# SOLAR RADIATION IN SOUTH AMERICA, PERIOD 1998-2004: SOME ASPECTS OF A SATELLITE-BASED DATA BASE

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**ABSTRACT.** Solar radiation estimates for South America were analyzed for the period January 1998-December 2004. Data base was provided by the operation model GL1.2 running at CPTEC. In order to perform the analysis, average over consecutive 5 days was calculated and spatial averages over a grid with 0,4°×0.4° resolution were considered. Some characteristic seasonal averages and annual cycles for several regions are shown. The accuracy of estimates is made evident by comparison with surface network stations. Coherence with two recently published Atlases is also evident. Present results suggest that GL is providing a reliable high resolution time series, which will attain 10 years length in a near future.

**Radiação Solar 1998-2004 na América do Sul: Alguns aspectos de uma base de dados baseada obtida por satélite**

**RESUMO.** Foi analisado o período janeiro 1998-março 2005 de estimativa de irradiação solar diária na América do Sul. Os dados provêm do modelo GL1.2 rodando operacionalmente no CPTEC. Para análise, foram utilizadas médias de 5 dias (pêntadas), em médias espaciais de 0,4°×0,4° no período 1998-2004. São apresentadas algumas características sazonais e ciclos anuais de várias regiões. A coerência com Atlas recentemente publicados é evidente. A comparação com dados de superfície evidencia a qualidade das estimativas. Os resultados presentes sugerem que brevemente estará disponível uma série temporal de 10 anos de radiação solar.

**Palavras-chave**: Radiação solar, GOES, América do Sul

## INTRODUCTION

Several Atlases and data bases of solar radiation over Brazil have been built since 1970. For instance the National Institute of Meteorology (INMET 1979) published 1931-1960 averages, mainly for insolation (sunshine duration); Nunes et al. (1978) used actinographs and heliographs data bases and the Benett criterion. Funari (1983) used similar data, mainly for building a net radiation climatology. Tiba (2001) presented a new Atlas based in a comprehensive collection of existing sunshine, actinographic and pyranometric records. Recently, GOES satellite imagery and an adapted version of IGMK model (Köln University), the Brasil SR model, were used for building a Brazilian Atlas of 1995-1998 period (INEMET/LABSOLAR 1998).

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The model GL (Ceballos et al. 2004) is running operationally at CPTEC, processing GOES 12 VIS imagery and providing files of daily irradiation for South America and neighboring oceans. Lower resolution images were also processed for 1997 (Bottino and Vilas Boas 2005); therefore, nearly a decade of solar radiation files based on GL model is stored. This paper presents the analysis of some results obtained from a first compilation of solar irradiance, period October 1997 to March 2005. This compilation has been labeled as "GLPentad.v01"files.

## TIME SERIES AVAILABILITY AND PROCESSING

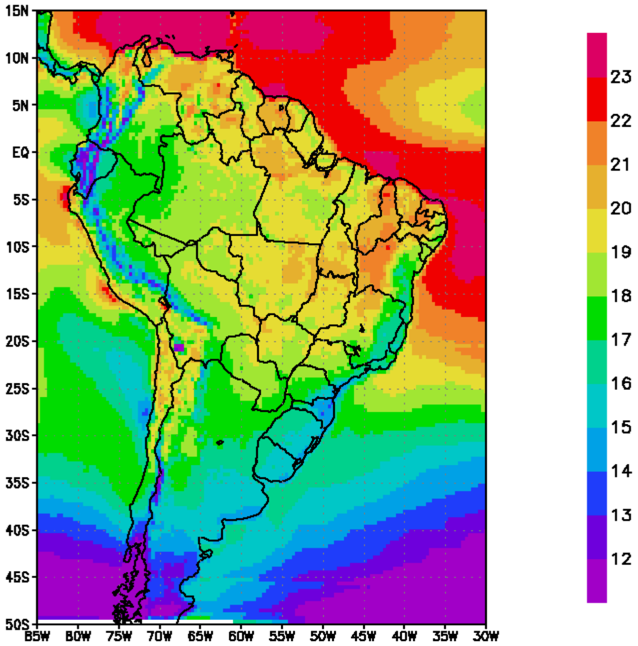
Physical units for solar radiation use to describe daily irradiation in $MJ.m^{-2}$ or kWh (for engineering practice), or daily mean irradiance in $W.m^{-2}$ (useful in several meteorological applications). GLPentad.v01 files are expressed in $W.m^{-2}$. Five GLPentad.v01 files are available for download at the internet URL http://satelite.cptec.inpe.br/htmldocs/radiacao/fluxos/radsat.htm → "Séries históricas", corresponding to South America, to three Brazilian regions (Northeast, Southeast and Amazon), and to the Southernmost American region including Argentina, Uruguay, Chile and (partially) Paraguay and Bolivia. The same URL provides information about other specifications for file processing.

GL model (version 1.2) works with GOES VIS images sampled to fit channel 4 resolution (about 4 km at satellite nadir). The final files have 0.04º resolution, but represent the average in a 3×3 pixels target centered at that pixel (see Ceballos *et al*. 2004 for additional information about model, and the internet URL at CPTEC http://satelite.cptec.inpe.br/ → "radiação solar e terrestre" for validation analyses of operational results). In order to allow easier computer handling for climatological studies, GLPentad files provide data with time resolution of five days (average over consecutive 5 days = 1 pentad) with 73 pentads in one year (the last pentad has actually 6 days in leap-years 2000 and 2004). Therefore, six pentads cover *approximately* one month. Considering space resolution, GLPentad.v01 data correspond to averages within a grid with 0.4°× 0.4° cells. Missing data in a cell are indicated with zero value.

## SOME PRELIMINARY RESULTS

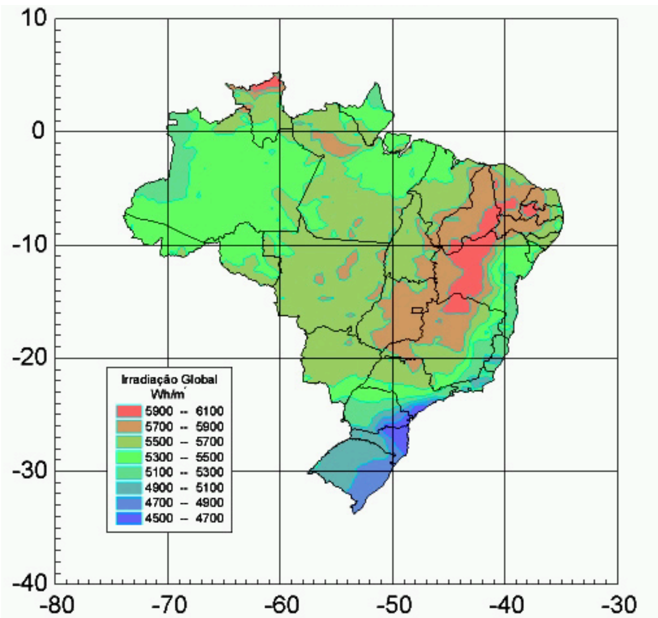
For the sake of having regularly distributed periods, the analysis was restricted to 1998-2004 interval. Zeros were substituted by the average of the 5-pentad period centered at the missing pentad. An annual cycle could be built for each of 73 annual pentads, assessing the average of seven values in 1998-2004. Seasonal geographical distributions were calculated as averages of 18-pentad groups (as a matter of fact, three-month periods). The last season included an additional pentad. The

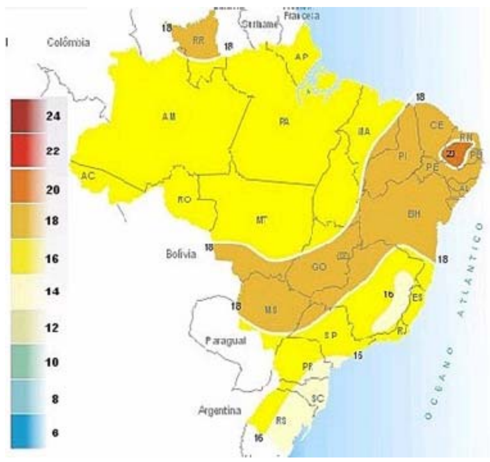
Matlab7 software was appropriate for easily handling this type of processing, as well as graphical output of results.




**Figures 1**. Daily irradiation. Top: annual mean, model GL (GOES-E based), period 1998-2004. Units: $MJ.m^{-2}$
Bottom, left: annual mean, Brasil-SR model (GOES-E based), period 1995-1998 (source: INMET/Labsolar, 1998). Units: $Wh.m^{-2}$.
Bottom, right: annual mean obtained from surface data: pyranometers and heliographs (source: Tiba, 2001). Units: $MJ.m^{-2}$. Period: source dependent; not longer than 5 years for most part of stations.

Equivalence:
1 $kWh.m^{-2}$= 3.6 $MJ.m^{-2}$




**Mean annual distribution of solar radiation**.

Figure 1 displays a comparison between annual means for Brazil in three cases: 1) GL model (1998-2004), pixels with 0.4º resolution; 2) Atlas based on Brasil-SR (INMET/LABSOLAR 1998), interpolated from grid with 0.5° resolution; 3) Atlas based on ground data (Tiba, 2001), probably obtained by kriging-type interpolation. The second one uses $Wh.m^{-2}$ units in lieu of $MJ.m^{-2}$. The satellite-based charts show a region with values of at least 19 $MJ.m^{-2}$ = 5250 $Wh.m^{-2}$ attaining Mato Grosso and Pará. Inside this region, another one with at least 21 $MJ.m^{-2}$ = 5830 $Wh.m^{-2}$ crosses throughout the Semiarid Northeast down to northwestern Minas Gerais. The generic behavior has been caught by the third source, but scarcity of ground data does not allow a detailed description.

This first comparison makes evident the ability of satellite based methods for getting better details of geographical distribution of solar irradiation. It is to be noted that both satellite methods seem coherent, in despite of difference in models and of time periods considered (means in 1995-1998 are about the same as in 1998-2004). Another noteworthy advantage is the description of solar irradiation over ocean and Amazon region, where scarce ground data are available. Some remarkably high values made evident near Northeastern coast or in front of Northern coast of Venezuela are interesting to be inspected mainly in the context of input/output of NWP programs.

Nevertheless, some shortcomings of GL model must be addressed, such as confusion between (bright) cloudy pixels and snow or salt cover (Andes Cordillera, and an extended *salar* in southwestern Bolivia). Other physical or temporary limitations are described in Ceballos *et al.* (2004); one of them is the loss of image frequency when rapid scan is decided by NOAA, face to the proximity of events like hurricanes.

**Annual cycle of solar radiation**

Figure 2 illustrates the cycles of three sites, two of them being at neighboring locations in São Paulo and Minas Gerais states: Silveiras (22.80S 44.84W) and Lavras (21.22S 44.97W), and the third in Pernambuco (Caruaru, 8.24S 35.91W). All of them are relatively far from ocean coast. In order to obtain a smoother behavior, a) deviations from the average higher than 100 $W.m^{-2}$ were not considered in the sample of 7 years; b) a moving average of size 5 was adopted for each pentad. It is seen that Lavras and Silveiras have very close cycles and exhibit a minimum for pentads 64-66. This is probably due to systematic intrusion of cold fronts over São Paulo and Minas in November. Caruaru, in Northeast Brazil, shows nearly a maximum for those pentads. The same figure illustrates interannual fluctuations of solar radiation, showing the annual cycle of standard deviation of pentadic means. For instance, Southern Brazil has a maximum from October to March (due to the rainy season). It is interesting to note that standard deviation of pentadic values has an annual cycle of values of about 7-10% of the mean $<G>$ during winter and 20-25% during summer (rainy season). On the other hand, a Northeastern site like Caruaru does not show not an interseasonal qualitatively different behavior of fluctuations.

Difference between Lavras and Silveiras in Figure 2 showed that short-scale variations of irradiation are not large along the year. Figure 3 illustrates another aspect of such comparisons. It is seen that two stations included in the same cell of 0.4º size have not large differences (monthly average uses to be lower than 20 $W.m^{-2}$), while the mean monthly deviation of model minus ground measurement is about 20 $W.m^{-2}$. It is suggested a long-term stability of model; improvements in performance could be associated to a better description of cloud reflectance during summer events, at least for Brazilian Southern region.

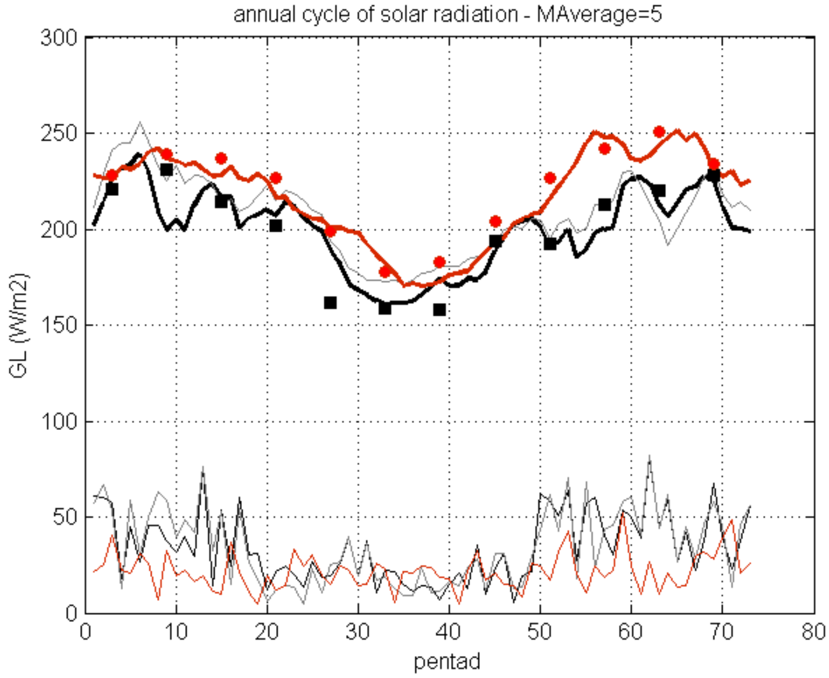



**Figure 2**. Model GL: mean annual cycle (1998-2004) at three sites in Brazil. Red: Caruaru, PE. Black: Silveiras, SP. Grey: Lavras, MG. Squares and circles are monthly averages of automatic stations at Silveiras and Caruaru, period 1999-2004. **Bottom**: Annual cycle of standard deviation of pentadic values for 7 years.

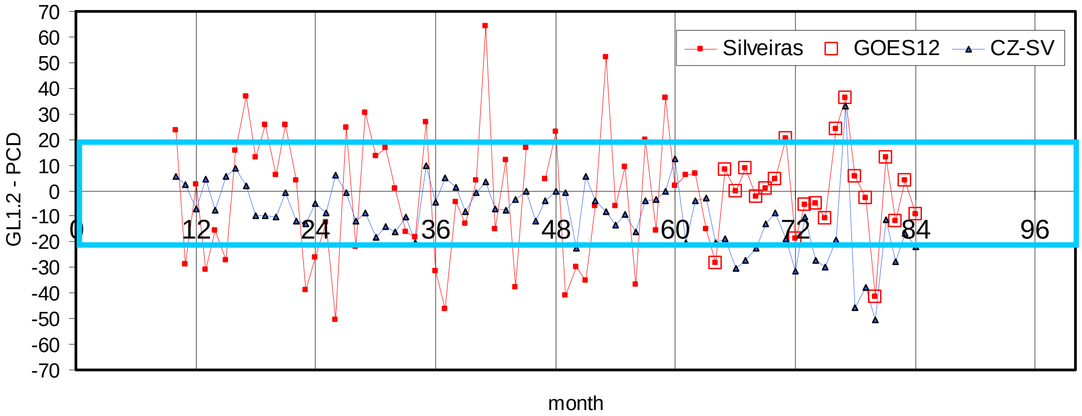



**Figure 3**. Monthly mean error related to Silveiras time series. Starting: January 1998. CZ-SV (blue): Difference between Cruzeiro and Silveiras (located inside the same pixel of GLPentad file). Cruzeiro calibration presented problems since about 64$^{th}$ month. The change from GOES 8 to GOES 12 does not show large differences, at least until December 2004 (84$^{th}$ month).

A monthly statistics (table not shown here) informs that the annual mean error for Silveiras lied between -0.2% and -2.8% (**bias**) in 1999-2004. Monthly means have mean errors between 1% and -10% (with a high deviation in May: 20%); standard deviation of monthly errors in the sample of 6 years [**random** error] lies between 6% (July) and 13% (November) of mean or “about-climatological” values.

## CONCLUSION

The model GL1.2 is presented in a preliminary version (“GLPentad v01” files) for 1998-2004 period, being useful for time series studies. It exhibits spatial coherence of mean values when compared with several Atlases. Comparison with ground truth makes evident a coherent description of annual cycles as well as relatively low errors, considering the simplified characteristics of the assessment model and the files format. This type of files, in a nearly becoming 10-year length version, will be useful for establishing a preliminary but rather detailed climatology of solar radiation over South America. Further improvements should include a systematic comparison with the network of automatic stations (in order to detect and eliminate effects of outlier data). Specific studies should introduce model correction in snow-covered regions.

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