Inter-comparison of Solar Resource Data Sets: NASA-SRB/SSE versus DLR-ISIS Global and Beam Irradiance

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ABSTRACT

Two satellite-derived solar irradiance data sets covering the full globe are compared against each other. One is NASA's SSE (Surface meteorology and Solar Energy) data set, the other DLR's ISIS (Irradiance at the Surface derived from ISCCP cloud data). Both consist of boxes with coarse spatial resolution: SSE has approximately 100 km wide boxes, ISIS 280 km. Both data sets are based on long-term archives: SSE so far covers 10 years, ISIS 21 years. Also both data sets offer information on global hemispherical irradiance and direct normal irradiance, required for planning of concentrating or tracking solar energy devices. The two satellite schemes use differing cloud detection, aerosols and water vapor, and separate radiative transfer calculations. Comparing both data sets in 12 different regions worldwide allows analyzing effects of different climates and satellite viewing geometries on quality. It is found that both data sets agree reasonably well for global irradiance indicated by an RMS deviation below 9%. On average over all regions SSE reports approximately 6% less irradiance than ISIS. This bias is similar for direct normal irradiance, but RMS is much higher exceeding 20%.

1. SOLAR RESOURCE DATA NEEDS

Besides other components of the radiation balance solar radiation at the Earth's surface is an important issue for climate research. Clouds are the dominating atmospheric constituent for radiative fluxes. Therefore, NASA set up the International Satellite Cloud Climatology (ISCCP, Rossow, et al., 1996) to derive a global view on the distribution and properties of clouds. Besides climatological questions such cloud climatology may also be used to derive solar irradiance products supporting development of solar energy worldwide. Analysis of technical and economical potentials energy requires profound knowledge of available resources. From analysis of long-term measurements (e.g. Gilgen et al., 1998, Liepert, 2002 or Wild et al. 2005) it is known that the available amount of energy from the sun varies from year to year and also shows trends. To analyze the effects of these changes on solar power yields it is desirable to get data sets spanning over several decades. Best would be if these are available worldwide not just for the few measurement sites, where long time-series are monitored. Satellite data can deliver the complete picture.

In atmospheric research usually the total flux from the upper hemisphere GHI (global hemispherical irradiance) is sufficient. But for solar energy it is of great benefit to separate the total flux into its diffuse and direct component. Direct irradiance normalized to the direction of the sun (DNI) is of great advantage for simulation of concentrating solar devices which can only focus this part of solar radiation. For large PV plants tracking systems gets more and more popular and also concentrating PV seems to be more and more feasible, both requiring DNI as input for system simulation. Therefore, the data sets described here are aiming to provide total and beam irradiance.

ISCCP forms the base for both data sets presented here. NASA SSE products rely on the ISCCP medium resolution archive, for which an independent cloud processing is done. The second data set is derived by the German

Aerospace Center (DLR) also based on ISCCP but in rougher resolution. The International Satellite Cloud Climatology Project's (ISCCP) D type data set provides a coarser resolution equal area grid with 280 km box size. Both data sets are described briefly. Then a chapter analyzes the differences between the two, from which finally conclusions are drawn in respect to solar applications.

2. NASA's SSE AND SRB DATA SETS

SSE (Surface meteorology and Solar Energy, http://eosweb.larc.nasa.gov/sse) is a data set, which NASA created for applications in the field of renewable energy (Stackhouse et al, 2004). SSE's solar radiation products are closely related to the processing of data for the Surface Radiation Budget Project (SRB, Stackhouse et al., 2002, Cox et al., 2004), which is part of WCRP / GEWEX (World Climate Research Programme / Global Energy and Water Experiment). Here we analyze mainly this underlying data set. In the areas investigated SRB similar to ISCCP relies mainly on cloud detection from geostationary satellites. The main difference in the two SRB releases covered here is that the earlier SRB release 2.0 (corresponding to SSE release 5.0) spans 12 years and uses column water vapor profiles based on the GEOS-1 model (Schubert et al., 1993), while SRB release 2.5 (corresponding to a future SSE release) spans 21.5 years and uses data from GEOS-4 (Bloom et al., 2005, see Fig. 1). The SRB data set features the algorithm of Pinker and Laszlo (1992) as delivered to the GEWEX program and subsequently modified. The aerosol background properties are assigned relative to surface type using the WCP-55 aerosol optical properties. The optical depths of the aerosol distributions are modified to match clear-sky albedos computed on a 1x1 degree 3-hourly basis. It is noted that the model does not explicitly compute a direct normal flux but this is inferred from the diffuse component estimate. Thus, SSE direct normal fluxes are not computed in this fashion but use the estimate of the total flux with a parameterization based on either a modified RETScreen (Leng et al., 2002) another method using an extended Page (1964) method to estimate diffuse flux that is subtracted from the estimated total. Unfortunately, SSE monthly direct normal data could not be made available in time for this paper.

3. DLR's ISIS DATA SET

Solar irradiance components can also be produced by the methodology of Lohmann et al. (2006). This method relies on two-stream radiative transfer calculations with an approximation for spherical geometry to calculate global and direct irradiance. By the distributed-k approach irradiance values are integrated over the solar spectrum from 0.3 µm to 3 µm. Required input parameters to the scheme are physical properties, which describe the relevant optical properties of the atmosphere in the solar spectrum. These basically are cloud frequency, optical depth, and height, the broadband aerosol optical depth, and the concentration of water vapor and ozone. For further properties values from standard atmospheres are sufficient.

Currently, the Lohmann method is mainly driven by input from the ISCCP FD data set (Zhang et al. 2004). Therefore, the data set derived by this method is called ISIS (Irradiance at the Surface derived from ISCCP cloud data). It covers the full period from July 1983 to December 2004 in 3-hourly resolution at a spatial resolution of 280 km. Further, climatological monthly means of tropospheric aerosols are gathered from model calculations of the NASA GISS GCM (Tegen et al. 1997). The lack of a more realistic aerosol data set means that the annual cycle is reproduced but not temporal changes from year to year for the tropospheric aerosol load. Additionally, stratospheric aerosol according to Sato et al. (1993) is added to account for the effect of volcanic eruptions. Since this data set ends 1999, an exponential decrease is assumed until December 2001 and a constant background aerosol thereafter. Fig.2 gives an example from ISIS again for the region of the U.S. Southern Great Plains.

ISIS has been compared in an earlier study (Lohmann et al., 2006) with direct irradiance derived from high resolution Meteosat-data. Averaged over the area of a complete ISCCP-box a mean underestimation of 2% for DNI is recognized. To this underestimation an additional bias needs to be added as Schillings et al. (2004) find that the high resolution DNI values from the applied Meteosat-based method show an average bias of -5% against pyrheliometer measurements. Thus, it is assumed that ISIS DNI has a mean bias of approximately -5% to -10% in the analyzed regions.

Further, Riihimaki et al. (2006) compare the data set for three stations in Oregon with long-term measurements and additionally with high resolution results from Perez et al. (2002) using the GOES satellite. From this study it is concluded that ISIS gives 1% to 3% higher values for GHI than the box-average from Perez et al. (2002). But it most be noted that this bias seem to be variable during the

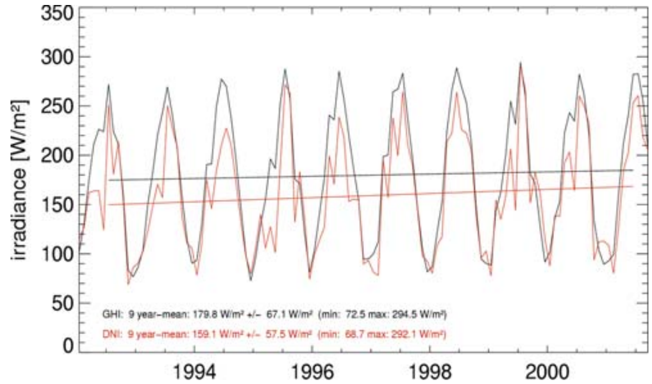

Fig. 1 Monthly values of solar irradiance from the NASA SRB data set (release 2.5) for a region in the US Southern Great Plains (global hemispherical irradiance in black, direct normal irradiances in red).

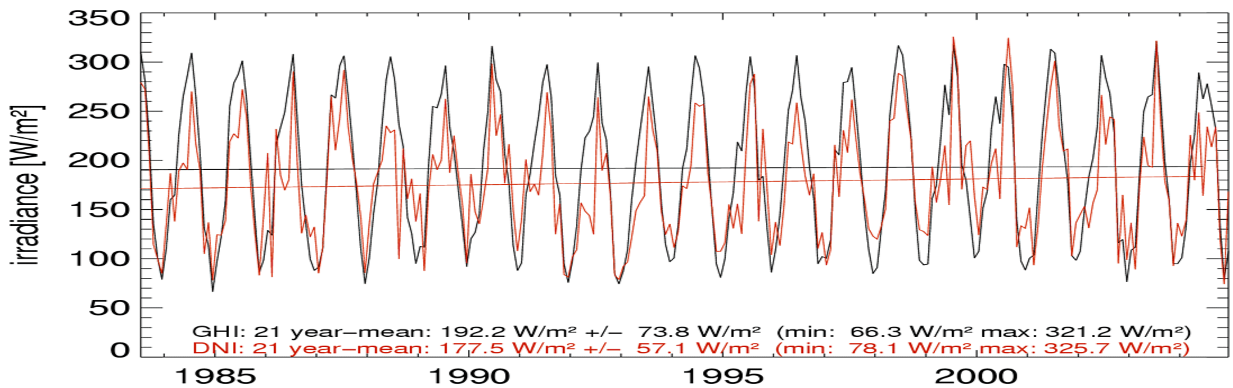

Fig. 2: Monthly values of solar irradiance from the DLR ISIS data set for region in US Southern Great Plains. Global hemispherical irradiance (black) remains fairly constant since 1983, while direct normal irradiance (red) shows an increase.

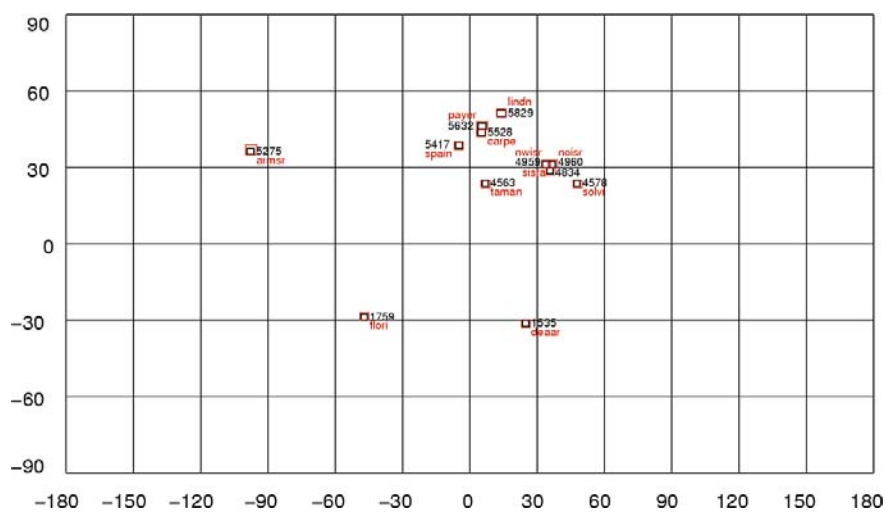

Fig. 3: Map indicating all regions, for which inter-comparisons are made. SRB regions are displayed in red, ISIS in black.

5 years compared and it is also found that Perez et al. (2002) in the 0.1° x 0.1° resolution shows a bias of -4% against pyranometer measurements averaged over the 3 sites investigated by Riihimaki et al. (2006). Thus, it is assumed that long-term averages of GHI from ISIS show a mean bias in the order of 0% to +3% at least in midlatitudinal climate.

4. RESULTS AND DISCUSSION

The two data sets are compared for the 12 regions displayed in the map of fig. 3. As spatial resolution of SRB with approximately 100 km is significantly higher than the 280 km spaced boxes of ISIS, the SRB/SSE results are averaged over regions, which approach the wider ISCCP-boxes. Typically around 9 SRB-boxes cover one ISCCP-box. But because grids of SRB and ISIS do not match the regions to be compared still differ by various extends. Therefore, results must show some difference depending on extend of the overlapping area.

SRB and ISIS originally consist of 3-hourly data. To handle the amount of data all values are temporallily averaged over full calendar months. Fig. 4 shows scatter-plots summarizing all monthly values for all 12 regions. The results separated by regions are shown in table 1. In this inter-comparison negative mean bias (MB) indicates that SRB is lower than ISIS.

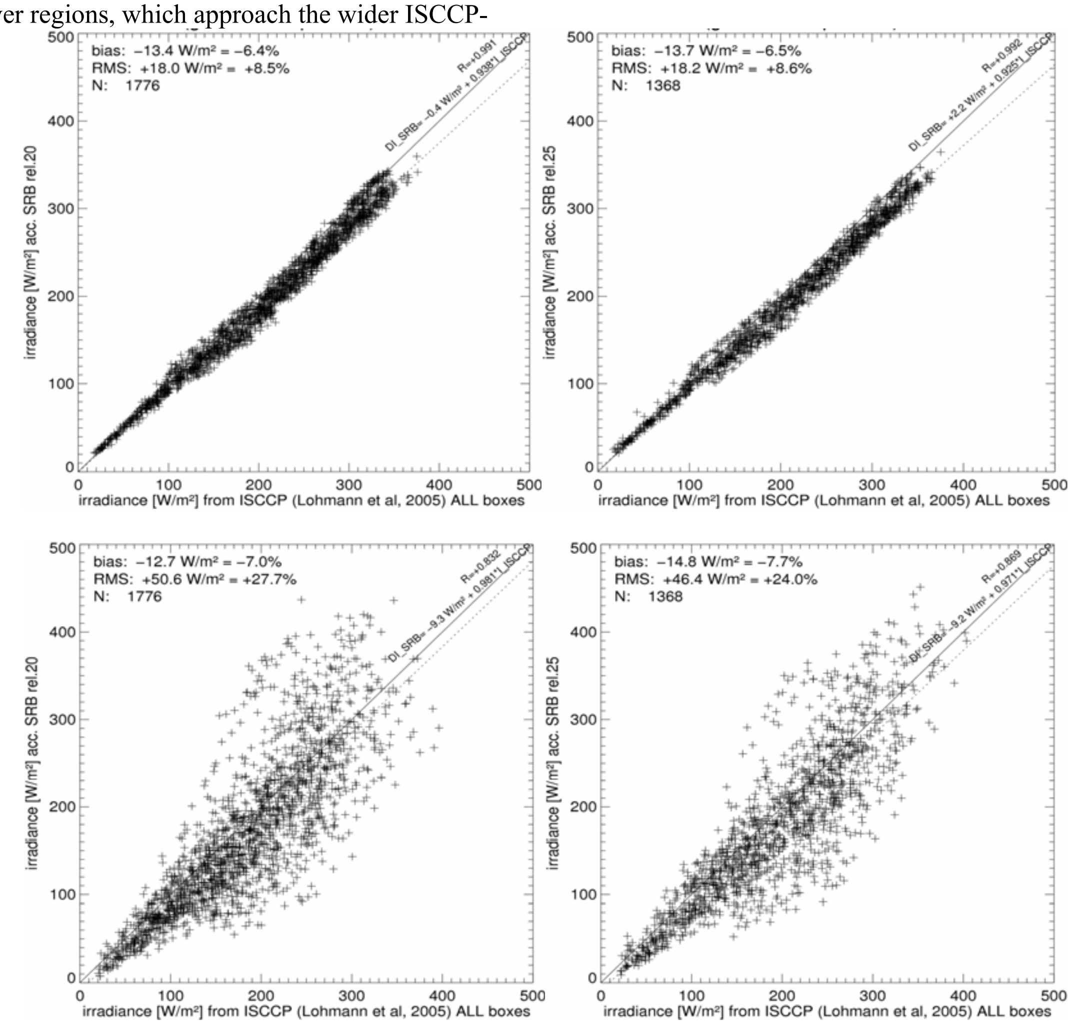

Fig. 4: Scatter plots of ISCCP-derived monthly values versus SRB release 2.0 (left) and SRB release 2.5 (right). Global irradiance (upper panels) shows much better coincidence than beam irradiance (lower panels)

TABLE 1: OVERVIEW ON DIFFERENCES BETWEEN NASA-SRB RELEASE 2.5 AND DLR-ISIS

REGION ISCCP box	GHI MB [%]	GHI RMS [%]	DNI MB [%]	DNI RMS [%]
De Aar, South Africa 1535	-7.4	7.8	-15.6	19.9
Florianopolis, Brazil 1759	+0.8	4.8	+8.1	13.4
Tamanrasset, Algeria 4563	-10.8	11.1	-19.1	29.2
Solar Vil., Saudi Arabia 4578	-7.8	8.4	+11.2	35.1
Southern Israel 4832	-9.4	9.6	-14.1	21.4
Northwest Israel 4959	-3.3	4.4	+7.9	23.3
Northeast Israel 4960	-10.5	10.8	-10.8	23.9
ARM S.G. Plains, USA 5275	-6.2	7.9	-10.7	14.6
Spain 5417	-6.1	7.0	-15.1	20.1
Carpentras, France 5528	-2.5	4.3	-5.0	11.2
Payerne, CH 5632	-5.9	8.6	-14.2	18.3
Lindenberg, D 5829	-3.0	6.9	-7.4	17.0
average	**-6.5**	**8.6**	**-7.7**	**24.0**

A low root mean square deviation (RMS) of the monthly values indicates a good coincidence of the data sets. From the 12 regions analyzed here best agreement is reached for the region around Carpentras in Southern France. But RMS deviations are fairly constant across different sites. This indicates that there are low regional differences in the quality of the two procedures.

5. CONCLUSION

It is found that both data sets agree reasonably well for global hemispherical irradiance (GHI) indicated by an RMS deviation below 9%. On average over all 12 regions SRB reports approximately 6% less irradiance than the DLR ISIS data set. From inter-comparison to high resolution satellite data it is known that ISIS overestimates GHI in the range of 0% to 3%. Thus, it may be concluded that SRB and ISIS show quite similar performance for GHI. SRB seems to underestimate a few percent, while ISIS overestimates little.

The long-term mean bias between SRB and ISIS for direct normal irradiance (DNI) is also below -8%, but RMS is much higher exceeding 20%. From inter-comparison of ISIS against high-resolution satellite values and measurements it is concluded that ISIS underestimates long-term means of DNI in the range of 5% to 10%. Therefore, it is expected that SRB could be in the order of 15% to low for beam irradiance.

Results from site to site vary significantly. Mean bias for GHI ranges from -10.5% to +0.8%, for DNI from -15.6% to +11.2%. This indicates that the bias is rather variable. As results for DNI vary even more, it is concluded that quality of beam irradiance probably is less than for global irradiance.

The two SRB versions investigated in this paper show little differences. Especially for global irradiance SRB release 2.5 shows very similar results. A small improvement of SRB release 2.5 against 2.0 is recognized for beam irradiance. On average RMS with ISIS and scattering in fig. 4 decreases for results from the newer release.

Parts of the observed differences between both data sets might be caused by slightly differing regions due to non-matching grids. It is expected that this leads to an increase of RMS differences. For the mean bias over all 12 regions the spatial mismatch should average out. It is assumed that main reason for the systematic differences is actually caused by differing cloud detection schemes.

The validation of the ISIS data set against measurements and high resolution satellite data still covers only few sites. An analysis with many more sites is under way. Revised results from this detailed validation can influence the findings drawn here. Also NASA performs additional validation with surface measurements, which lead to improved knowledge about accuracy. Values given here will be updated then and still must be regarded as preliminary results.

DLR ISIS data are now available over more than 21 years from July 1983 to December 2004. This allows also analyzing temporal homogeneity over this period and possible trends separately for the two irradiance components (figure 2). Long-term time-series partly fit well to measurements, but also some discrepancies are recognized. Therefore trends derived from ISIS and SRB must be handled with caution. SRB release 2.0 covers 1983 to 1995. Meanwhile SRB release 2.5 ranges also from 1983 to 2004, but only 1992 to 2001 could be considered here. Thus, in future it will be possible to cross-check the different data sets for temporal changes. Careful evaluation of this satellite-derived long-term time-series with ground-based long-term measurements is under way in the frame of the GEWEX radiative flux assessment.

Nevertheless long-term averages are reasonably stable and thus both data sets compared here could serve as the base to estimate the technical potentials of various solar applications worldwide. When simulating solar energy systems that heavily depend on the availability of beam irradiance it is expected that results derived by help of ISIS better approach the actual resource.

Advantage of the SRB data set is that the higher resolution shows much more spatial variability than the ISIS data set, which has only 280 km wide boxes. Therefore, it is easier to identify areas favorable for solar energy. Nevertheless for the purpose of site identification a far higher resolution is required. The sources of ISCCP actually have approximately 0.1° resolution. With today's computer power it gets possible to process data sets covering the full Earth in such high resolution to derive data which is more precise and site-specific.

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