Time Series of Daily Mean Solar Irradiance over South America: Some Results of 11 Years of CPTEC GL Model Using GOES Imagery

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Abstract Distribution of solar radiation over South America is daily assessed by the CPTEC's GL1.2 model using GOES satellite imagery (VIS channel). A time series of 11 years, January 1996 to Dezember 2006 is now available and may be used for climatological, agricultural and energy-source studies in the scale of 1 day, 0.04°. A compact version (averages over 0.4° and five-day intervals) is available for download. Comparison with values provided by several solarimetric stations exhibits fair fitting (about 7% or less for monthly averages). This resolution allows for an acceptable detail of geographical distribution. Comparison of annual cycles for 5 and 11 years suggest that both periods have similar behavior within one standard deviation expected for each average pentad, so that the 11-year series can be used for preliminary climatic studies.

Keywords: solar radiation, GOES, GL model, South America
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INTRODUCTION

CPTEC/INPE performs direct readout of GOES imagery since 1996. Time and space resolution has been about 0.12 x 0.12 degrees until September 1997 (with three-hourly readout), and 0.04 x 0.04 since October 1997 (time resolution at least half-hourly). The model GL version 1.2 developed at CPTEC/INPE (Ceballos et al. 2004) has been used for assessment of global and visible irradiance at the highest available time and space resolution, generating solar radiation data for South American area (about 45°S to 10°N, 100°W to 30°W). The set of GL files is used for generating distributions of daily average over this area; daily charts are released through CPTEC internet site http://satelite.cptec.inpe.br – *Radiação solar e atmosférica*. The resultant time series attained 11 years length in December 2006.

For climatological purposes, the eleven-year data base was used for building binary files with five-day-0.4x0.4-degree averages (average pentads), also available through the abovementioned CPTEC URL. This paper presents some characteristics of GL results, concerning its accuracy and the stability of time series in a context of 5 and eleven years.

MODEL AND VALIDATIONS

Structure and parameterizations of GL model are described in Ceballos et al. [2] (see also URL http://satelite.cptec.inpe.br/radiacao/) and illustrated by Figure 1. Partition is made in VIS and NIR interval. The first one is conservative in the troposphere (no absorption) with a correction for O_3 attenuation in stratosphere, while clear sky does not scatters radiation in NIR interval, clouds can reflect and absorb but are opaque for downward radiation. Therefore, only Cu cloud fields let partial transmission of NIR direct radiation. It is assumed a VIS reflectance varying linearly with cloud cover; total cover is found for $R_{VIS}>0.465$. Presently, model GL runs at CPTEC processing GOES 10 imagery. Model provides results with 0.04° resolution but must be meant as the

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average within 0.12°×0.12°. The eleven-year data base (1996-2006) has been used for building binary files with five-day and 0.4°×0.4° averages (average pentads). For climatological purposes, these files conserve the information about time and space variability of solar radiation while handling simpler data files. These files are available for download at the abovementioned URL.

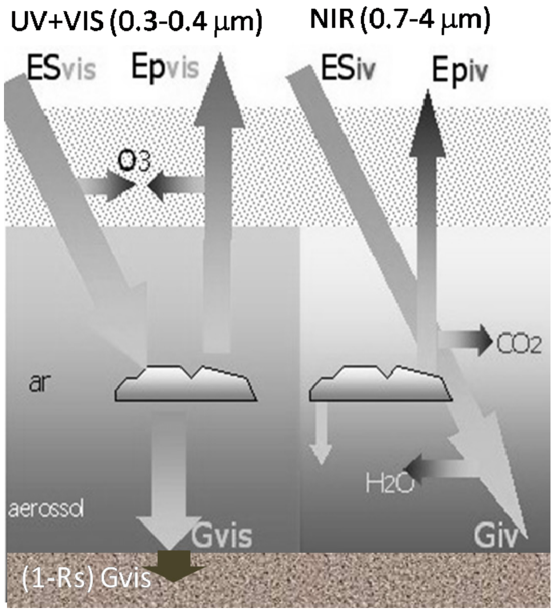

FIGURE 1. Schematic structure of GL/CPTEC model for solar radiation assessment by satellite

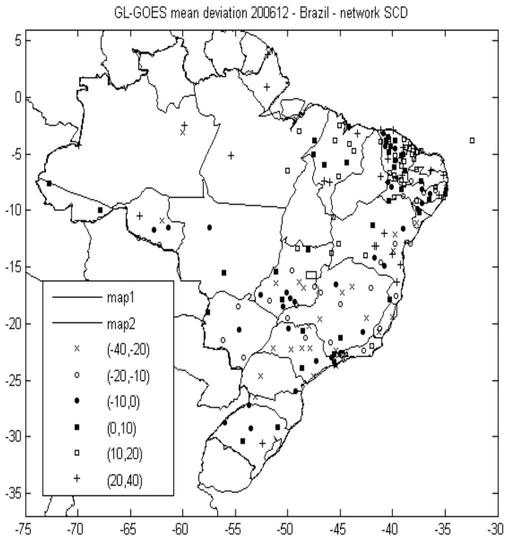

FIGURE 2. Validation of monthly GL results comparing with a pyranometric network. Symbols indicate difference of GL related to network value.

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(a) (b)

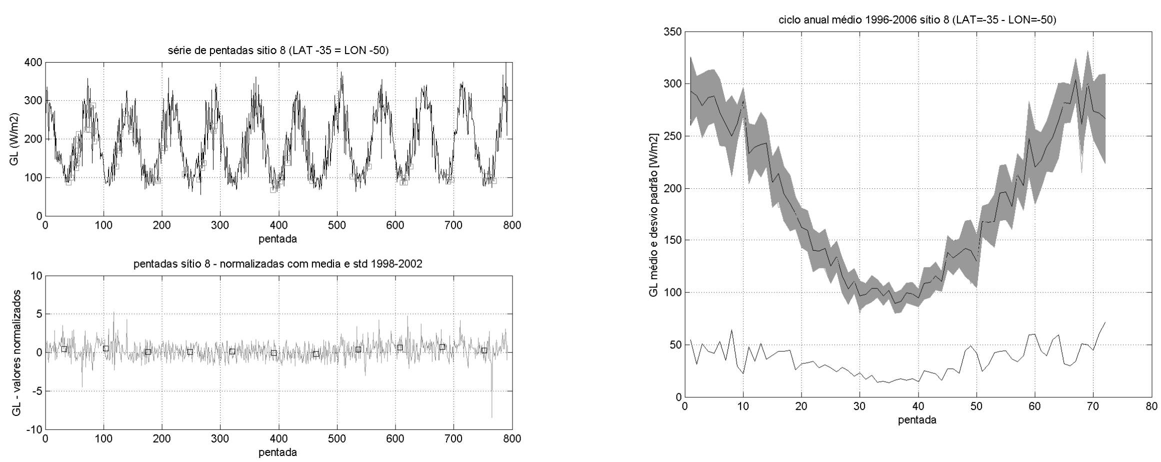

FIGURE 3. Time series for a site located at 35°S 50°W (Atlantic Ocean, near Uruguay). (a) 11-year pentadic series. (below) The same series, normalized with the average annual cycle 1998-2002 and the standard deviation of 5 values for each pentad. (c) Mean annual cycle for 5 years and 11 years (black line). The first cycle is included within the standard deviation expected for averages of 11 years (yellow region). Bottom: Annual cycle of 11-year standard deviation.

The general accuracy of global radiation estimates may be stated by comparison of monthly averages (0.04° resolution) with the corresponding averages of a Brazilian meteorological network associated to Brazilian satellite SCD [Satélite de Coleta de Dados = Data Collecting Satellite]. Distribution of deviation from "ground truth" over Brazil for Dezember 2006 is shown in Figure 2. Deviations higher than 30 W.m^{-2} are usually due to ground instrument problems only. Coherence of monthly mean distributions with recently published Atlases (for instance Pereira *et al.* [2]) has also been noticed.

Figures 3 describe statistical characteristics of time series choosing a site in Atlantic Ocean, near Uruguay. The 11-year series (3a) shows well-defined annual cycles. Red squares indicate missing pentads. Original GOES images for years 1996-1997 provided sampled pixels for GOES 8; since 1998, imagery had full resolution. Also, GOES 8 was substituted by GOES 12 since March 2003 and corrections for sensor decay were applied only from September 2006 on. In order to test homogeneity of the series, it was normalized using the average annual cycle during 1998-2002 and the corresponding standard deviations for each one of 73 annual pentads. Figure (3a) shows that normalized series rarely exceed the limits ±3, as expected. It makes evident the absence of tendencies, except during not corrected calibration for GOES 12. It is also evident that the period with sampled pixels for GOES 8 is "noisier", as it is the GOES 12 period. Figure 3 shows the average annual cycle of daily mean irradiance, for 1998-2002 (in red) and for 1996-2006. Expected fluctuation for the 11-year average (within one standard deviation) makes evident the statistical equivalence of 5-year and 11-year average annual cycle. This fact suggests the ability of the 11-year series for describing climate of solar radiation over South America.

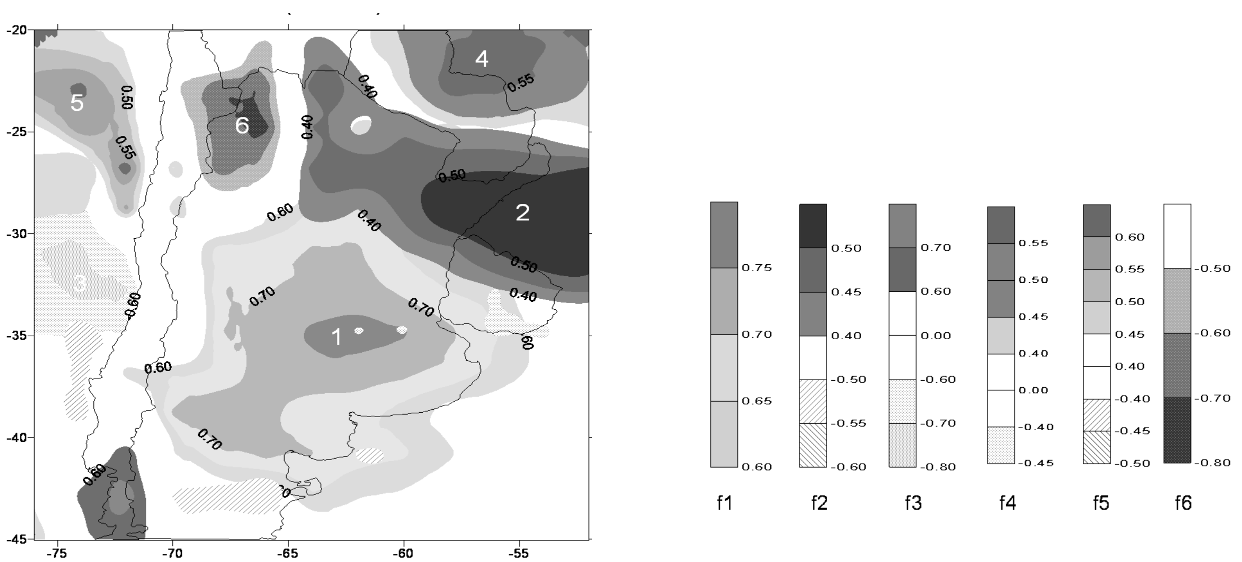

FIGURE 4. Results of factor analysis in principal components over Uruguay-Argentina-Chile region. No rotation applied. Six factors are identified. Factor loadings scales (f1 … f6) are indicated on the right.

AN APPLICATION: FACTOR ANALYSIS OF TIME-SPACE BEHAVIOR

Figure 4 illustrates a simple application of factor analysis to time series within Uruguay-Argentina-Chile region, December-February. Normalized irradiances were used (related to the average and standard deviation of pentads in those months). Six factors cumulated 72% of total variance. Even if a Varimax rotation can improve definition of main factors, Figure 4 allows for detection of main regional behaviors. It is seen that during summer Central Argentina has its own behavior (f1), while Southern cloud systems can be associated to cold fronts (factor not numbered), Northeast shows influence of mesoscale convective systems (f2) and Northern Argentina seems present a higher altitude behavior (f6). Northern Paraguay and neighboring Brazil present convective explosions which induce the displacement of instability waves (f4) and Pacific has characteristic Sc cloudiness associated to regional subsidence (f3, f5). Indeed, characteristic temporal behaviors can be expected for each region, determining local performance of solar energy and/or evaporation regimes. These aspects could hardly be described by the simple climatological mean.

CONCLUSIONS

Eleven years of GOES VIS imagery were run using model GL/CPTEC for estimating solar radiation over South American region. This data base allowed to release a high resolution, daily-valued time series which shows relatively low errors for monthly averages over Brazil and expectedly over South America and neighboring oceanic regions. Data file is directly available for download in the simplified version of averages over 5 days (pentads) with 0.4°×0.4° resolution, easier to handle and useful for climatological studies. Statistics of annual cycle suggests that 5-year and 11-year time series are virtually equivalent in a statistical context, allowing for their use in climatological studies.

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