based estimates from “ground truth”, as well as mean deviation between both satellite values; b) the associated standard deviation.

Table 1. Comparison of Model GL with seven stations of Brazilian Meteorological Network (sources: G= GOES, M= Meteosat, Net= Network). Numbers indicate mean deviation **m** and standard deviation **s** (m ±s). Units: daily mean irradiance in $W.m^{-2}$

				April 2010 (GOES 13)			July 2010 (GOES 12)		
	site	Lat °S	Lon °W	G-Net $W.m^{-2}$	M-Net $W.m^{-2}$	G-M $W.m^{-2}$	G-Net $W.m^{-2}$	M-Net $W.m^{-2}$	G-M $W.m^{-2}$
1	Quixeramobim	5.17	39.29	-17±24	2±21	-13±22	12±10	8±11	3±8
2	Cabrobó	8.50	39.31	-10±26	10±28	-18±16	-4±11	-6±14	2±11
3	Caruaru	8.24	35.98	-20±21	2±22	-18±16	6±9	3±13	4±8
4	Aracaju	10.95	37.05	-11±15	18±18	-32±24	6±6	12±10	-6±10
5	Salvador	13.00	38.51	5±29	10±21	-6±19	18±16	14±12	3±9
6	São Paulo	23.50	46.62	-5±17	-3±11	3±21	12±10	2±14	10±11
7	Santa Maria	29.70	53.70	1±20	1±13	-3±16	10±8	5±11	5±8

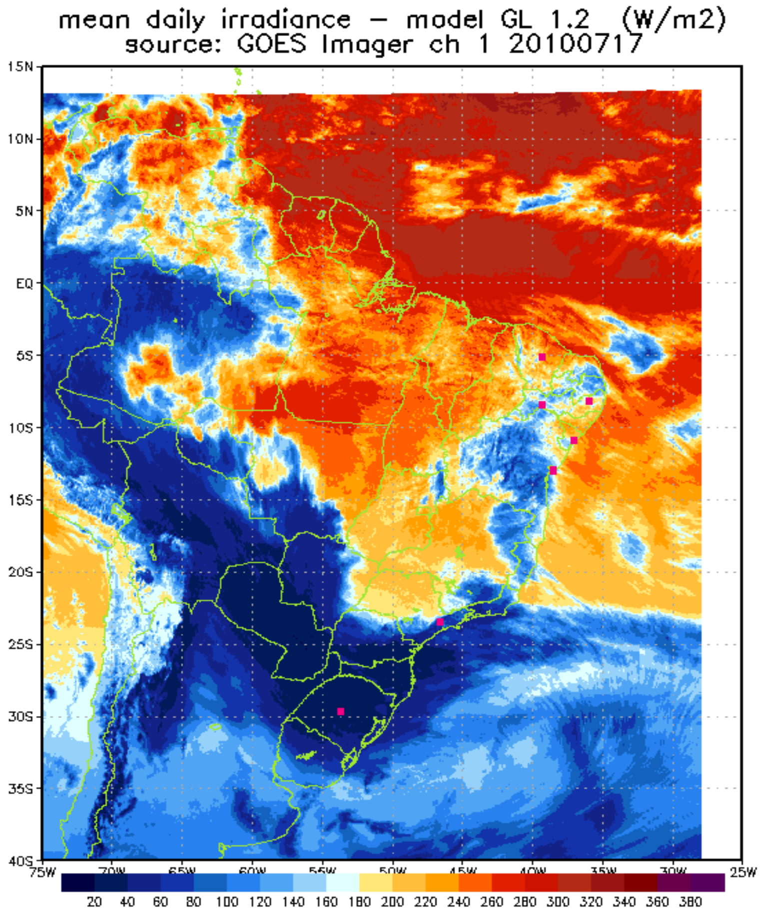


Figure 3. Daily mean irradiance at 17th July, 2010. Image source: GOES 12 (4 images per hour). Mean irradiance is the total irradiation (in $J.m^{-2}$) divided by 86400 seconds. Seven stations chosen for model comparisons are marked with magenta squares. For water column, version GL1.2 assumes typical values of 3.5 $g.cm^{-2}$ (south from 20°S) and 4.5 $g.cm^{-2}$ (north from 20°S).

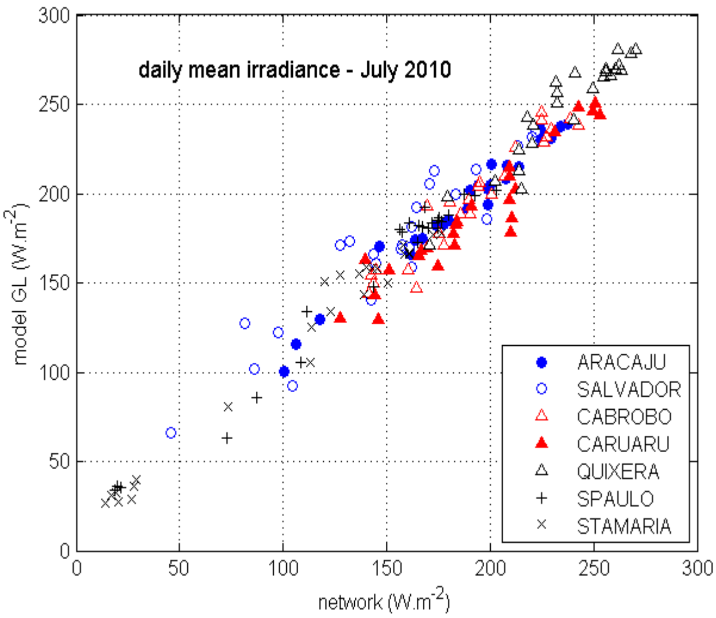
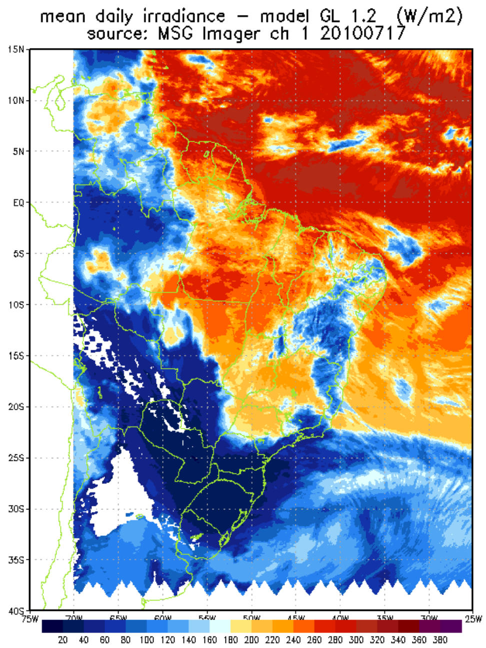


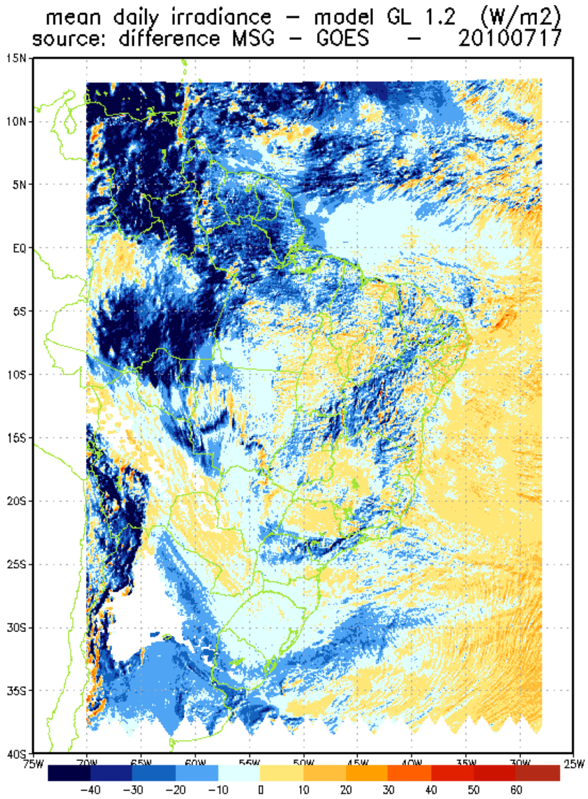
Figure 4. Comparison of daily mean irradiance for July 2010: GOES 12- based model versus ground truth (seven sites). Linear regression coefficient is r= 0.978.

Figure 3 shows stations location and geographical distribution of mean solar irradiance using GOES imagery for 17th July 2010. Figure 4 illustrates the comparison of values of GOES-based model versus ground truth during July 2010. It was found a linear regression coefficient r=0.978. Linearity was similar when using Meteosat-based GL estimates (r= 0.973).

GOES 13 and GOES 12 were the sources of full South American imagery. MSG always produced 4 images/hour, which is not the case for American satellite. GOES 10 had furnished imagery of South American region each 15 minutes since March 2007 until December 2009, and GOES 12 assumed this task since May 2010. GOES 13 performed the transition, providing a lower number of images per day. Last but not least GOES 13 VIS imagery had a standard correction for sensor degradation previously used for GOES 10, whereas GOES 12 reflectance factors were compared with MODIS imagery over a bright target (Salar de Uyuni, Bolivia). As described in section 2, GL model is strongly dependent of observed reflectance factor. Those different qualities of input data clearly induced a higher mean deviation for sites 1-4, as shown in Table 1 (southern sites 6-7 exhibit lower seasonal cloudiness in April, thus a lower mean error in GL estimates). It is seen that a better calibration of GOES images allows for similar values using GOES or MSG (by the way, constant quality of SEVIRI calibration allows for similar deviations from network in April as well as in July).

Figures 5 allow for comparisons in a continental scale. A single day was chosen (20100717) with the presence of clouds all over Brazilian northeastern coast and a strong frontal system extended over southern Brazil, northern Argentina, Paraguay and Bolivia. Central Brazil exhibits predominance of clear-sky conditions. Differences between GOES and MSG fields makes evident some important issues:





Figures 5. GL estimates for daily mean irradiance on July 17th 2010 using SEVIRI channel 1.

Left: MSG-based field. Scale color is the same as Figure 3.

Right: Deviation of MSG-based from GOES-based estimates.

a) In July, daily solar irradiance exhibits values between 40-60 $W.m^{-2}$ under frontal cloud coverage and 220-300 $W.m^{-2}$ in mostly clear-sky conditions.

b) Atlantic areas (predominantly with clear-sky conditions) exhibit differences ±10 W.m^{-2} east from 50°W and south from 5°N.
c) Southern frontal region with strong cloudiness has similar description by both satellites (within -10 to 0 W.m^{-2}).
d) Difference can attain -25 W.m^{-2} over cloudy regions parallel to eastern Brazilian coast. Clouds might be seen by MSG with higher reflectance than GOES does (thus yielding lower solar irradiance). This difference is not observed for cloud systems over Atlantic and only weakly over Brazilian northeastern extreme. Anisotropy of cloud reflectance could be the cause; statistical analysis of daily cycles is being performed.
e) MSG line-of-sight is too slant for places located south from 40°S, along Chile, and throughout far western Brazil describing an arch until Amazonas mouth. These are the western boundaries for MSG-based estimates; deviations are higher than 30 W.m^{-2} even for not so developed cloudiness.

4. CONCLUSIONS

Physical structure of GL model is simple but consistent, with VIS reflectance as main variable. Careful correction of sensor degradation should allow for similar irradiance estimates using GOES-based or SEVIRI-based imagery. Testing this issue over Brazilian Northeastern and Southern areas (seen with similar zenithal angle by both satellites), daily irradiances are fitted with correlation coefficient r=0.97, mean deviation lower than 20 and standard deviation lower than 10W.m-2. While these conclusions may be preliminary (an extended analysis of performance is being performed, for seasonal confirmation of these results and diagnosis of importance of anisotropy of cloud reflectance), the use of MSG imagery seems to be not only an alternative for GOES availability over a large area of South America; indeed, it could be used for shortwave radiation estimation over Atlantic Ocean and African continent.

5. Acknowledgements. Brazilian National Research Council (CNPq) has partially granted this work.

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