EUMETSAT Satellite Application Facility on Climate Monitoring

Validation Report

Meteosat (MVIRI) Solar Surface Irradiance and effective Cloud Albedo Climate Data Sets

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Executive Summary

The solar irradiance (SIS = Surface Incoming Solar radiation) and the direct irradiance (SID = Surface Incoming Direct radiation) derived from the Meteosat first generation satellites (Meteosat 2 to 7, 1982-2005) have been validated using ground based observations from the Baseline Surface Radiation Network (BSRN) as a reference. The validation target values for the mean absolute difference between satellite-derived and surface-measured radiation is defined by the target accuracy for monthly/daily means of 10/20 W/m² for SIS and 15/25 W/m² for SID plus an uncertainty of the ground based measurements of 5 W/m².

The mean absolute differences of the monthly mean surface incoming solar (SIS) and surface incoming direct radiation (SID) are 7.8 W/m^2 and 11.0 W/m^2, respectively, i.e., well below the respective targets of 15 and 25 W/m² for all sites. Moreover, nearly 90 % and about 85 % of the monthly mean absolute difference values of surface solar and direct irradiance are below the target values.

The daily mean data of the surface incoming solar radiation (global irradiance) have a mean absolute difference of 15 W/m², which is below the target value of 20 W/m². The mean absolute difference of the daily mean direct irradiance (SID) is 21 W/m^2, i.e. smaller than the target value of 30 W/m².

The target accuracy is therefore achieved for monthly and daily means. No trends in the bias are detectable, demonstrating the stability and homogeneity of the surface incoming solar radiation and the surface incoming direct radiatoin products. For the effective cloud albedo the accuracy is derived from the SIS accuracy. The target value of 0.1 is reached with exception of the winter period for latitudes above 55 degree, where higher uncertainties might occur.

Applicable Documents

Reference	Title	Code
AD.1.	CM-SAF Product Requirement Document	SAF/CM/DWD/PRD/1.6

Reference Documents

Reference	Title	Code
RD.1.	Algorithm Theoretical Baseline Document (ATBD) Meteosat (MVIRI) Solar Surface Irradiance and effective Cloud Albedo Climate Data Sets MVIRI_HEL	SAF/CM/DWD/ATBD/MVIRI_HEL
RD.2.	Product User Manual: Meteosat (MVIRI) Meteosat (MVIRI) Solar Surface Irradiance and effective Cloud Albedo Data Sets. MVIRI_HEL	SAF/CM/DWD/PUM/MVIRI_HEL

1 The EUMETSAT SAF on Climate Monitoring (CM SAF)

EUMETSAT has setup and operates a Network of ***Satellite Application Facilities*** (SAF) which together with the EUMETSAT central facilities constitute the EUMETSAT Application Ground Segments for MSG and EPS. The SAFs are located in a National Meteorological Service or other approved institute of a EUMETSAT member state. The scope of the SAF activities is to deliver products, at the level of geophysical parameters, based primarily on the satellite data.

Each SAF is developed and operated according to a Cooperation Agreement, signed between EUMETSAT and the Host Institute, which manages the programme. Funding from the Host Institute and co-operating entities complements the EUMETSAT Contribution to the project.

The **Satellite Application Facility on Climate Monitoring (CM SAF)** targeted its development in the period 1999-2003 on generation and archiving high quality data sets on a continuous basis for the following application purposes:

- The monitoring of the climate state and its variability,
- The analysis and diagnosis of climate parameters to identify and understand changes in the climate system,
- Input for climate models to study processes in the climate system on a European and global scale and for climate prediction,
- Validation of simulation models (climate and NWP).

The development of the CM SAF started in January 1999 with a Consortium comprising:

- Deutscher Wetterdienst (DWD), Germany, as Host Institute, with Institute of Atmospheric Physics (GKSS),
- Koninklijk Meteorologisch Instituut van België / Institut Royal Météorologique de Belgique, (KMI - IRM), Belgium, with Free University of Brussels (VUB), and Royal Military Academy (RMA),
- Finnish Meteorological Institute (FMI), Finland,
- Royal Netherlands Meteorological Institute (KNMI), The Netherlands,
- Swedish Meteorological and Hydrological Institute (SMHI), Sweden,

The CM SAF started an Initial Operations Phase (IOP) covering the period January 2004 to February 2007.

During this Initial Operations Phase (IOP) the Meteorological Service (MeteoSwiss) of Switzerland has become a new partner to the Climate SAF Consortium.

The objectives of the CM SAF IOP were the following:

- Complete all necessary development, verification and validation activities concerning MSG1 related products, which were postponed from the development phase because of MSG1 launch delay.
- Produce, control and distribute operationally in an offline mode CM SAF products which have been developed during the development phase, and which can be elaborated on an operational basis using available satellite data during IOP time period, together with the necessary User Support activities.

- Continue R&D activities necessary to prepare for the use of METOP-1 data in CM SAF products.
- Complete and extend the product line of the CM SAF stepwise (versioning approach), according to recommendations from users, evaluation and review boards and subsequent Steering Group decisions.
- Conduct R&D activities for the enhancement of current CM SAF products or for some possible new products, to take for instance into account some of the recommendations expressed during the CM SAF workshop.

The **Continuous Development and Operations Phase (CDOP)** started in 2007 covering the period March 2007 – February 2012.
The scope of the CM-SAF CDOP is as follows:

- Implement version 3 of the CM-SAF IOP in operational mode
- Routine generation and improvement of the IOP operational products and services
- Provision and quality assessment of data sets suitable for climate analysis on longer time scales. The following objectives are of primary importance in this context:
  - The establishment of high quality long time series with known error characteristics and temporal stability of those quantities from different instruments.
  - The extension of the product palette by additional GCOS ECVs and derived products to facilitate climate process understanding and monitoring, specifically for a more complete description of the energy and water cycle.
  - The enhancement of the user support in the fields of climate monitoring and climate research.
  - The extension from regional to the global scale for some products.
- Preparation for the MTG era:
  - Support to EUMETSAT in the Definition of the End User Requirement for MTG (2007/2008);
  - Support to EUMETSAT in the Definition of End User Requirements for post-EPS
  - Planning for the use of enhanced and new MTG sensors for development in CDOP follow-on phase.

2 Introduction

The radiation budget at the Earth's surface is a key parameter for climate monitoring and analysis. Satellite data allow the determination of the radiation budget with a high resolution in space and time and offer a large regional coverage by the combination of different satellites. The CM SAF processed a 23 year long (1983-2005) continuous surface incoming solar (SIS) and surface incoming direct (SID) radiation climate data record (CDR) from Meteosat's First Generation satellites. Additionally, a CDR of the effective cloud albedo (CAL) was generated. The validation of these CDRs is described in this document.
Data from EUMETSAT's geostationary Meteosat satellites of the First Generation (Meteosat 2-7) are used. The SIS and SID CDR are processed using a climate version of the Heliosat algorithm (Beyer et al. 1996; Cano et al. 1986) to obtain information about effective cloud albedo. The effective cloud albedo is used as input for MAGIC, which calculated the clear sky radiation and consideres the effect of the effective cloud albedo on the irradiance. MAGIC is a sophistacted eigenvector look-up table method (Mueller et al. 2009). Heliosat is extended by addition of a self-calibration method accounting for changes in the satellites (switches, degradation) and a modification in the determination of the surface albedo. Both alterations to Heliosat and the clear sky algorithm are presented in the ATBD [RD.1.]. More information on the products can be found in the PUM [RD.2]
The CM SAF SIS and SID datasets are presented in Figure 2–1 as seasonal means on the full disc. Within the annual cycle the datasets show the correct patterns with the highest radiation values in regions with highest sun elevation and lowest values in the winter hemispheres (lowest sun elevation). Furthermore, the shadowing effect of clouds on radiation is very well depicted (especially for SID) in the stratocumulus region close to the western, South African coast and in the tropics with the large amount of cumulus clouds.

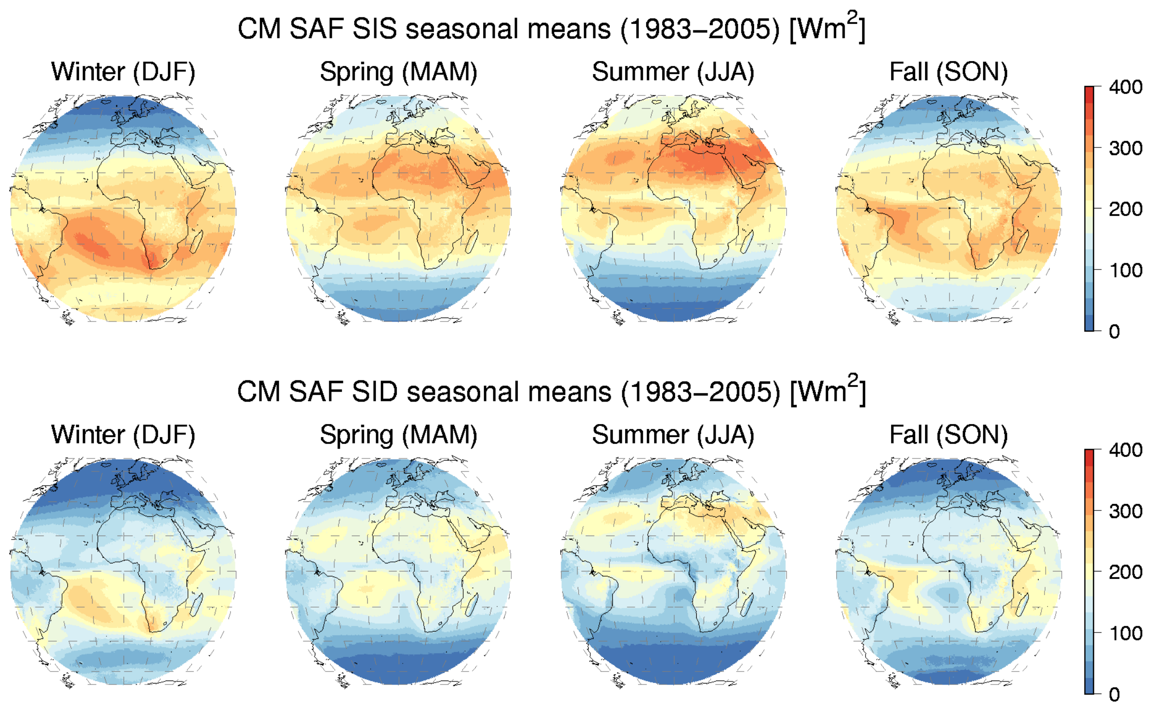


Figure 2–1: Seasonal means of SIS (upper row) and SID (lower row) for the whole CDR (1983-2005)

3 Validation procedure

3.1 Validation data

The validation of the new data sets for the surface incoming solar radiation (SIS) and the surface incoming direct solar radiation (SID) is performed by comparison with high-quality ground based measurements from the Baseline Surface Radiation Network (BSRN, Ohmura et al. 1998).The BSRN stations used for the validation are listed in

, their location are diagrammed in Figure 3–1. Thereby, only those stations were used that have an overlap of at least 12 months with the satellite data. The selected 12 stations are located mainly on the northern hemisphere but they cover the main climatic regions and they span a substantial part (1992-2005) of the satellite time period. The effective cloud albedo (CAL) as a pure satellite product cannot be validated by comparison with ground based measurements directly. As the effective cloud albedo is the satellite observation which is used to derive SIS, the accuracy evaluated for SIS can be used to estimate the accuracy of the effective cloud albedo.

Table 3-1: *List of used BSRN stations for the validation*

Station	Country	Code	Latitude [°N]	Longitude [°E]	Elevation [m]	Data since
Bermuda	Bermuda	Ber	32.27	-64.67	8	1.1.1992
Camborne	UK	Cam	50.22	-5.32	88	1.1.2001
Carpentras	France	Car	44.05	5.03	100	1.8.1996
De Aar	South Africa	Daa	-30.67	23.99	1287	1.5.2000
Florianopolis	Brasil	Flo	-27.53	-48.52	11	1.6.1994
Lerwick	UK	Ler	60.13	-1.18	84	1.1.2001
Lindenberg	Germany	Lin	52.21	14.12	125	1.9.1994
Payerne	Switzerland	Pay	46.81	6.94°E	491	1.9.1992
Sede Boger	Israel	Sbo	30.9	34.78	500	1.1.2003
Solar Village	Saudi Arabia	Sov	24.91	46.41	650	1.8.1998
Tamanrasset	Algeria	Tam	22.78	5.51	1385	1.3.2000
Toravere	Estonia	Tor	58.25	26.46	70	1.1.1999

To derive monthly and daily mean values from the surface measurements, the hourly means of one month were calculated first to reduce the impact of missing data values on the averaging. These hourly mean values are then averaged to derive the monthly and daily mean radiation data to be used as the reference value for the validation.

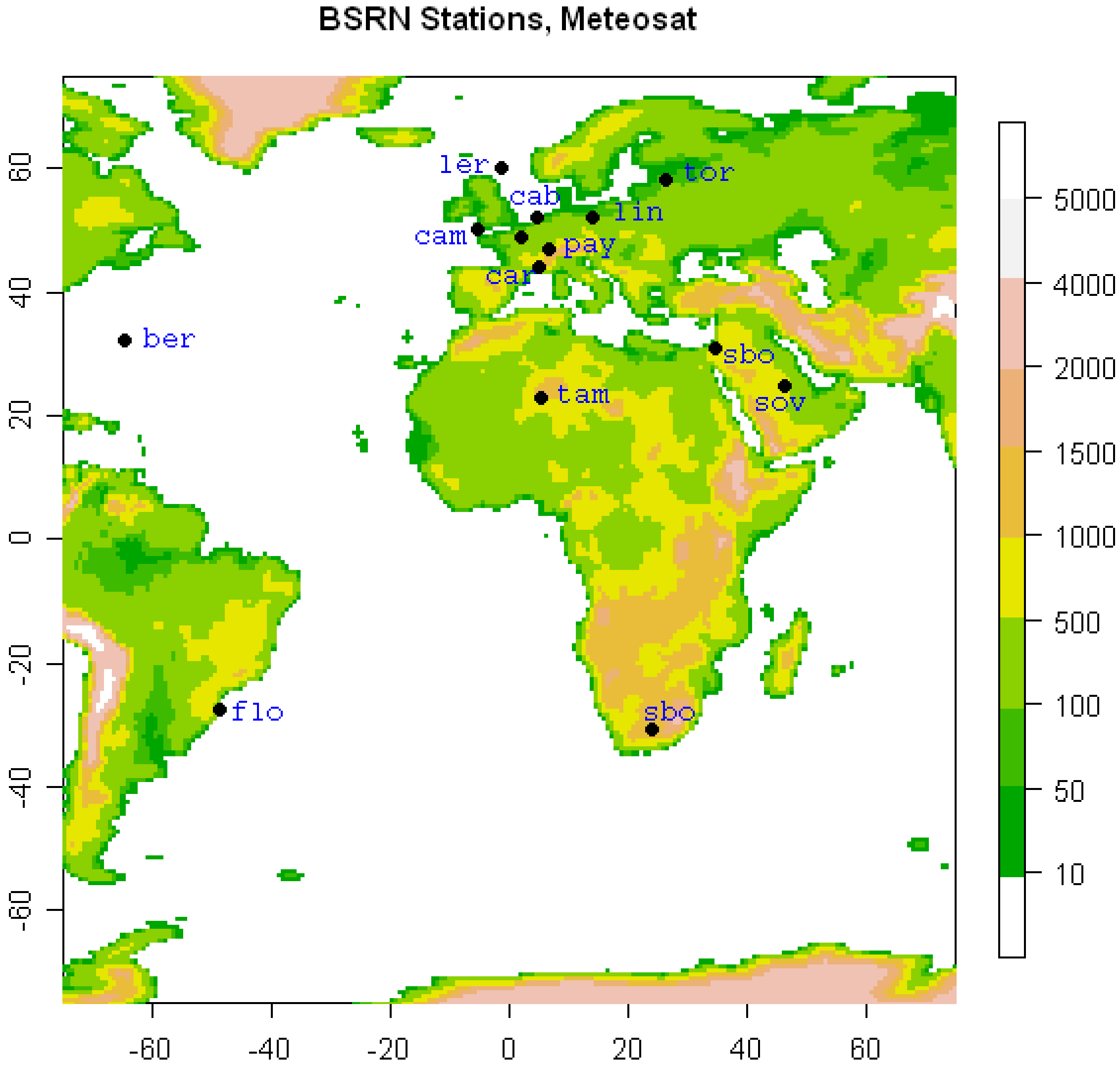


Figure 3–1: Location of the BSRN stations used for he validation. Black dota are the locations of the stations. The underlying map shows the topography, the legend is meter above sea level.

The employed validation accuracies for SIS and SID as well as for daily and monthly means are summarized in

. They are based on the target accuracy defined in the CM SAF CDOP Product Requirements Document [**RD.2.**]. Furthermore, the validation accounts for the non-systematic error of the BSRN data of 5 W/m^2 for solar irradiance measurements (Ohmura et al. 1998).

Table 3-2: *Validation thresholds, targets and optimal accuracy for monthly mean as well as for instantaneous and daily mean SIS and SID as given in the Product Requirement Table version 1.6.*

	SIS [W/m²]			**SID [W/m²]**			**CAL**		
	Threshold	Target	Optimal	Threshold	Target	Optimal	Threshold	Target	Optimal
Monthly	15	10	8	20	15	12	0.15	0.1	0.05
Hourly/Daily	25	20	15	30	25	20	0.2	0.15	0.1

3.2 Datasets used for evaluation

In addition to the validation with surface measurements, the quality of the CM SAF SIS CDR is evaluated with already available datasets. These include the ISCCP flux dataset (FD, Rossow; Duenas 2004, http://isccp.giss.nasa.gov/products/products.html), the GEWEX surface radiation budget (SRB, Gupta et al. 2006, http://gewex-srb.larc.nasa.gov/) and the ERA-Interim data set (Berrisford et al. 2009). Unfortunately, to the best of our knowledge, no comparable data set for SID is available.

The ISCCP and GEWEX datasets are based on the same satellite data from geostationary and polar orbiting satellites that allow a global coverage. They differ in the applied algorithm to retrieve the surface radiation and in the spatial resolution, which is 2.5° in the case of the ISCCP FD dataset and 1° for the GEWEX SRB dataset. Daily means of the data were used for the comparison for the time range from 1983 to 2005. ERA-Interim is a model-based reanalysis dataset of the European Centre for Medium Range Weather Forecast (ECMWF, www.ecmwf.int). It spans the time range between 1989 and the present. The resolution of the data is 1° and daily means covering the time range from 1989 to 2005 were generated from the 6-hourly model output available from the ECMWF archive. Monthly means for each data set were calculated by averaging the corresponding daily means.

For the validation, the three datasets were statistically analysed in the same way as the CM SAF data set. Here, the same monthly/daily mean values from the surface observations were used, i.e., only those data are considered that are spatially and temporally covered by the CM SAF dataset.

3.3 Statistical measures

The validation employs several statistical measures and scores to evaluate the quality of the SIS and SID CDR. Beside the commonly used bias and standard deviation, we also use the (mean) absolute deviation and the correlation of the anomalies derived from the surface measurements and the CM SAF dataset. Bias and standard deviation alone provide not sufficient information of the climate quality of a data record. For each dataset we further provide the number of months that exceed the target accuracy to characterize the quality of the data sets. In the following, the applied quality measures are described. Thereby, the variable ‘y’ describes the dataset to be validated (e.g., CM SAF) and ‘o’ denotes the reference dataset (i.e., BSRN). The individual time step is marked with ‘k’ and ‘n’ is the total number of time steps.

Bias

The bias or (also called mean error) is simply the mean difference between the average of two datasets, resulting from the arithmetic mean of the difference over the members of the data sets. It indicates whether the dataset on average over- or underestimates the reference dataset.

$$\mathrm{Bias} = \frac{1}{n}\sum_{k=1}^{n}(y_k - o_k) = \bar{y} - \bar{o}$$

Mean absolute difference

In contrast to the bias, the mean absolute difference (MAD) is the arithmetic average of the absolute values of the differences between each member (all pairs) of the time series. It is therefore a good measure for the mean “error” of a dataset.

$$\mathrm{MAD} = \frac{1}{n}\sum_{k=1}^{n}\left|y_k - o_k\right|$$

Standard deviation

The standard deviation SD is a measure for the spread around the mean value of the distribution formed by the differences between the generated and the reference dataset.

$$\mathrm{SD} = \sqrt{\frac{1}{n-1}\sum_{k=1}^{n}\left((y_k - o_k) - (\bar{y} - \bar{o})\right)^2}$$

Anomaly correlation

The anomaly correlation AC describes to which extend the anomalies of the two considered time series correspond to each other without the influence of a possibly existing bias. The correlation of anomalies retrieved from satellite data and derived from surface measurements allows the estimation of the potential to determine anomalies from satellite observations.

$$AC = \frac{\sum_{k=1}^{n}(y_k - \bar{y})(o_k - \bar{o})}{\sqrt{\sum_{k=1}^{n}(y_k - \bar{y})^2}\sqrt{\sum_{k=1}^{n}(o_k - \bar{o})^2}}$$

Here, for each station the mean annual cycle $\bar{y}$ and $\bar{o}$ were derived separately from the satellite and surface data, respectively. The monthly/daily anomalies were then calculated using the corresponding mean annual cycle as the reference.

Fraction of time steps above the validation target values

A measure for the uncertainty of the derived dataset is the fraction of the time steps that are outside the requested target value‘T’. The target values is given by the target accuracy of the respective CM-SAF product, plus the non-systematic error (uncertainty) of the BSRN measurements (Ohmura et al. 1998).

$$\mathrm{Frac} = 100 \cdot \frac{\sum_{k=1}^{n} f_k}{n} \text{ with } \begin{cases} f_k = 1 & \text{if } y_k > T \\ f_k = 0 & \text{otherwise} \end{cases}$$

4 Validation results

In this section the validation results of the Surface Incoming Solar Radiation SIS, the direct iradiance SID and the effective cloud albedo CAL are presented.
For the comparison with the BSRN station data the hourly, daily and monthly means of the satellite product are compared with the respective hourly, daily and monthly means derived from the BSRN stations. The means of the BSRN station have been derived independently using the complete temporal resolution (minutes) of the BSRN stations. The comparison results in a mean bias, mean absolute difference, anomaly correlation, standard deviation and fraction of months above limit for each individual station. For overall results covering all stations an average over the the "mean" results of each station is performed. In addition to the results presented in the section plots containing additional results for each individual stations are given in the Appendix with section number 8. This gives an insight in differences of bias values over the time and for different locations.
The statitical quantities used to define the accuracy of the variable are the mean absolute difference and the fraction of month above limit. In order to match the target accuracy the mean abosulete deviation has to be below the target accuracy and 90% of the monthly (daily) measn has to be below the target accuracy plus the uncerrtainty of the ground based measurements.,

4.1 Surface Incoming Solar radiation: SIS

Monthly means

The results of the validation of the monthly mean SIS are summarized in Table 4-1 for the overall performance of the CM SAF CDR at all BSRN stations. It shows that the MAD of the dataset is significantly better than the requested limit for the target accuracy of 15 W/m^2 and even fulfills the optimal accuracy requirement of 8 W/m^2. In total only 10.7% of the monthly mean data exceed the target accuracy. The dataset is also able to reproduce the anomalies of SIS that were measured at the surface, which is shown by the high anomaly correlation of 0.89.
Also included in this table are the corresponding values for the three evaluation datasets. It is visible that for nearly all quality measures the CM SAF SIS CDR has the highest quality among the evaluated data sets.

Table 4-1*: Statistics for the comparison of monthly mean SIS between the mean of all BSRN stations and CM SAF as well as ERA-Interim, GEWEX and ISCCP*

SIS	**N_{mon}**	**Bias [W/m^2]**	**MAD [W/m^2]**	**SD [W/m^2]**	**AC**	**$Frac_{mon}$ > 15 W/m^2 [%]**
CM SAF	878	4.24	7.76	8.23	0.89	10.71
ERAinterim	878	5.48	10.41	12.15	0.8	24.6
GEWEX	878	-2.42	12.03	11.03	0.82	31.89
ISCCP	878	-0.02	11.56	11.25	0.78	29.16

A detailed illustration of the bias and the MAD at each considered BSRN stations and for all stations is shown in Figure 4–1. The box-whisker plots represent the range between the 25% and 75% percentiles (1st and 3rd quartile – Q_1 and Q_3) with the coloured boxes and the whiskers extend to 1.5 times the interquartile range IQR=Q_3-Q_1. This is the original definition brought forward by Tukey (1977). It is standard in statistical literature (see e.g. Wilks: Statistical methods in the Atmospheric Sciences) and in statistical software (R). There is no distribution assumed. The quartiles and thus the IQR are determined from the data only.

Additionally, the median (2nd quartile – Q_2) is depicted as well as the mean value and the standard deviation SD. Both, SD and IQR are measures for the spread of the corresponding distribution.

The CM SAF dataset has the lowest MAD of all four datasets. Furthermore, the spread of the bias is also very small. ISCCP and GEWEX strongly underestimate the incoming solar radiation at the desert stations of Sede Boqer, Solar Village and Tamanrasset. The CM SAF SIS CDR and ERA-Interim perform much better at these stations. At the station of Lerwick the opposite can be observed. ISCCP and GEWEX yield much better SIS values than CM SAF. This might be due to the position of the station, which is located far north and thus, close to the border of the satellite's visible disk. Additional information from polar satellites is used in ISCCP and GEWEX datasets. They likely help to constrain SIS in such areas.

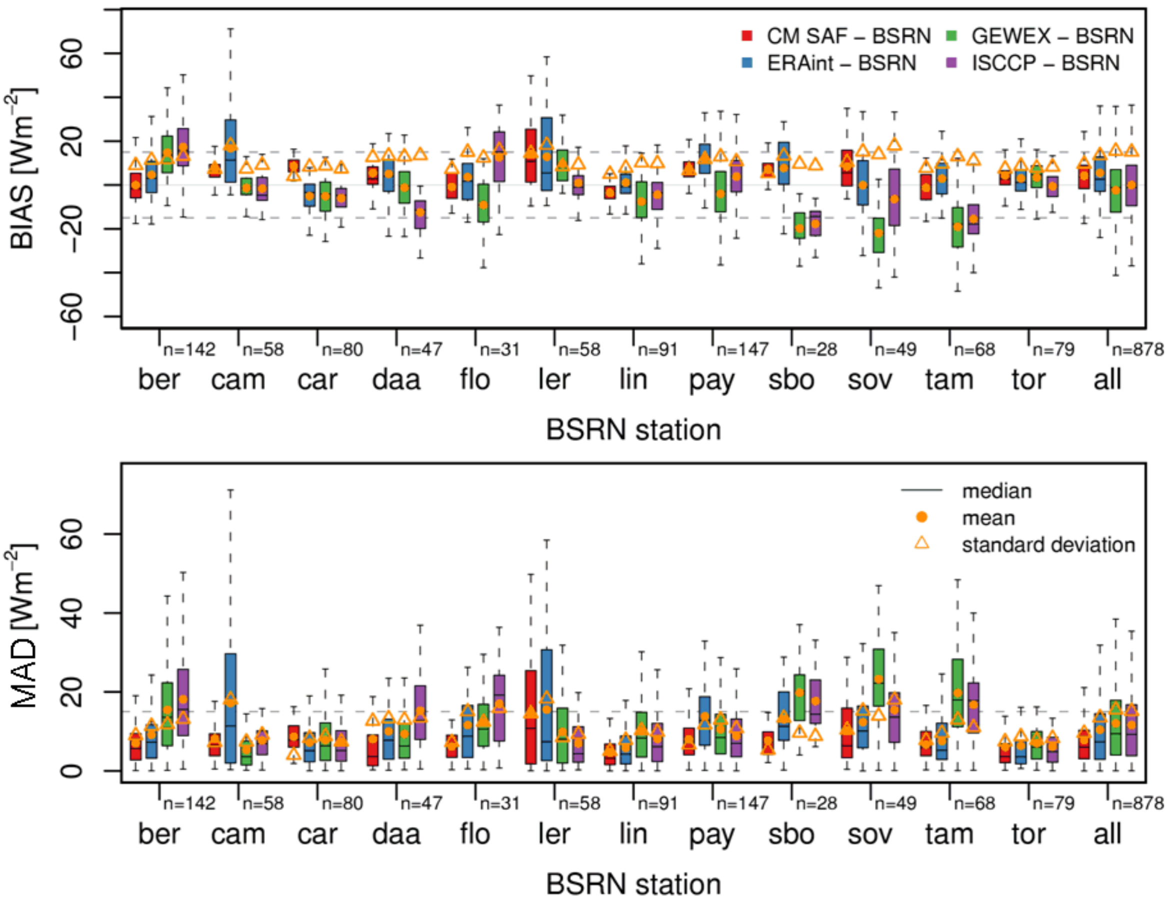


Figure 4–1: Bias and MAD for the comparison of monthly mean SIS between the BSRN stations and CM SAF as well as ERA-Interim, GEWEX and ISCCP. All is the global box-whisker plot comprising the results of all station.

Daily means

Table 4-2 provides the validation result for the daily means of the CM SAF SIS CDR. As expected, the mean bias values are very comparable to of the ones previously shown for the monthly means while the mean absolute difference values for the daily means are about twice as high as those for the monthly means. Still, the mean absolute difference of the CM SAF SIS daily mean data set (i.e., 15.05 W/m^2) is well below the target value of 25 W/m² and very close to the optimal accuracy of 15 W/m^2. Nearly 85 % of the MAD values meet the accuracy requirement. Thus, the accuracy requirement is fulfilled for the daily means.
In comparison to the BSRN reference, the performed evaluation shows that relative to the datasets ERA-Interim, GEWEX and ISCCP the CM SAF SIS dataset clearly performs better. Especially the spread of those dataset is considerably larger resulting in higher uncertainties.

Table 4-2: *Statistics for the comparison of daily mean SIS between the mean of all BSRN stations and CM SAF as well as ERA-Interim, GEWEX and ISCCP*

SIS	**N_{day}**	**Bias [W/m^2]**	**MAD [W/m^2]**	**SD [W/m^2]**	**AC**	**$Frac_{day}$ > 25 W/m^2 [%]**
CM SAF	29790	4.41	15.05	23.36	0.92	16.32
ERA-Interim	29790	5.32	25.97	38.41	0.74	35.17
GEWEX	29790	-2.56	22.22	30.72	0.85	31.66
ISCCP	29790	0.43	25.78	36.47	0.76	36.22

The bias and the MAD for the individual BSRN stations are shown in Figure 4–2. Generally, the CM SAF SIS CDR shows the best performance with lowest MAD and smallest spread, at nearly all stations the target accuracy is reached. The only exception is Florianopolis, where the MAD slightly exceeds the target accuracy of 25 W/m². However, the evaluation datasets perform even worse at Florianopolis with extremely large spreads. Problems with the surface measurements (that cancel out when calculating monthly averages) could be responsible for this anomalous behaviour in all datasets.

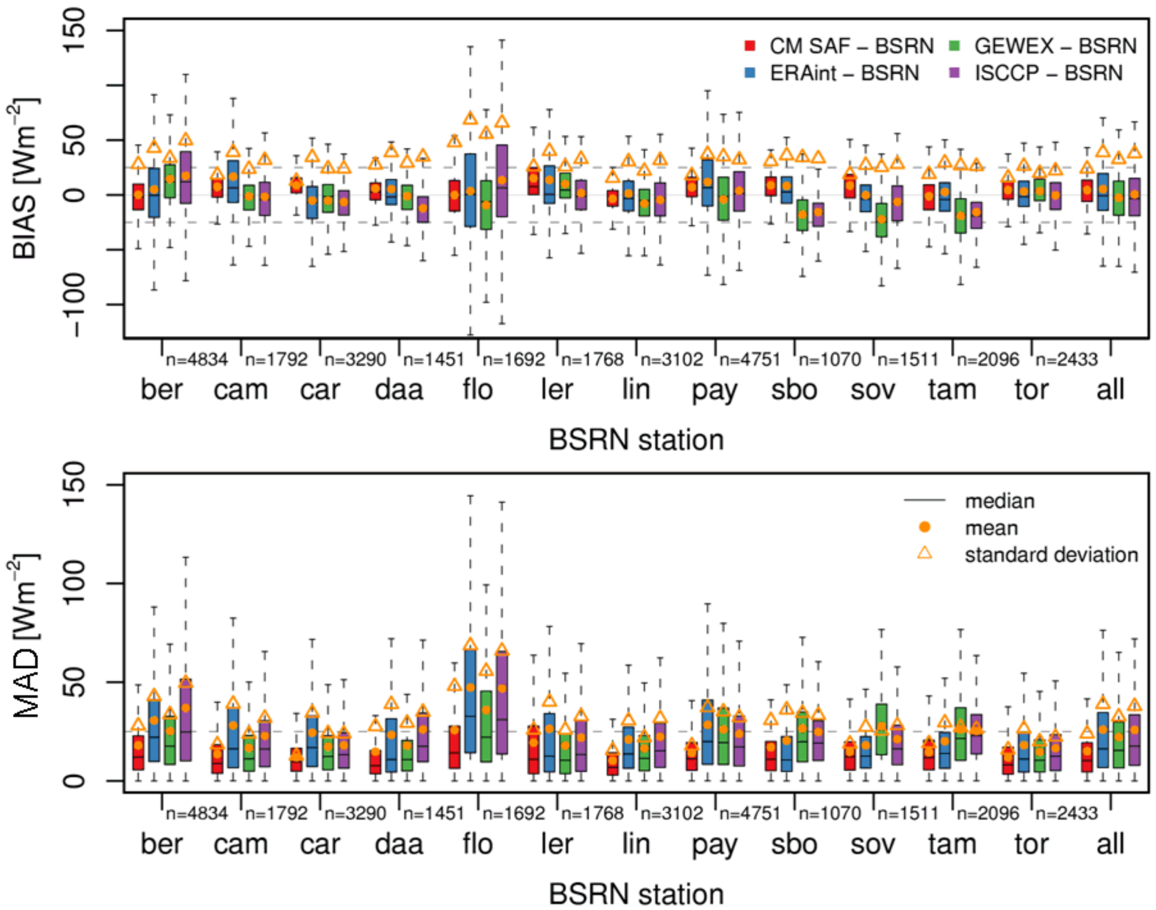


Figure 4–2: Bias and MAD for the comparison of daily mean SIS between the BSRN stations and CM SAF as well as ERA-Interim, GEWEX and ISCCP. All is the global box-whisker plot comprising the results of all station.

Hourly means

The climate quality and accuracy of SIS hourly values is already proofed by the validation results of the daily and monthly means, as those means are based on the hourly values. More over, averaging over a certain time period increases the comparability of the satellite based area solar irradiance and the ground point measurements significantly. Hence, comparing averaged values (averaging time > 1 day) is more reliable in order to define the accuracy. In this term Table 4-3 provides only additional information about the accuracy of the hourly means. The bias values have been averaged for each month in order to calculate the fraction of month with bias values above 25 W/m². The target accuracy of 25 W/m² (Bias), is achieved for all stations. Instead of the mean absolute difference of the hourly values, the relative mean absolute difference of the monthly mean diurnal cycle has been calculated and used as quality measure for the monthly means. The relative mean absolute difference of the monthly mean diurnal cycle has been calculated as follows. First the monthly mean diurnal cycle has been calculated for the BSRN and the satellite products at the respective stations. Afterwards the difference between the hourly values of the monthly mean diurnal cycle has been calculated in relative units (per cent). The arithmetic mean of the absolute values of these relative differences is then applied in order to calculate the relative mean absolute difference for each station. The respective value gives a measure of the expected accuracy (for each hour) of the monthly mean diurnal cycle in %. Relativee units are preferable here, because of the large SZA dependency of the diurnal cycle (e,g 20 W/m² is a small error at local noon, but a large error at sunrise). Instead of the anomaly correltation the correlation C is given.

Table 4-3: *Statistics for the comparison of hourly mean SIS between BSRN stations and CM SAF. Validation results are given for each station. The last line (SUM) shows the mean of the respective statistical quantities over all stations results. rMAD is the relative mean absolute difference of the monthly mean diurnal cycle and C is the correlation between in-situ and BSRN stations.*

SIS	N	Bias [W/m^2]	rMAD [$^{\%}$] of MMDC	C	Frac > 25 W/m^2 [%]
Ber	3696	-4.6	6.3	0.86	16.8
Cam	1440	13.1	7.5	0.86	10
Car	2352	17.1	5.9	0.95	11.8
Daa	1176	8.9	5.2	0.91	14.2
Flo	3192	-0.6	6.4	0.89	10.5
Ler	888	19.4	13.4	0.79	30.2
Lin	2448	-5.1	6.5	0.88	2
Pay	3408	14.2	7.3	0.9	16.8
Sbo	600	15.0	4.5	0.95	16
Tam	1680	-1.4	3.2	0.95	7.1
Tor	1944	6.3	8.4	0.84	12.3
SUM		**7.5**	**6.8**		**13.4**

4.2 Surface Incoming Direct radiation: SID

Monthly means

Table 4-4 shows the validation results of the CM SAF SID CDR. The MAD is 11.0 W/m^2 and hence, well below the required target value of 20 W/m^2 needed to outperform the target accuracy and also better than the optimal accuracy of 12 W/m^2. Thus, the accuracy requirement is fulfilled. The standard deviation and, thus, the spread are also slightly larger for SID than for SIS (15.67 W/m^2 compared to 8.23 W/m^2). The fraction of months that show differences outside of the accuracy requirement is comparable to the corresponding value for SIS. The anomaly correlation is still very good with a value of 0.83.

Table 4-4: *Statistics for the comparison of monthly mean SID between the mean of all BSRN stations and CM SAF*

SID	N_{mon}	Bias [W/m^2]	MAD [W/m^2]	SD [W/m^2]	AC	$Frac_{mon}$ > 20 W/m^2 [%]
CM SAF	805	0.89	11.0	15.67	0.83	15.4

The results for the individual BSRN stations are shown in Figure 4–3. For nearly all stations the accuracy requirement is met. Both bias and MAD are well within the requested ±20 W/m^2.

In comparison to SIS, SID bias and MAD are within the (target) limits at Lerwick. However, the spread is still substantial. At Lerwick the target accuracy is exceeded during several months. The possible causes outlined for SIS should also hold for SID.

Larger issues are present at the station of Tamanrasset where SID is substantially underestimated by the CM SAF CDR. Also the two other desert stations, Sede Boqer and Solar Village, show relatively high MADs and spreads. At all three stations, however, the relative error is small as these stations experience high direct solar radiation. The cloudless conditions result in a higher sensitivity of the SID on the direct clear sky radiation, which depends on the prescribed atmospheric conditions. Especially uncertainties in the profiles of water vapour and the amount and optical properties (especially scattering properties) of aerosol particles (e.g., in dust storms) result in substantial uncertainties in the direct clear sky radiation. Additionally, the SID ground measurements at the station Tamanrasset are suspicious, as discussed in more detail later on.

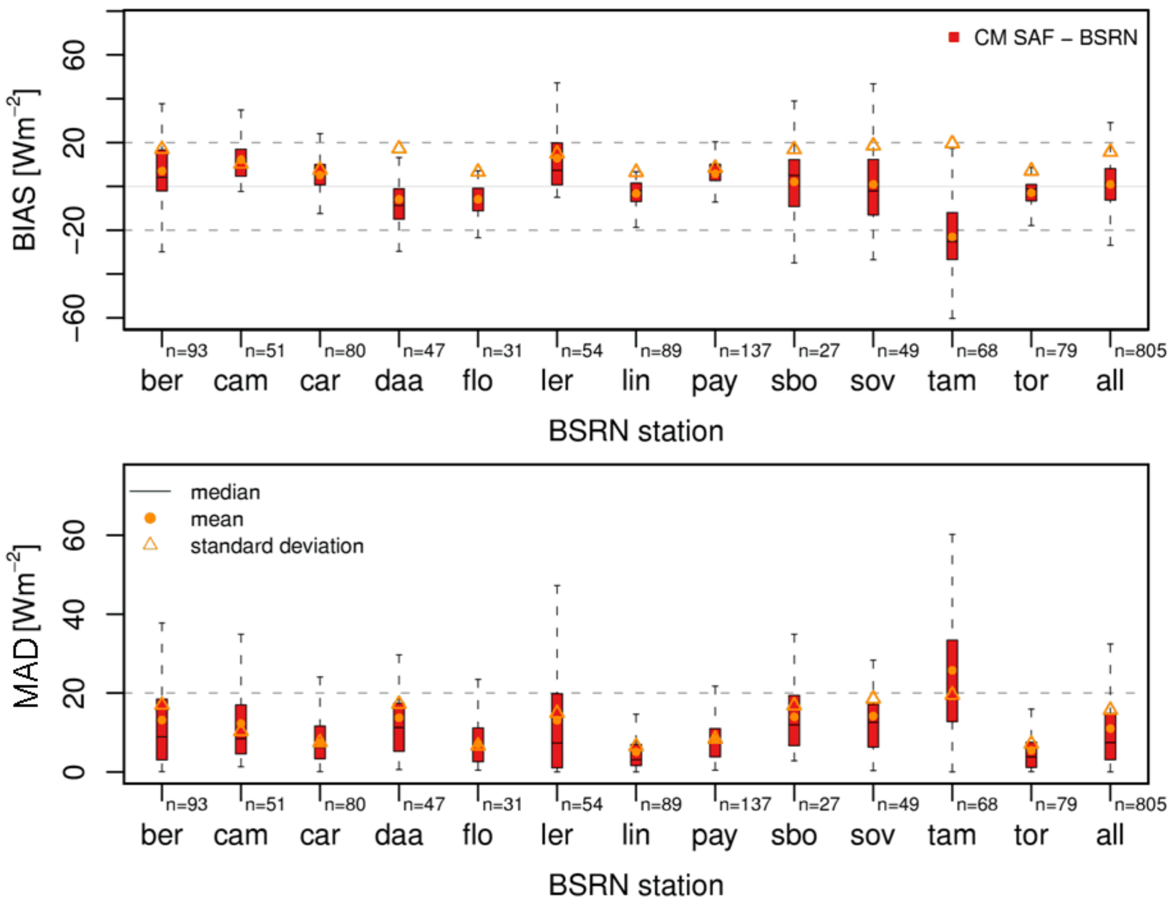


Figure 4–3: Bias and MAD for the comparison of monthly mean SID between the BSRN stations and CM SAF. All is the global box-whisker plot comprising the results of all station.

Daily means

The validation results for the daily means of the CM SAF SID CDR are shown in Table 4-5. The MAD is slightly larger than for the daily mean SIS CDR (20.73 W/m^2 compared to 15.05 W/m^2), but it is well below the required limit of 30 W/m^2 needed to meet the target accuracy and very close to the optimal accuracy of 20 W/m^2. Thus, the target accuracy requirement is fulfilled. As for SIS, also the daily mean SID shows a larger spread than the monthly means.

Table 4-5: *Statistics for the comparison of daily mean SID between the mean of all BSRN stations and CM SAF*

SID	N_{day}	Bias [W/m^2]	MAD [W/m^2]	SD [W/m^2]	AC	$Frac_{day}$ > 30 W/m^2 [%]
CM SAF	26614	0.74	20.73	31.74	0.89	23.42

The results for the individual stations in Figure 4–4 show the same features as for the monthly mean SID. Exceptionally large MADs again occur at the mostly sunny, cloud free desert stations of Sede Boqer, Solar Village and Tamanrasset. Apart from that, all other stations have a MAD well below the requested target value.

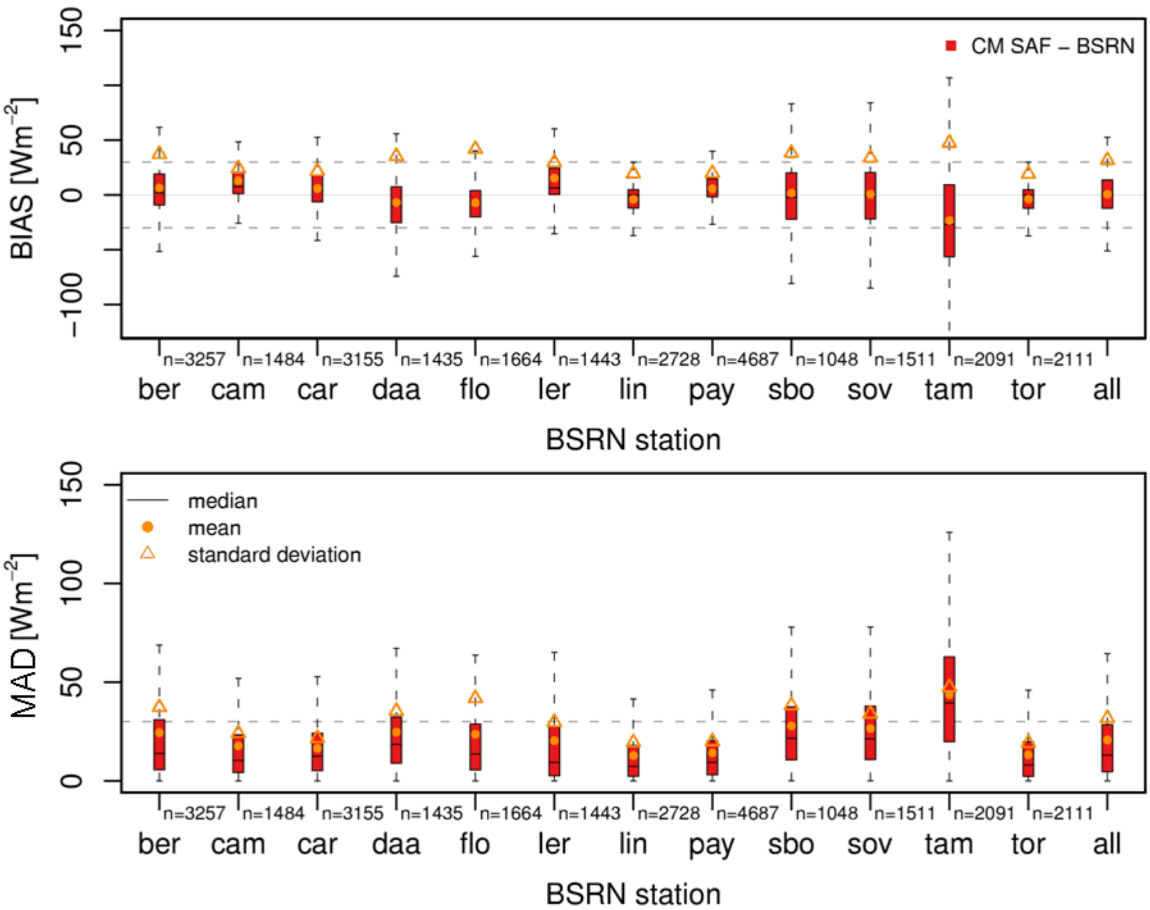


Figure 4–4: Bias and MAD for the comparison of daily mean SID between the BSRN stations and CM SAF. All is the global box-whisker plot comprising the results of all station.

Hourly means

The climate quality and accuracy of SID hourly values is already proofed by the validation results of the daily and monthly means, as those means are based on the hourly values. More over, averaging over a certain time period increases the comparability of the satellite based area solar irradiance and the ground point measurements significantly. Hence, comparing averaged values (averaging time > 1 day) is more reliable in order to defined the accuracy. In this term the validation results presented in this paragraph provides only additional information about the accuracy of the hourly means. The bias values have been averaged for each month. These averaged bias values were then used to calculate the fraction of month with bias values above 25 W/m². The target accuracy of 25 W/m² (Bias) is achieved for all stations, with exception of Tamanrasset. However, large Bias values occur also for the results gained with the MSG SID, processed in the operational chain. Yet, the used aerosol climatology, water vapour and cloud information is different for the SID MSG processing. For Taramansset SID is dominated by clear sky situations. It is unlikely that different two different aerosol and water vapour climatologies fail so extremely. Hence it has to be considered that the ground measurments of SID are inaccurate.
Instead of the mean absolute difference of the hourly values, the relative mean absolute difference of the monthly mean diurnal cycle has been calculated and used as quality measure for the monthly means. The relative mean absolute difference of the monthly mean diurnal cycle has been calculated as follows. First the monthly mean diurnal cycle has been calculated for the BSRN and the satellite products at the respective stations. Afterwards the difference between the hourly values of the monthly mean diurnal cycle has been calculated in relative units (per cent). The arithmetic mean of the absolute values of these relative differences is then applied in order to calculate the relative mean absolute difference for each station. The respective value gives a measure of the expected accuracy (for each hour) of the monthly mean diurnal cycle in %. Relativee units are preferable here, because of the large SZA dependency of the diurnal cycle (e,g 20 W/m² is a small error at local noon, but a large error at sunrise). Instead of the anomaly correltation the correlation C is given.

Table 4-6: *Validation results for the hourly SID values.*

SID	**N_{day}**	**Bias [W/m^2]**	**rMAD [%] of MMDC**	**C**	**Frac > 30 W/m^2 [%]**
Ber	1728	10.6	8.9	0.76	29.2
Cam	1080	17.5	11.5	0.8	15.5
Car	2640	11.2	7.3	0.92	6.3
Daa	840	-15.7	7.1	0.89	20.0
Flo	1368	-1.3	9.1	0.82	26.3
Ler	624	22.8	16.2	0.75	30.7
Lin	1656	-9.3	12.7	0.82	10.1
Pay	3048	4.9	8.6	0.78	10.2
Sbo	744	1.8	6.0	0.85	35.4
Tam	1680	-53.1	13.5	0.86	70.0
Tor	1704	-13.6	11.2	0.74	12.7
SUM1 with Tam		-2.6	10.2		24.2
SUM2		2.43	9.8		19.64

4.3 Effective cloud albedo CAL

The effective cloud albedo is derived from the satellite observations, using Equation 4.1

Equation 4.1 $$n = \frac{\rho - \rho_{srf}}{\rho_{\max} - \rho_{srf}}$$

Here, ρ is the observed reflectance ρ_{srf} is the clear sky reflectance and $\rho_{\max}$ the measure for the maximal cloud reflectance. The effective cloud albedo is therefore a satellite observable and it is not possible to validate this quantity by comparison with ground based measurements directly. The uncertainty of the effective cloud albedo is discussed in the Algorithm Theoretical Baseline Document (ATBD). The effective cloud albedo is the satellite observation, which is used to derive the solar irradiance. Hence, the accuracy evaluated for SIS can be used to estimate the accuracy of the effective cloud albedo. Uncertainties in SIS are due to uncertainties in the effective cloud albedo and due to uncertainties in the clear sky irradiance. Here we assume a perfect clear sky irradiance (no errors), which relates all uncertainties in SIS to the effective cloud albedo. The results obtained in the following can be considered the lower limit of the accuracy for the effective cloud albedo.

The relation between the effective cloud albedo CAL and the solar irradiance is pre-dominantly given by:

Equation 4.2 SIS = (1-CAL)*SIS,clear

For CAL values larger than 0.8 Equation 4.2 is slightly modified, but this modification has no effect on the estimated accuracy of the effective cloud albedo. Based on Equation 4.2 the “worst case” accuracy of the effective cloud albedo can be derived as a function of the clear sky irradiance. The overall SIS mean absolute difference consists of the mean absolute difference for cloudy and for clear sky. Hence, figure Figure 4–5. shows the maximal error in the cloud index, which would only be given for a mean absolute difference of zero in the clear sky irradiance. It is clear that this evaluation method is a workaround, but the effective cloud albedo is a satellite observable and can not be hardly validated “directly”.

Monthly means

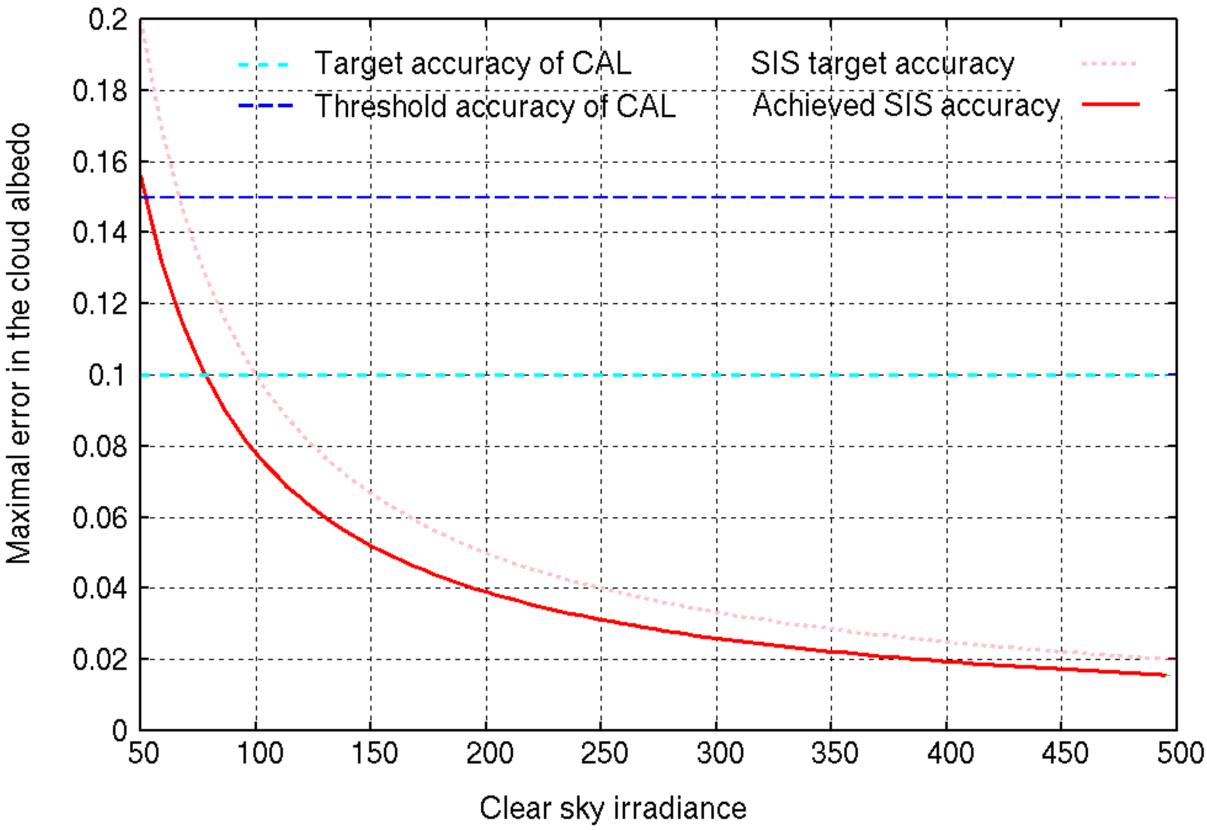


Figure 4–5: Maximal error of the monthly mean effective cloud albedo in dependency of the clear sky irradiance based on the derived SIS accuracy. The target accuracy is 10 W/m². For the achieved SIS accuracy the mean absolute difference given in Table 4-1 has been used.

Figure 4–5 shows that values above the target accuracy of 0.1 only occur for clear sky irradiances below 70 W/m². Values above the threshold accuracy of 0.15 only occur for clear sky irradiances below 50 W/m². Hence, it can be concluded that the target accuracy of the effective cloud albedo is achieved with exception of the winter months above latitude of 55° North and South, respectively. The method fails to provide secure information whether the target accuracy is fulfilled during the winter period (+/-1.5 month period around the respective winter solstice), see Figure 4–6. During the winter period at high latitudes slant geometry for the retrieval of the effective cloud albedo is given (slant viewing geometry and low solar zenith angle) in addition to long-lasting cloud coverage. As discussed in the PUM (**RD.2.**) this leads to a higher uncertainty in the effective cloud albedo. Hence, it is likely that the target and threshold accuracy is not met during the winter period at high latitudes.

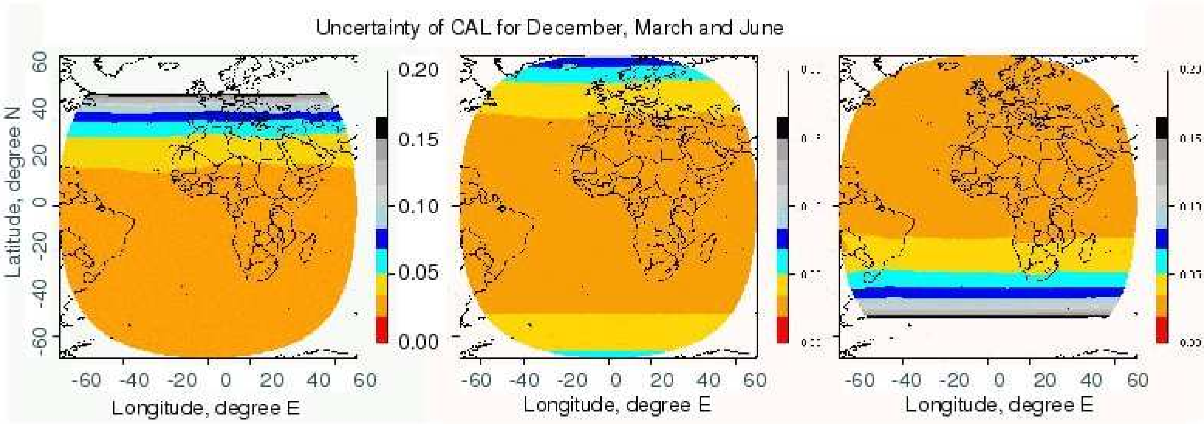


Figure 4–6: Uncertainty of the effective cloud albedo for Winter, spring and summer months. The applied method fails to provide the accuracy of the method for the white regions followed by the black colored "border".

Daily means

The same method as for the monthly means is applied to estimate the uncertainty of the daily mean effective cloud albedo.

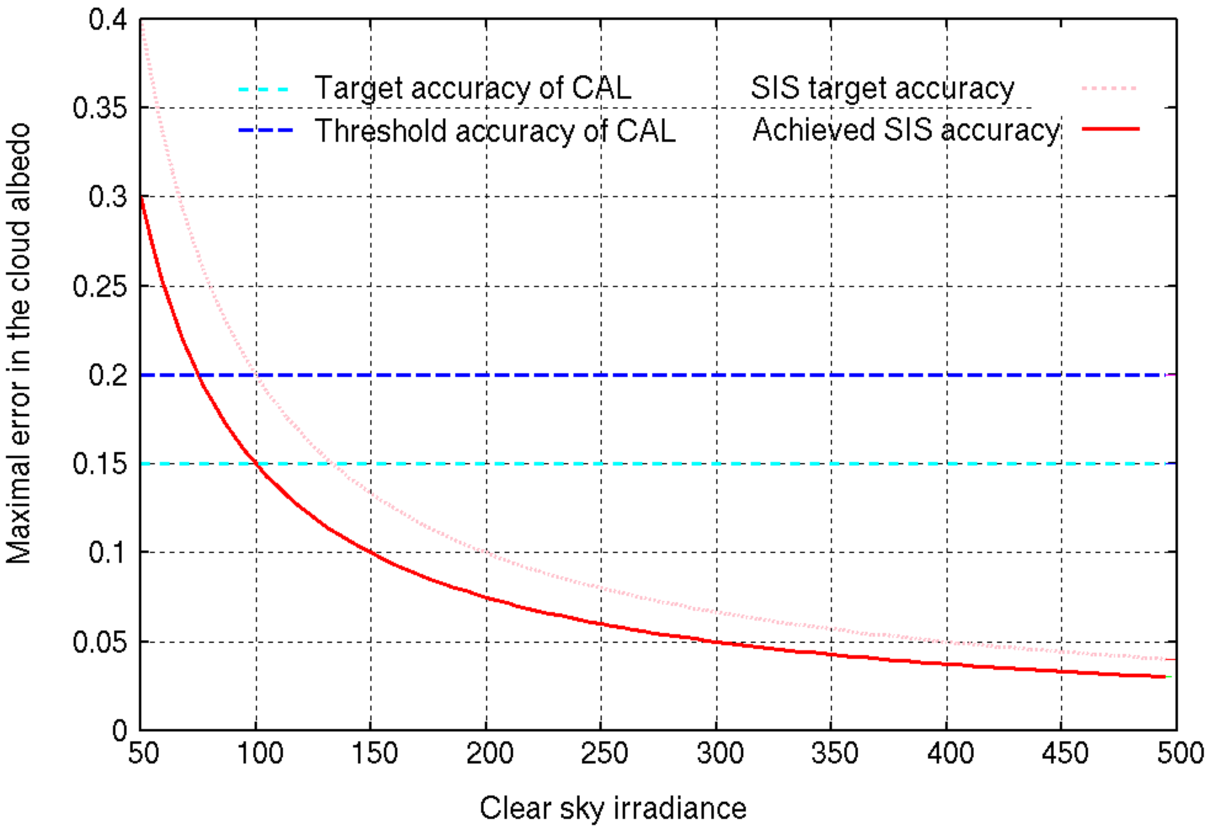


Figure 4–7: Maximal error of the effective cloud albedo (daily mean) for different clear sky irradiance values based on the derived SIS accuracy for daily means. The target accuracy is 20 W/m². For the achieved SIS accuracy the mean absolute difference given in Table 4-2 has been used.

In Figure 4–7 it is shown that values above the target accuracy of 0.15 only occur for clear sky irradiances below 100 W/m². Values above the threshold accuracy of 0.2 only occur for clear sky irradiances below 75 W/m². Hence, based on the evaluated SIS accuracy it can be stated that the target accuracy of the effective cloud albedo is achieved for the majority of the MFG disk throughout the year. However, the method fails to provide secure information whether the target accuracy is fulfilled during the winter period (+/-1.5 month period around the respective winter solstice). During the winter period at high latitudes a slant geometry for the retrieval of the effective cloud albedo is given (slant viewing geometry and low solar zenith angle) in addition to long-lasting cloud coverage. As discussed in the PUM (**RD.3.**) this leads to a higher uncertainty in the effective cloud albedo. Hence, it is likely that the target and the threshold accuracy is not met during the winter period at high latitudes.

5 Homogeneity of the solar irradiance (SIS and SID) CDRs

The definition of a climate data record requests that the time series is homogeneous over time, so that it can be meaningful statistically evaluated by for instance performing a trend analysis. Artificial steps and/or temporal trends in the dataset, e.g., due to changes in the satellite instrument, would result in unrealistic changes and trends, which do not represent changes or trends of the climate.

Special attention is given to the times when the satellite instruments changed. Table 5-1 gives an overview over the major operational periods (longer than 3 months) of the individual Meteosat satellites. Switches between satellites for a few days due to the decontamination procedure are not listed here, for a complete listing of Meteosat operational periods see Rigollier et al. (2002).

Table 5-1: *Major operational periods for the used Meteosat satellites*

Satellite	**From**	**To**
Meteosat 2	16 Aug 1981	11 Aug 1988
Meteosat 3	11 Aug 1988	19 Jun 1989
Meteosat 4	19 Jun 1989	24 Jan 1990
Meteosat 3	24 Jan 1990	19 Apr 1990
Meteosat 4	19 Apr 1990	4 Feb 1994
Meteosat 5	4 Feb 1994	13 Feb 1997
Meteosat 6	13 Feb 1997	3 Jun 1998
Meteosat 7	3 Jun 1998	31 Dec 2005

A common method to test for homogeneity is to analyse the anomalies with respect to any obvious steps. Changes in the mean state from one satellite to the other would be visible as an increase or decrease in positive or negative anomalies. Another, more objective way to test the homogeneity of a time series is to analyze the temporal derivative of the time series. Here, inhomogeneities and changepoints appear as systematic (i.e., for all latitudes) positive or negative values for one time step.

Figure 5–1 shows the Hovmoeller diagram of the monthly mean anomalies of SIS and their temporal derivative. The zonal means were calculated for the longitude band from 10°W to 30°E (contains Europe, the Sahara and the South Atlantic). The time range contains all satellites starting with Meteosat 2 in 1983 until Meteosat 7 in 2005. The Hovmoeller diagrams for the SID CDR resemble the ones shown in Figure 5–1 and are therefore not shown here.

No obvious step is present in the time series of the anomaly for the whole time range. In the temporal derivative of the anomaly, however, a small jump is visible at the switch from Meteosat 3 to Meteosat 4 in April 1990. This feature is mostly prominent from the Equator to 40°N, thus, covering the region of the Sahara and North Africa. Also, there seems to be a slight inconsistency during the switch from Meteosat 5 to 6 in February 1997, which is however, limited to the region between the Equator and 20°N. For the mentioned regions and time spans, the CM SAF SIS and SID CDR should be used with care.

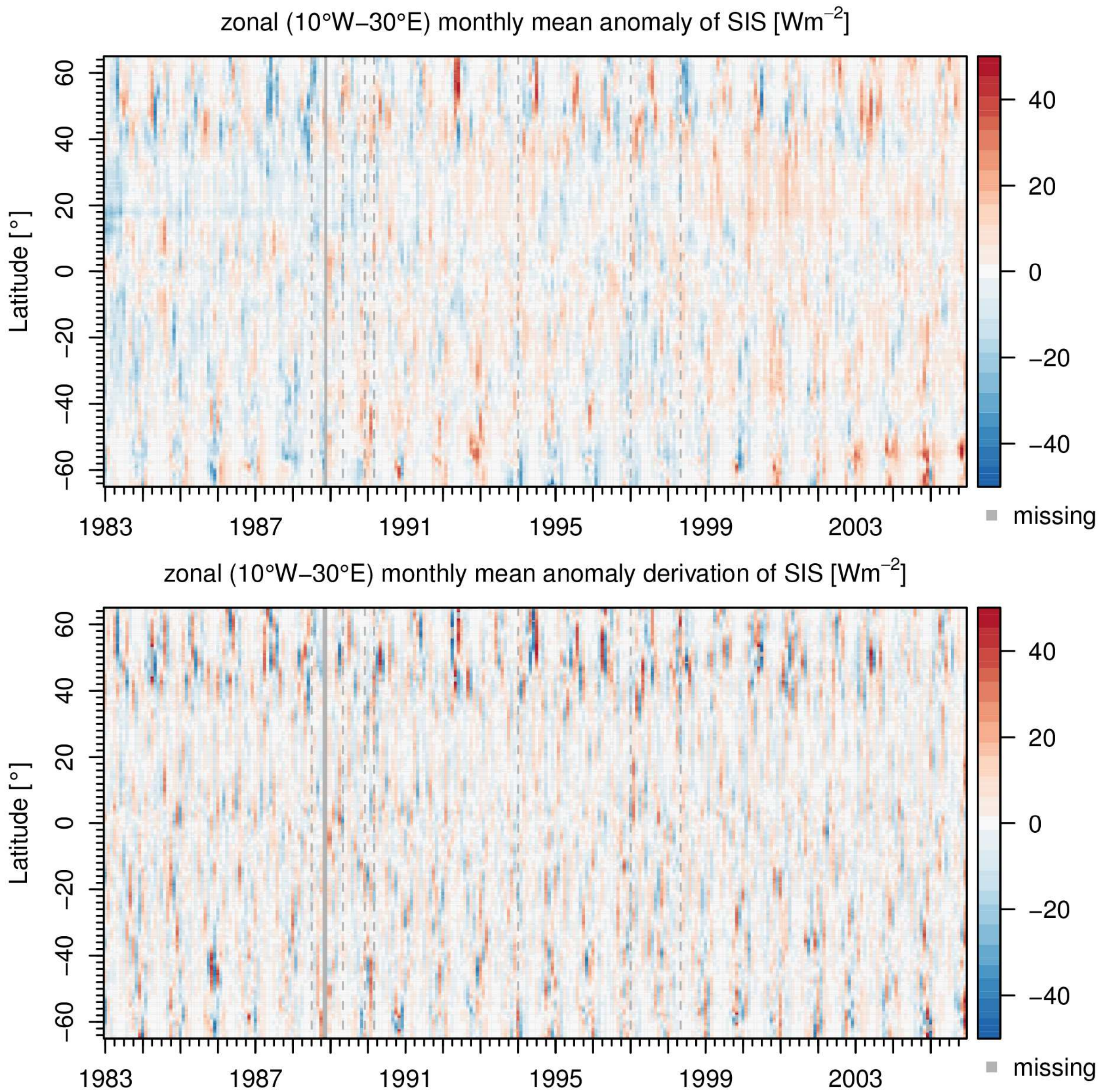


Figure 5–1: a) Hovmoeller plot of the monthly mean anomaly of SIS and b) their temporal derivative, satellite switches are marked with dashed lines

Figure 5–2 shows the temporal evolution of the normalized bias between the CM SAF data set and the BSRN data. The normalized bias is calculated as follows:
The arithmetic average over the complete time series of the BSRN and the satellite data is calculated for each station. The resulting mean difference (bias) is subtracted from all monthly means of the satellite data for each station. The mean difference (bias) over the covered time period is zero afterwards, however, **trends in the monthly differences are not affected by this normalization procedure**.
The differences between the monthly means of BSRN and satellite data are then averaged over all available stations, whenever monthly means from at least 3 stations are available. This leads to an overall time series of “normalized” differences of monthly means. This time series is then analysed for temporal trends. A trend in this time series would indicate in-homogeneities introduced by the self-calibration or the clear sky reflection maps. The applied method is necessary in order to avoid misleading trends in the monthly differences introduced by the quite different start and end points of the time series and the corresponding

mismatch in the weighting of regional bias values. For the test of the self-calibration it is necessary to avoid artefacts due to local bias values as only the temporal evolution of the time series for the complete disk is of relevance. Contrary, the temporal evolution of the normalised mean monthly differences is not affected by the different numbers of available stations for certain months and their local bias,

No temporal trend is present in the time series of the normalized monthly differences of the CM SAF SIS data set. Also the changes between the different satellite sensors are not visible in the normalized bias. This underlines the high stability and homogeneity of the CM SAF SIS data set. It is worth noting that a statistically significant negative trend in the normalized differences is present in the GEWEX and ISCCP SIS data sets, no trend is present in the ERA-Interim SIS data set (not shown here). The Meteosat 3-4 switch detected in Figure 5–1 is not part of the BSRN time period shown in Figure 5–2. The normalized differences for monthly means are plotted. The variation of the normalised differences is mainly in the order of +/- 5 W/m². This is a rather small variation for retrieved surface irradiance, especially if it is taken into account that the uncertainty of the ground measurements is in the order of 3-5 Watts/m² and that uncertainties in the atmospheric input information (aerosols, cloud) counts to the variation, too.

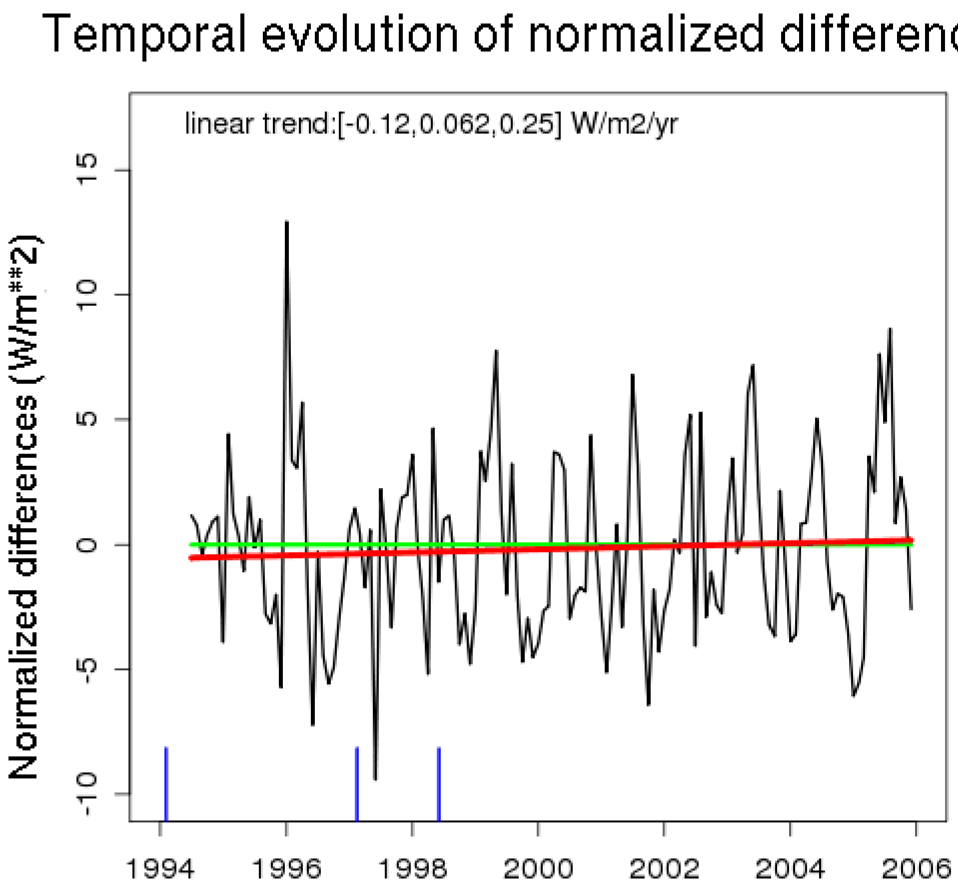


Figure 5–2: Temporal evolution of the normalized differences between the CM SAF data set and the BSRN data. Changes in the satellite instruments are indicated by the blue lines on the x-axis. The green line represents the zero line, the red line is the linear regression

6 Conclusion and Recommendation.

6.1 Conclusion

The satellite-derived data sets of the surface incoming solar and direct radiation (SIS and SID) from CM SAF have been validated by comparison with observations from 12 high-quality ground based stations of the BSRN network. The applied validation limit or target value combine the target accuracy defined in the PRD [RD.2.], which is based on the GCOS accuracy requirement for the variables of the surface radiation budget, and the systematic error of the BSRN surface measurements.

Before 1992 there are no BSRN measurements available, hence the data set could be not compared with BSRN ground based measurements for the period 1983-1992. However, we found no physical reason why the accuracy of the climate data ser should be significantly lower for this period, Exception might be specific regions in the Sahare desert.

The MAD of the monthly means of SIS and SID is significantly better than the target accuracy of 10 W/m² and 15 W/m² for the Mean Absolute difference (MAD) and the Mean Bias. The validation target is also reached for most considered stations, only at stations close to the border of the visible disc (SIS and SID) and at desert stations with high solar insulation ((SID) the MAD exceeds the target accuracy. At Tamanrasset SID shows quite large bias values, but this could be also due to inaccurate SID ground measurement. However, about 90 % (SIS) and 85% (SID) of the monthly MAD values are below the respective target value. Excluding Tamanrasset less SID valus would be be above the target value.

For the daily means the MAD is also better than the target accuracy of 20 and 25 W/m² for SIS and SID for the complete data set and also for most individual stations. The problematic stations are the same as for the monthly means. The mean absolute difference is above the target value at about 85% (SIS) and 75% (SID) of all considered days at all considered stations.

The evaluation of the SIS CDR with the SIS datasets from ERA-Interim, GEWEX SRB and ISCCP FD demonstrated that the monthly and daily mean CM SAF SIS CDR has a higher quality than the evaluation data sets. The MAD of the CM SAF SIS dataset is substantially lower and the differences to the BSRN measurements have a much smaller spread than the three evaluation datasets. More over the amount of mean absolute difference values above the target of 10 W/m² (plus uncertainty of ground measurements) is much lower for the CM-SAF climate data record.

Overall, it was shown that the target accuracy is achieved for monthly, daily and hourly means of the surface incoming solar (SIS) and direct radiation (SID) in the CM SAF CDR. There are no detectable trends in the bias demonstrating the stability and homogeneity of the irradiance product

This validation also demonstrates the accuracy of the effective cloud albedo. It is determined by the accuracy of SIS by a worst case approach. The worst case accuracy for CAL is 0.15 (threshold), 0.1 (target) and 0.05 (optimal) for periods and regions with a monthly mean clear sky irradiance above 50, 70 W/m² and 150 W/m², respectively. Hence, the requested accuracy is achieved for this cases. For the daily mean (hourly mean) CAL the threshold (0.2), the target (0.15) and the optimal (0.1) accuracy is met for daily mean clear sky irradiances above 75, 100 and 150 W/m², respectively.

However, for lower clear sky irradiance the method fails to provide information if the target accuracy can be reached, Lower monthly/daily mean clear sky irradiance (<70/100 W/m²) usually occur during wintertime above a latitude of +/-55°. The target accuracy might not be reached for these regions and period. More over, for slant geometries (border of Heliosat coverage) it is expected that the target accuracy is not met and even higher uncertainties might occur. Higher uncertainties might also occur for snow covered regions.

In general for SIS, SID and CAL higher uncertainties are expected over regions with long lasting snow cover a desert regions with (bright) sand surface. For SID higher are also expected in regions with high variation in aerosol properties.

Table 6-1: *Achieved validation results for SIS, SID and CAL.*

Product	**Summary on mean error (absolute)**
SID: Direct Irradiance at Surface.	*Mean absolute Difference below 15 W/m² and 85 % of (monthly) absolute difference values below 15 W/m² (+ uncertainty of ground based Measurements) for monthly means.* *25 W/m² for daily and hourly means (here bias) respectively.* *Higher bias values occur in the Alpine and other mountainous regions, e.g. due to uncertainties in area to point comparison and snow coverage.* *Higher bias values might also occur during wintertime above +/- 55 degree latitude.*
SIS: Solar Incoming Solar Radiation.	*Mean Absolute Difference below 10 W/m² and 90 per cent of (monhlly) absolute difference values below 10 W/m² (+ uncertainty of ground based measurements) for monthly means* *20 W/m² for daily and hourly means (here bias) respectively.* *Higher bias values occur in the Alpine and other mountainous regions, e.g. due to uncertainties in area to point comparison and snow coverage..*
CAL: Effective cloud albedo.	*Uncertainty of 0.1 for monthly means and 0.15 for daily and hourly means.* *Uncertainty of 0.05 and 0.1 respectively for clear sky irradiance monthly means above 150 W/m².* *Higher bias values might occur during wintertime above +/- 55 degree latitude.* *Higher bias values occur for slant viewing geometries at the border of the Heliosat coverage throughout the year.* *Higher bias values occur also for snow covered regions.*

6.2 Recommendations for future product improvement (e.g. CDOP-2):

1. Improvement of atmospheric input
   a. Higher spatial resolution of aerosol and water vapour climatology in order to account for changes in the profiles of water vapour and aerosols.
   b. Study to investigate the effect of a higher temporal resolution of water vapour, e.g. the use of daily means instead of monthly means
   c. Evaluation and improvement of monthly aerosol fields in order to replace the used aerosol climatology. It is expected that updated aerosol information will enhance the accuracy of the data set especially in desert regions
2. Calculation of an artificial HRV channel for MSG by combination of VIS006 and VIS008 channel for MSG in order to improve the homogeneity for the MFG MSG transition of the data record.
3. Improvement of algorithms.
   a. Implementation of a correction of broken clouds effect for direct beam irradiance.
   b. Optimisation of clear sky reflectance retrieval in order to minimise cloud contamination.
4. Analysis and evaluation of benefits and drawbacks of modifications with minor or regional effect on accuracy.
   a. Incorporation of the Infrared channel in the Heliosat algorithm in order to provide better detection potential for clouds over bright surfaces (snow)
   b. Cloud Parallax correction that accounts for horizontal shifts of high clouds due to the satellite viewing geometry (can be around 10 km for 10 km high clouds at 45 degree latitude, would possibly correct some of the errors in high latitude stations).
   c. Application of Meteosat First Generation visible channel calibration coefficients, yet to be generated by GSICS and comparison of these coefficients to the HELIOSAT selfcalibration method.
   d. Detection of cloud shadows. With the classical HELIOSAT, cloud shadows receive a low cloud index value since they are dark, and thus the surface incoming solar radiation (SIS) for these areas will be at maximum. This could potentially remove some of the remaining bias and spread

7 References

Berrisford, P., D. Dee, K. Fielding, M. Fuentes, P. Kallberg, S. Kobayashi, and S. Uppala, 2009: The ERA-Interim archive. {ERA Report Series} 1.

Beyer, H. G., C. Costanzo, and D. Heinemann, 1996: Modifications of the Heliosat procedure for irradiance estimates from satellite images. *Solar Energy*, **56,** 207-212.

Cano, D., J. M. Monget, M. Albuisson, H. Guillard, N. Regas, and L. Wald, 1986: A method for the determination of the global solar-radiation from meteorological satellite data. *Solar Energy*, **37,** 31-39.

Gupta, S., Stackhouse Jr., P., S. Cox, J. Mikovitz, and T. Zhang, 2006: Surface radiation budget project completes 22-year data set. *GEWEX News*, **16,** 12-13.

Mueller, R., C. Matsoukas, A. Gratzki, H. Behr, and R. Hollmann, 2009: The CM-SAF operational scheme for the satellite based retrieval of solar surface irradiance - A LUT based eigenvector hybrid approach. *Remote Sensing of Environment***,** 1012-1024.

Ohmura, A., and Coauthors, 1998: Baseline Surface Radiation Network (BSRN/WCRP): New precision radiometry for climate research. *Bulletin of the American Meteorological Society***,** 2115-2136.

Rigollier, C., M. Lefevre, P. Blanc, and L. Wald, 2002: The operational calibration of images taken in the visible channel of the meteosat series of satellites. *{J. Atmos. Ocean. Technol.}*, **{19},** {1285-1293}.

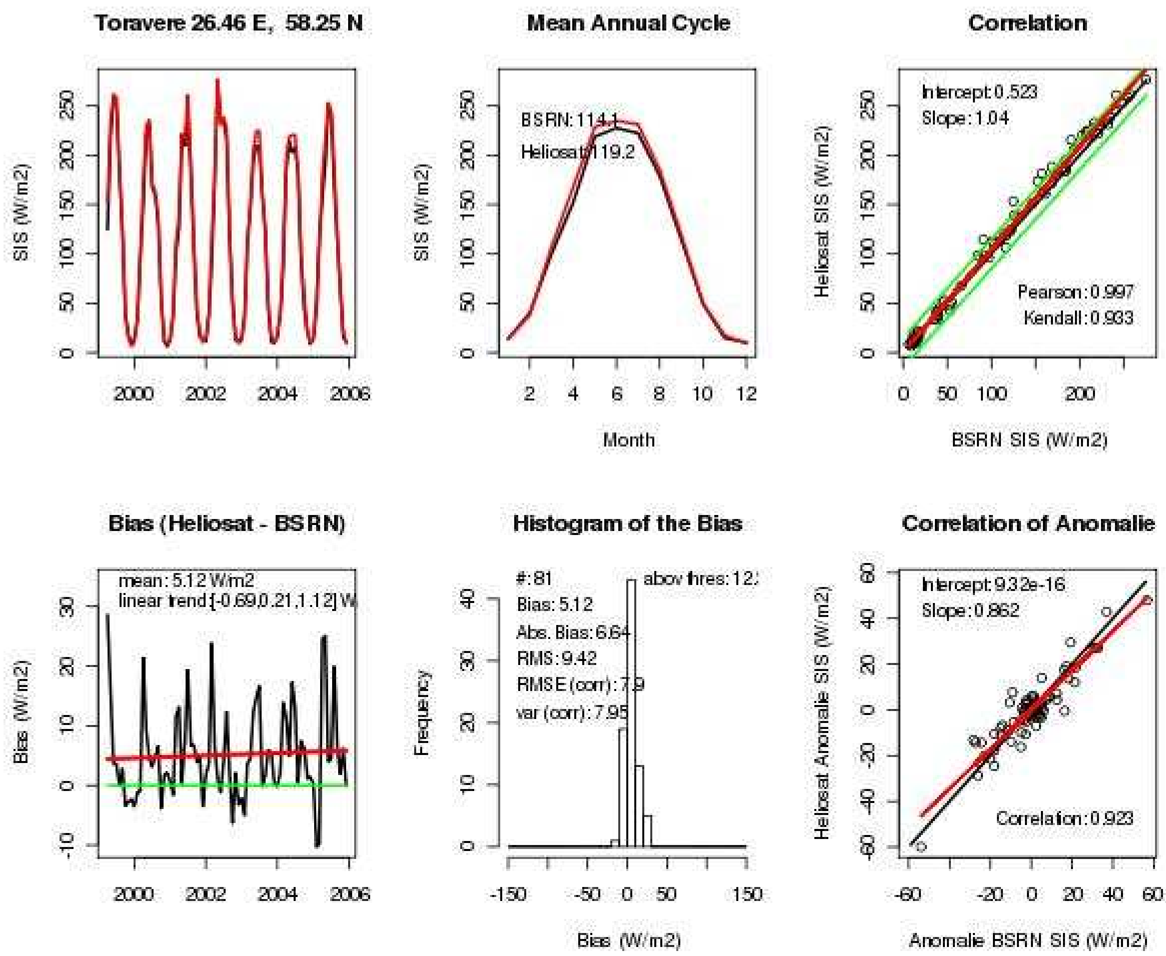
Rossow, W. B., and E. N. Duenas, 2004: The International Satellite Cloud Climatology Project (ISCCP) Web Site: An Online Resource for Research. *Bulletin of the American Meteorological Society*, **85,** 167-172.

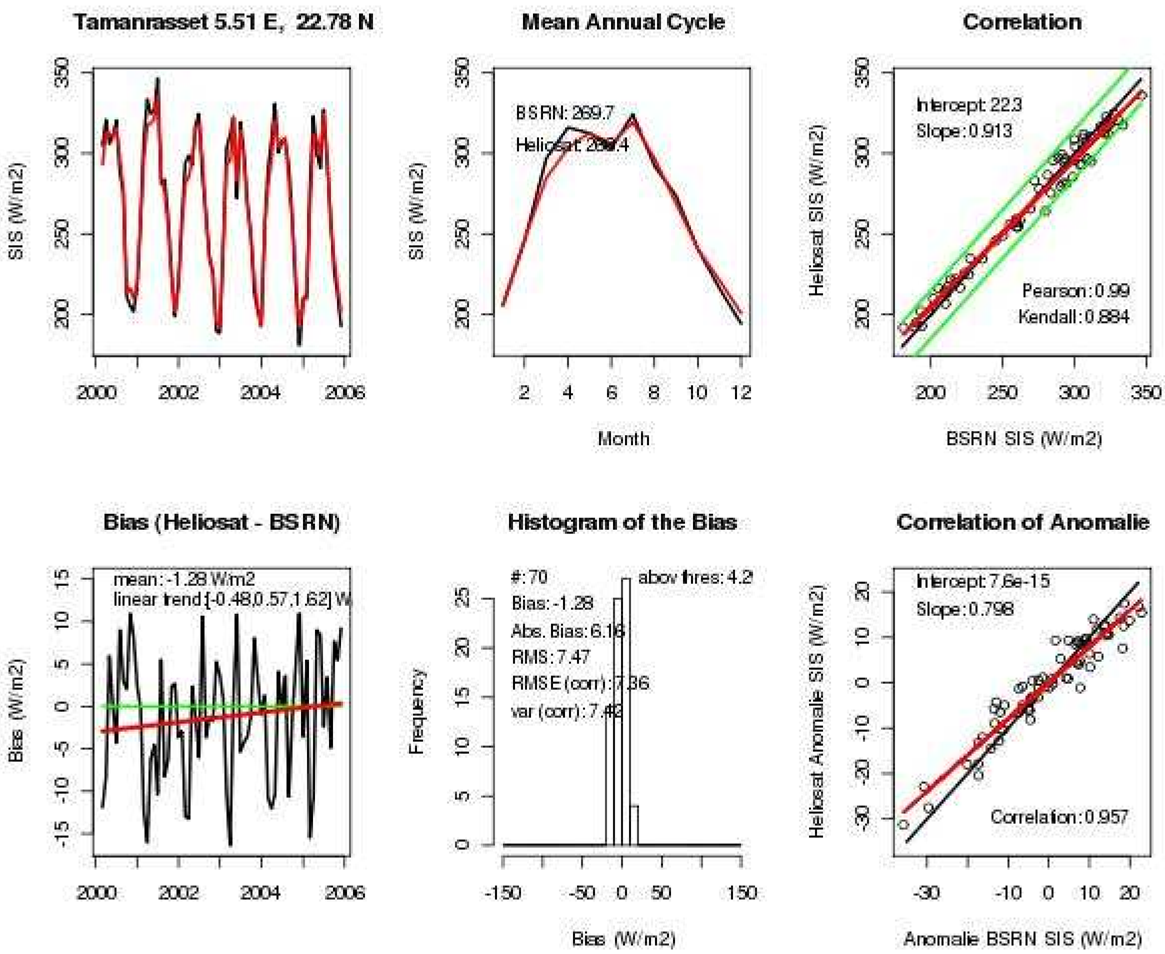
Tukey, John W. "*Exploratory Data Analysis*". Addison-Wesley, Reading, MA. 1977.

8 Appendix A: Figures of validation results for each station.

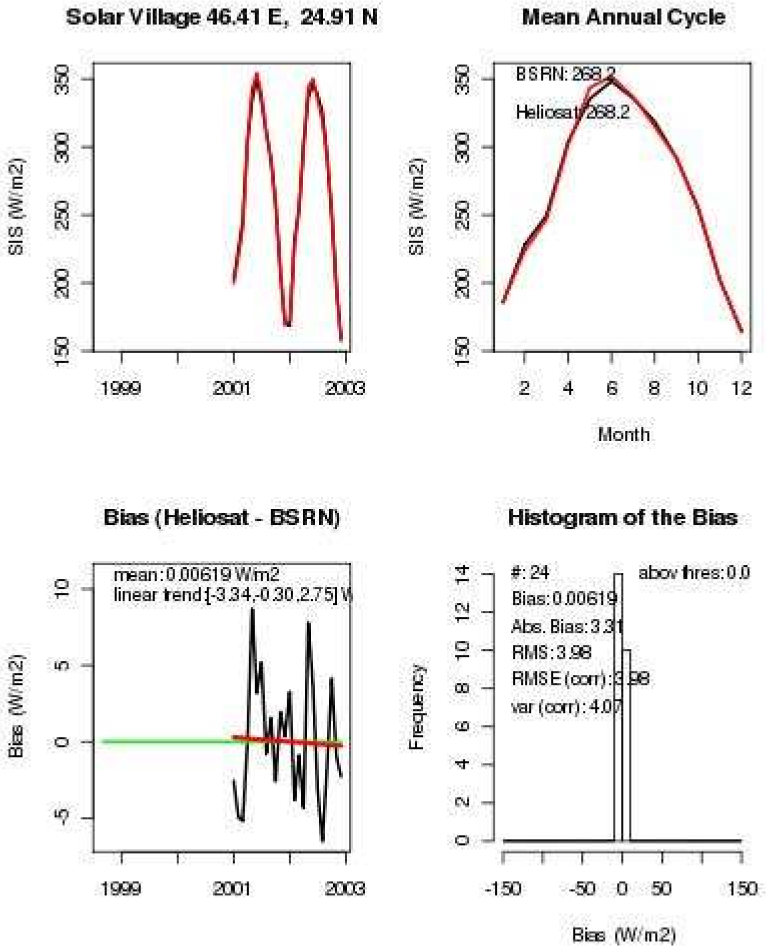
Figure 8–1: The following figures provide additional validation results for the individual stations.

It is shown always from left hand to right hand, the comparison of satellite and in-situ SIS for every month and for the mean annual cycle. In addition, statistical information i.e. correlation, bias, histogram of the Bias, and correlation of anomalies are given in the Figures. Red lines are satellite results and black lines are the BSRN measurements.
Mimatchs are visible for many station in the mean annual cycle.Howe,er, bias is expected to show an annual cycle due to increased solar irradiance during the summer period (identical relative deviation leads to larger deviation during summer time). Taking this into account the annual cycles are in generalwell representated by the satellite data.

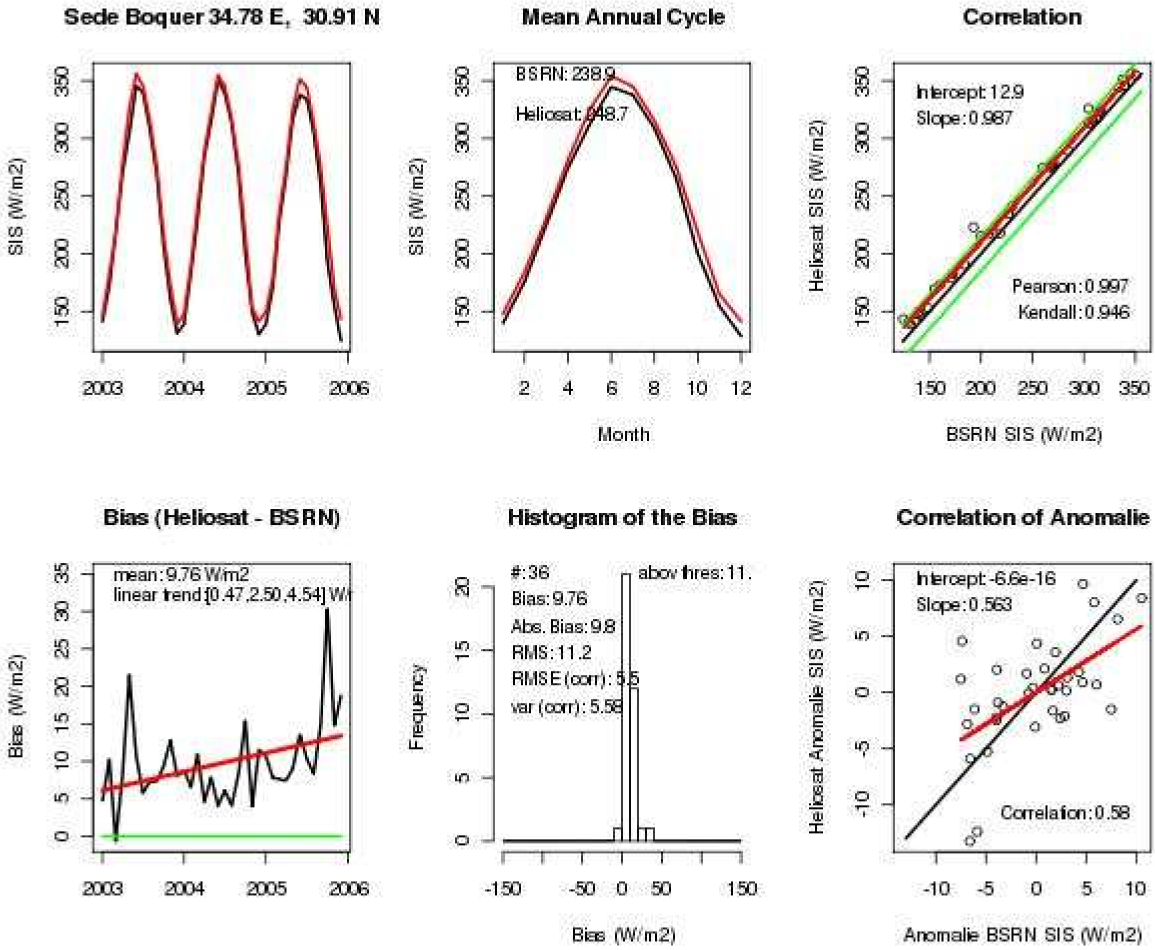




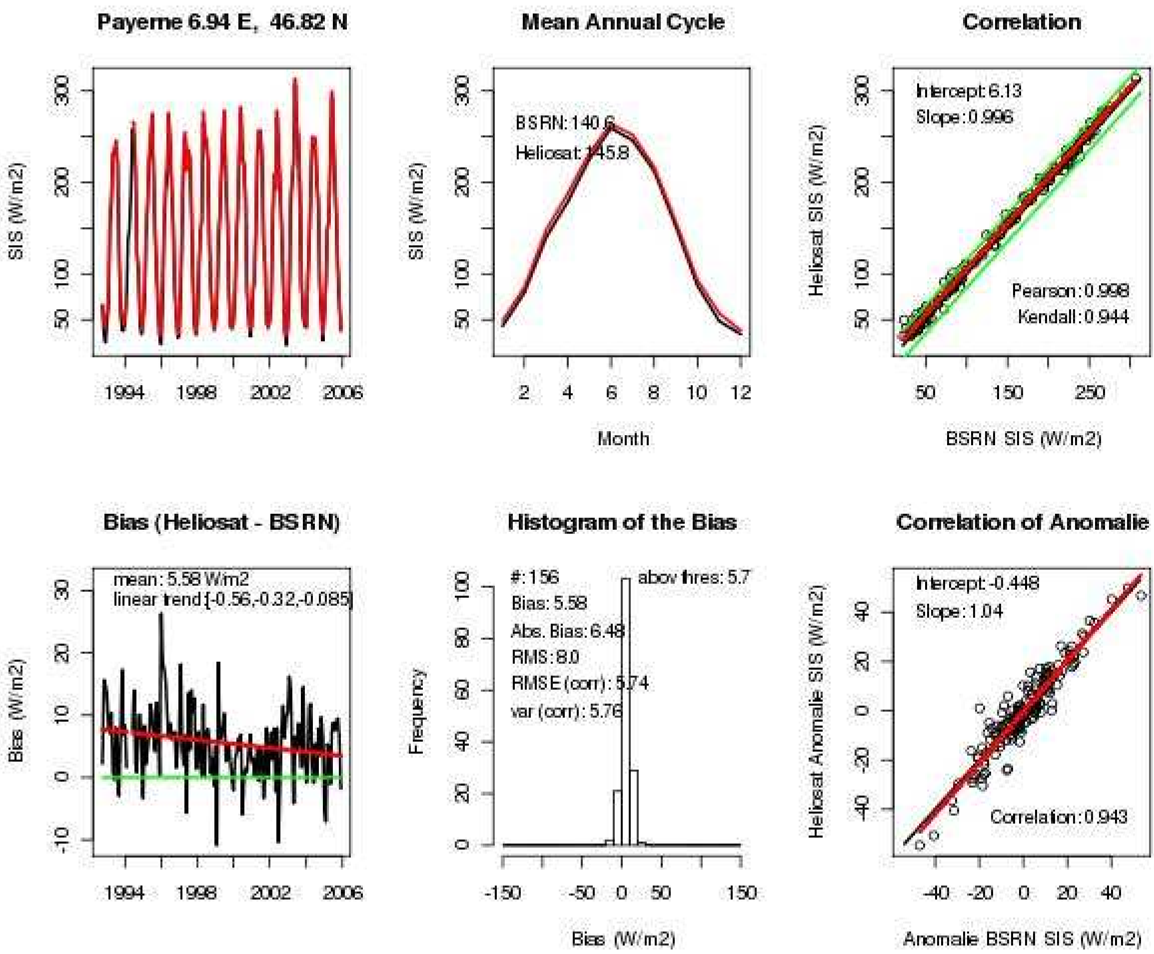
Tamanrasset 5.51 E, 22.78 N
SIS (W/m2)
Mean Annual Cycle
BSRN: 269.7
Heliosat: 268.4
Month
Correlation
Intercept: 22.3
Slope: 0.913
Pearson: 0.99
Kendall: 0.884
Heliosat SIS (W/m2)
BSRN SIS (W/m2)
Bias (Heliosat - BSRN)
mean: -1.28 W/m2
linear trend [-0.48,0.57,1.62] W
Bias (W/m2)
Histogram of the Bias
#: 70
abov thres: 4.2
Bias: -1.28
Abs. Bias: 6.16
RMS: 7.47
RMSE (corr): 7.36
var (corr): 7.42
Frequency
Bias (W/m2)
Correlation of Anomalie
Intercept: 7.6e-15
Slope: 0.798
Correlation: 0.957
Heliosat Anomalie SIS (W/m2)
Anomalie BSRN SIS (W/m2)



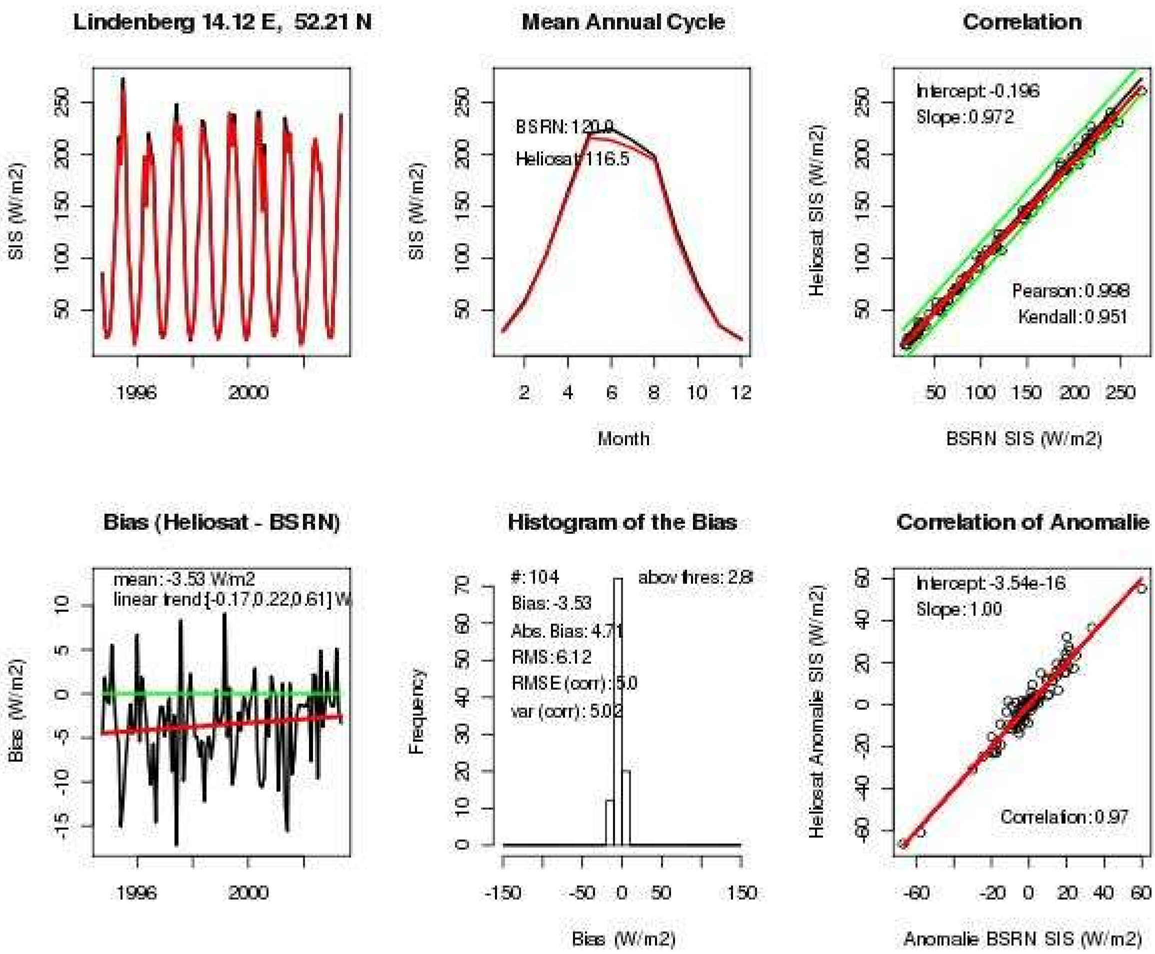
Solar Village 46.41 E, 24.91 N
SIS (W/m2)
Mean Annual Cycle
BSRN: 268.2
Heliosat: 268.2
Month
Correlation
Intercept: -4.98
Slope: 1.02
Pearson: 0.998
Kendall: 0.964
Heliosat SIS (W/m2)
BSRN SIS (W/m2)
Bias (Heliosat - BSRN)
mean: 0.00619 W/m2
Bias (W/m2)
Histogram of the Bias
#: 24
Bias: 0.00619
Abs. Bias: 3.31
RMS: 3.98
RMSE (corr): 3.98
var (corr): 4.07
Frequency



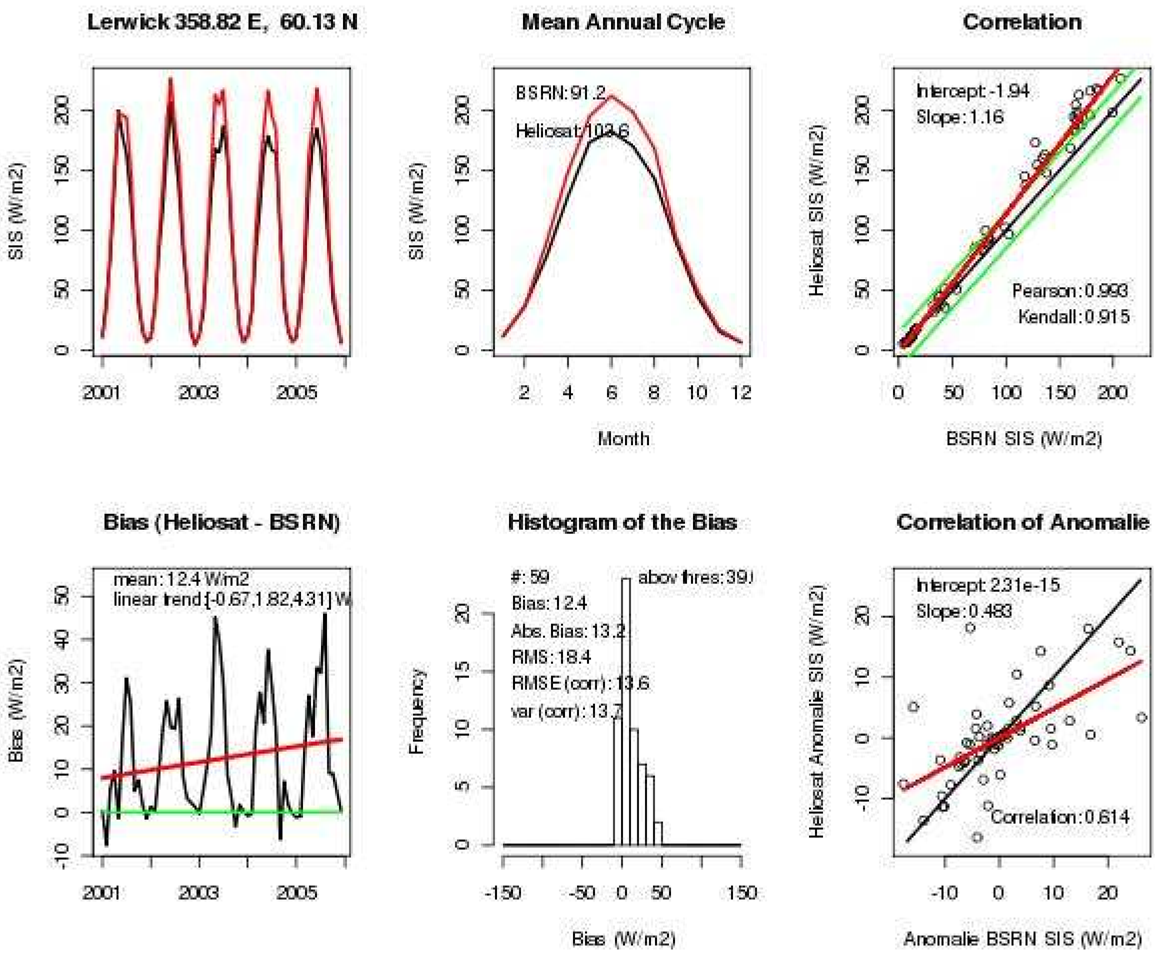
Sede Boquer 34.78 E, 30.91 N
SIS (W/m2)
Mean Annual Cycle
BSRN: 238.9
Heliosat: 248.7
Month
Correlation
Intercept: 12.9
Slope: 0.987
Pearson: 0.997
Kendall: 0.946
Heliosat SIS (W/m2)
BSRN SIS (W/m2)
Bias (Heliosat - BSRN)
mean: 9.76 W/m2
linear trend: [0.47,2.50,4.54] W/
Bias (W/m2)
Histogram of the Bias
#:36
abov thres: 11.
Bias: 9.76
Abs. Bias: 9.8
RMS: 11.2
RMSE (corr): 5.5
var (corr): 5.58
Frequency
Bias (W/m2)
Correlation of Anomalie
Intercept: -6.6e-16
Slope: 0.563
Correlation: 0.58
Heliosat Anomalie SIS (W/m2)
Anomalie BSRN SIS (W/m2)



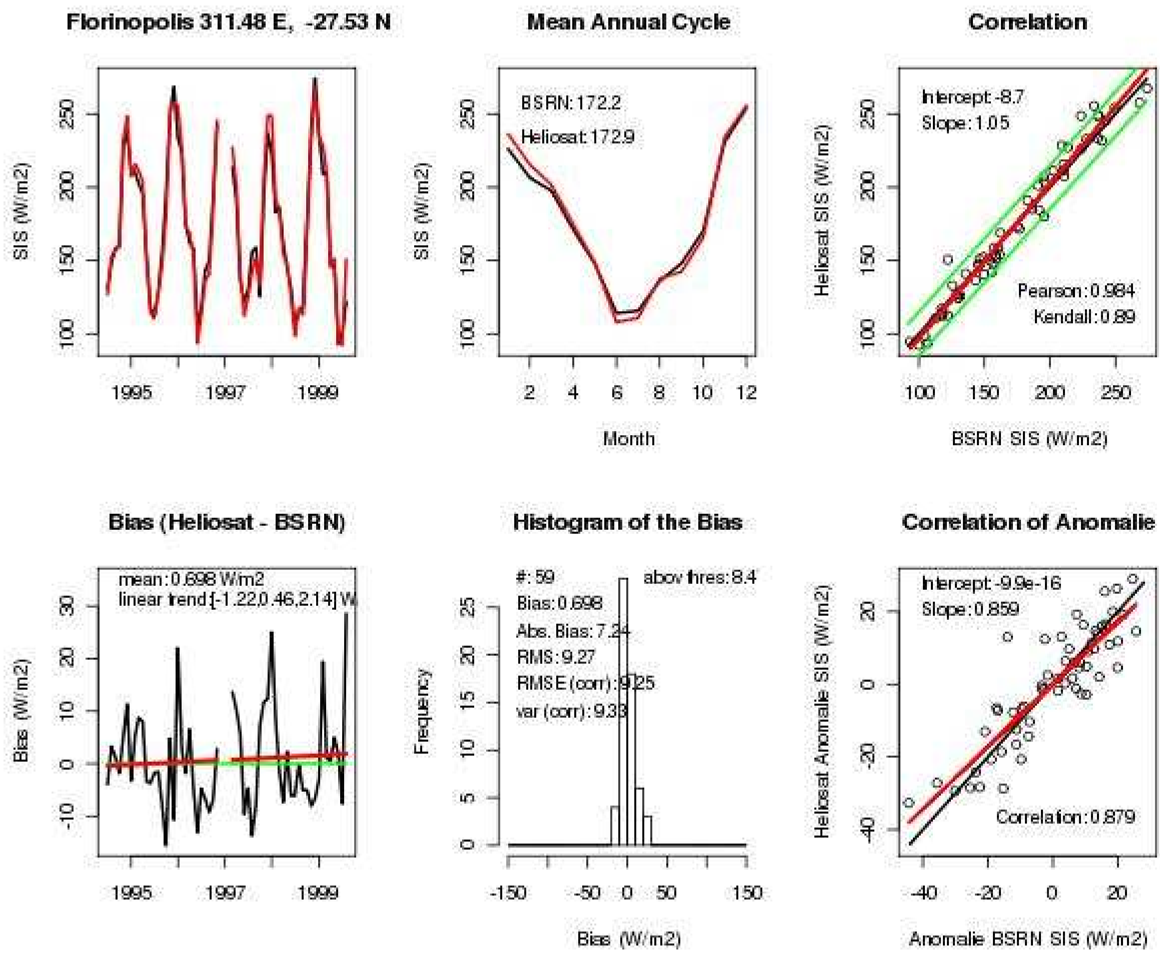
Payerne 6.94 E, 46.82 N
SIS (W/m2)
Mean Annual Cycle
BSRN: 140.6
Heliosat: 145.8
Month
Correlation
Intercept: 6.13
Slope: 0.996
Pearson: 0.998
Kendall: 0.944
Heliosat SIS (W/m2)
BSRN SIS (W/m2)
Bias (Heliosat - BSRN)
mean: 5.58 W/m2
linear trend [-0.56,-0.32,-0.085]
Bias (W/m2)
Histogram of the Bias
#: 156
abov thres: 5.7
Bias: 5.58
Abs. Bias: 6.48
RMS: 8.0
RMSE (corr): 5.74
var (corr): 5.76
Frequency
Bias (W/m2)
Correlation of Anomalie
Intercept: -0.448
Slope: 1.04
Correlation: 0.943
Heliosat Anomalie SIS (W/m2)
Anomalie BSRN SIS (W/m2)

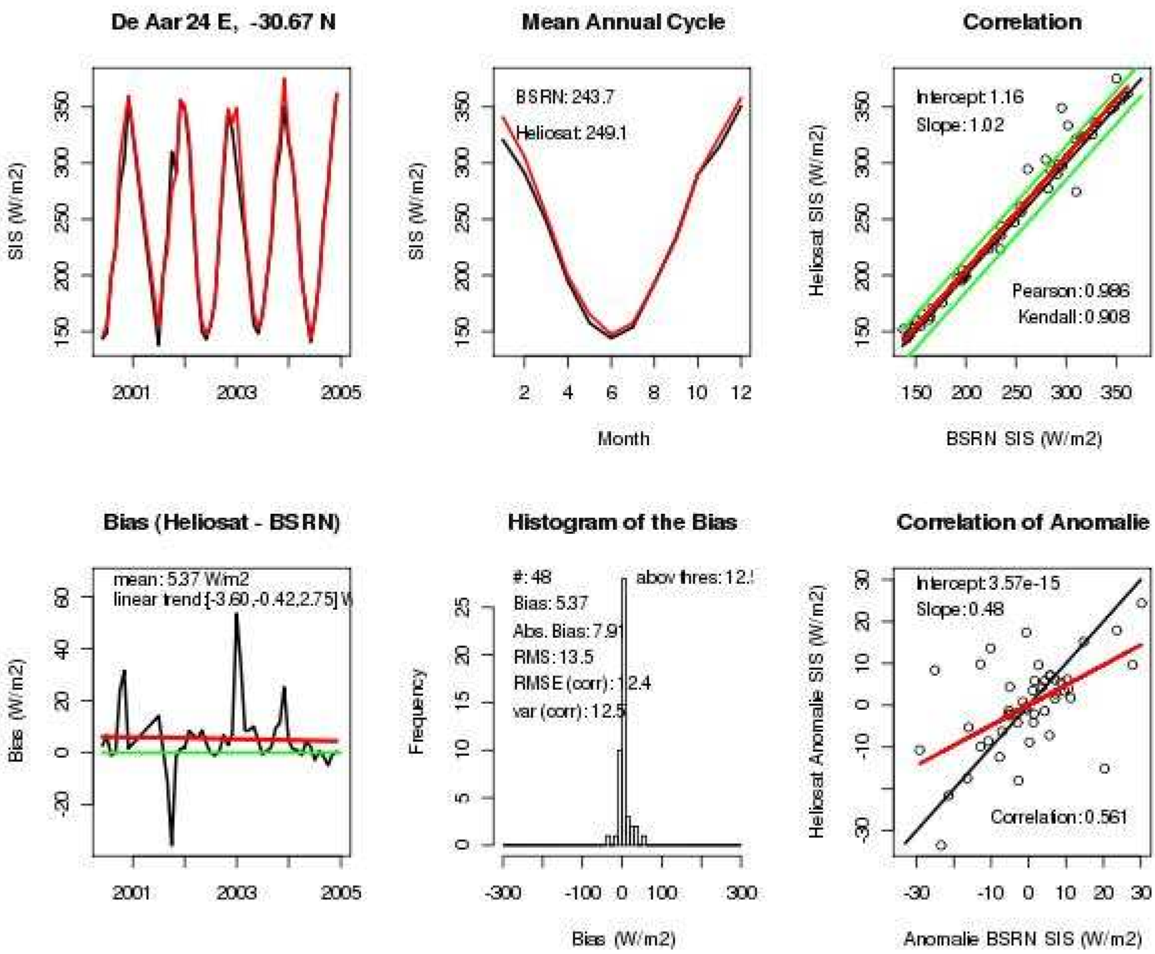


Lindenberg 14.12 E, 52.21 N
SIS (W/m2)
1996
2000
Mean Annual Cycle
BSRN:120.9
Heliosat:116.5
Month
Correlation
Intercept:-0.196
Slope:0.972
Pearson:0.998
Kendall:0.951
Heliosat SIS (W/m2)
BSRN SIS (W/m2)
Bias (Heliosat - BSRN)
mean:-3.53 W/m2
linear trend:[-0.17,0.22,0.61] W
Bias (W/m2)
Histogram of the Bias
#:104
abov thres: 2.8
Bias:-3.53
Abs. Bias: 4.71
RMS:6.12
RMSE (corr):5.0
var (corr): 5.02
Frequency
Bias (W/m2)
Correlation of Anomalie
Intercept:-3.54e-16
Slope:1.00
Correlation:0.97
Heliosat Anomalie SIS (W/m2)
Anomalie BSRN SIS (W/m2)

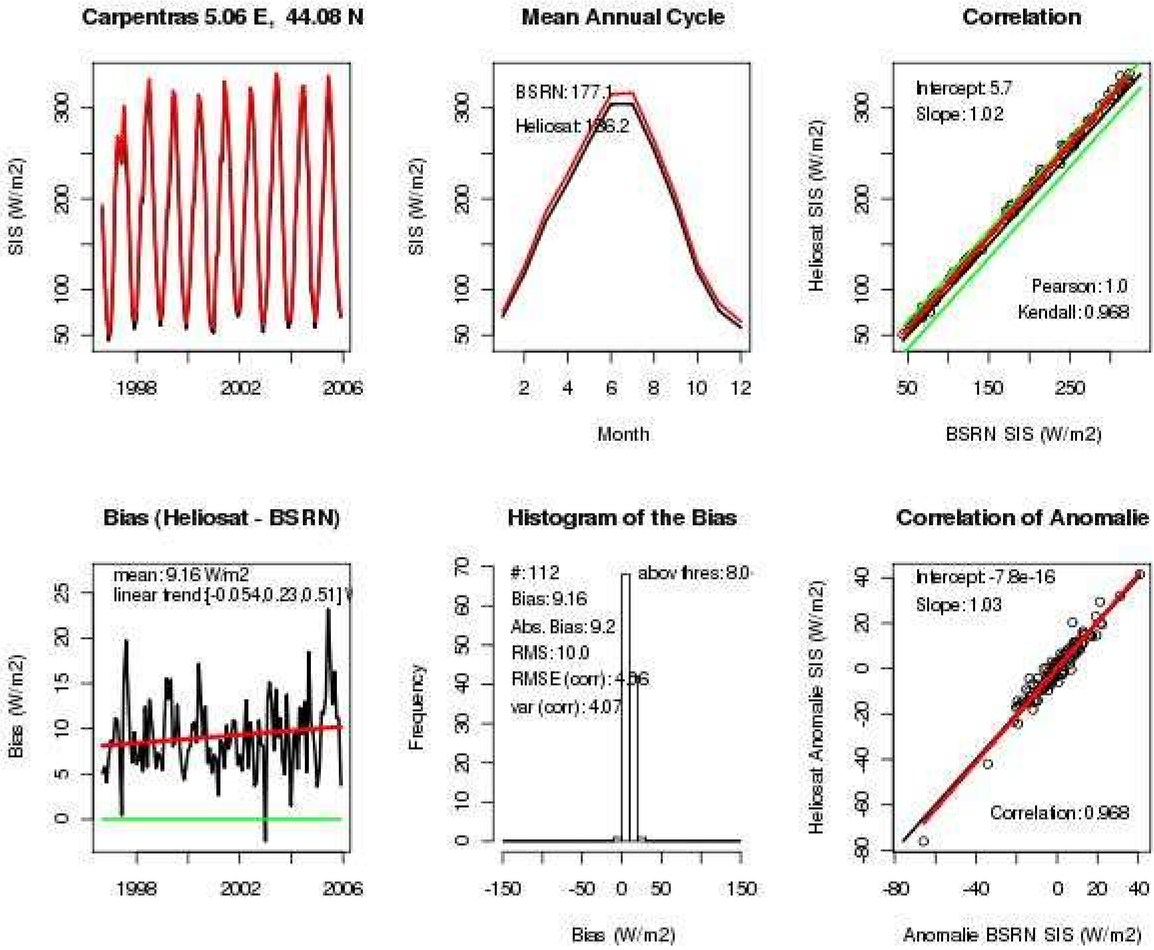


Lerwick 358.82 E, 60.13 N
SIS (W/m2)
Mean Annual Cycle
BSRN:91.2
Heliosat:102.6
Month
Correlation
Intercept:-1.94
Slope:1.16
Pearson:0.993
Kendall:0.915
Heliosat SIS (W/m2)
BSRN SIS (W/m2)
Bias (Heliosat - BSRN)
mean:12.4 W/m2
linear trend:[-0.67,1.82,4.31] W
Bias (W/m2)
Histogram of the Bias
#:59
abov thres:39
Bias:12.4
Abs. Bias:13.2
RMS:18.4
RMSE (corr):13.6
var (corr):13.7
Frequency
Bias (W/m2)
Correlation of Anomalie
Intercept:2.31e-15
Slope:0.483
Correlation:0.614
Heliosat Anomalie SIS (W/m2)
Anomalie BSRN SIS (W/m2)

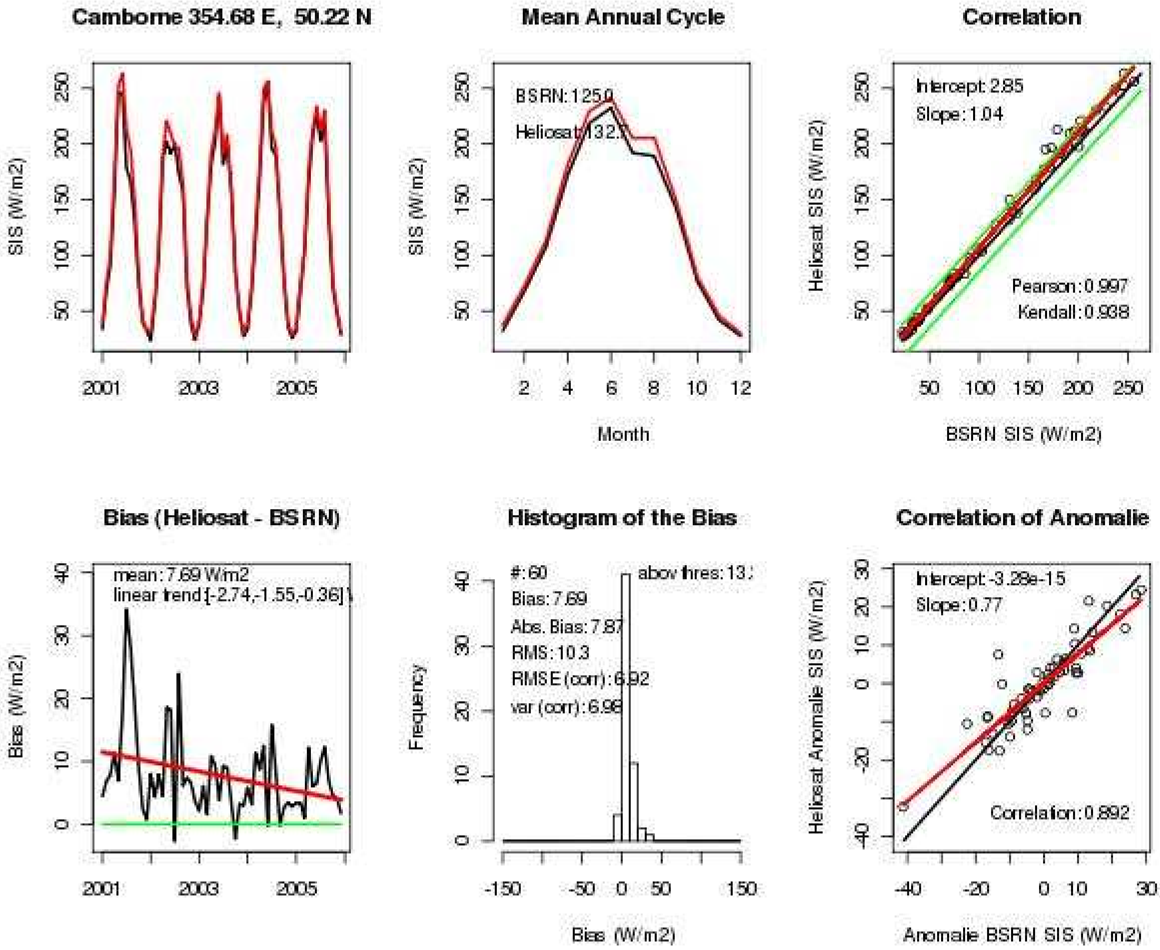

Florinopolis 311.48 E, -27.53 N
SIS (W/m2)
Mean Annual Cycle
BSRN: 172.2
Heliosat: 172.9
Month
Correlation
Intercept -8.7
Slope: 1.05
Pearson: 0.984
Kendall: 0.89
Heliosat SIS (W/m2)
BSRN SIS (W/m2)
Bias (Heliosat - BSRN)
mean: 0.698 W/m2
linear trend [-1.22,0.46,2.14] W
Bias (W/m2)
Histogram of the Bias
#: 59
abov thres: 8.4
Bias: 0.698
Abs. Bias: 7.24
RMS: 9.27
RMSE (corr): 9.25
var (corr): 9.33
Frequency
Bias (W/m2)
Correlation of Anomalie
Intercept -9.9e-16
Slope: 0.859
Correlation: 0.879
Heliosat Anomalie SIS (W/m2)
Anomalie BSRN SIS (W/m2)

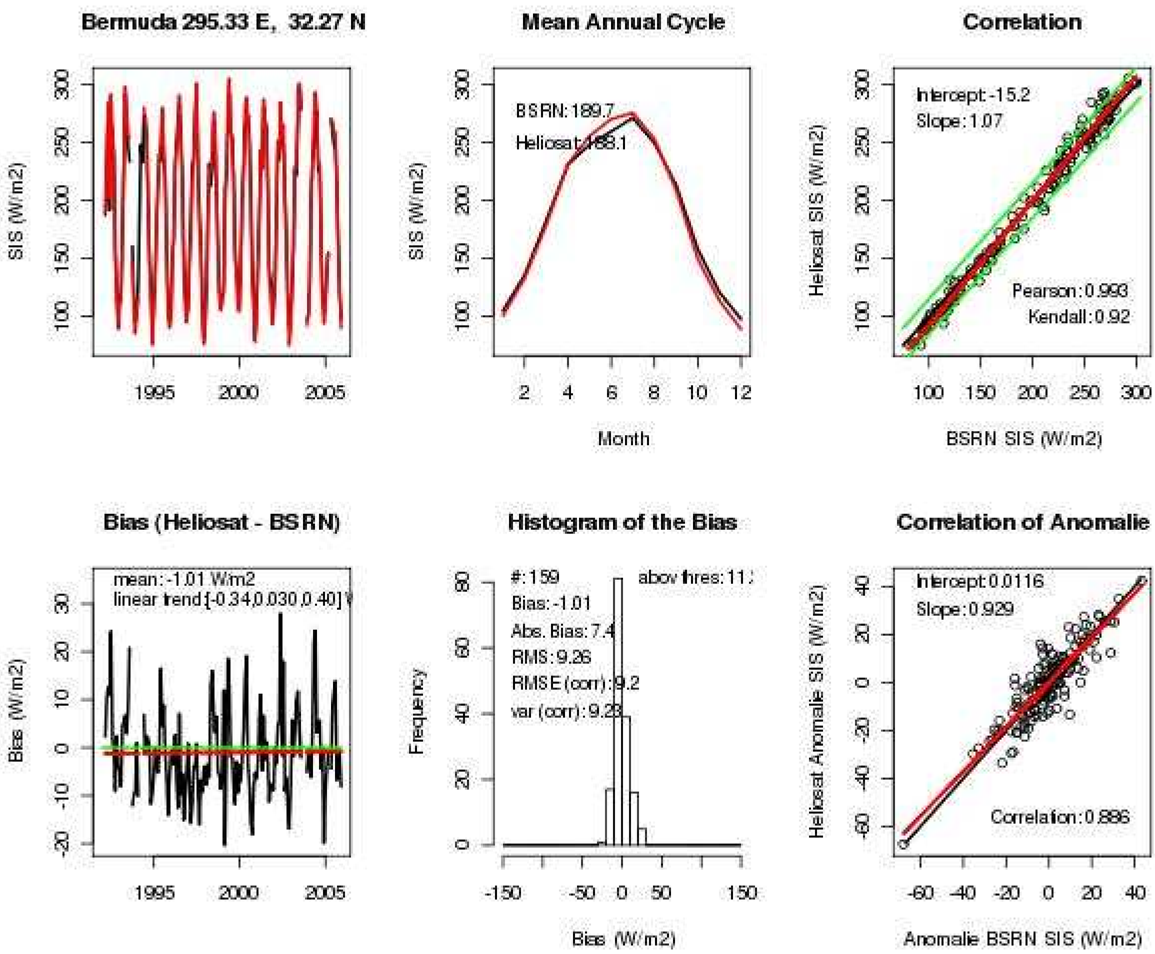


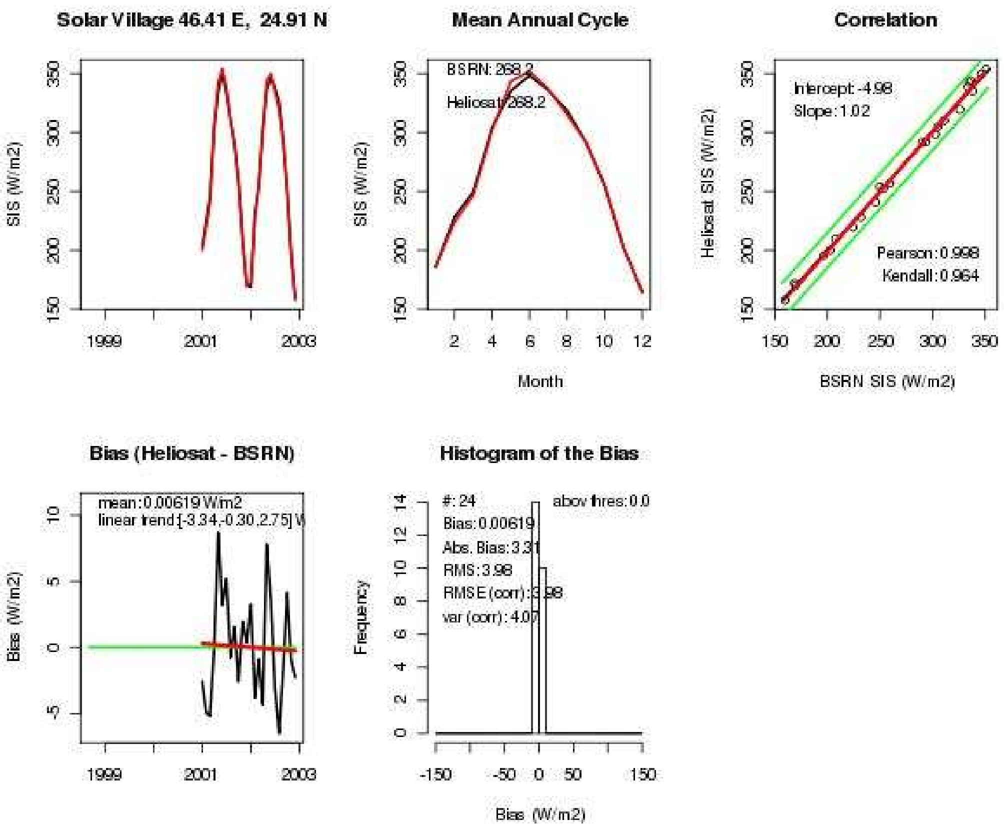
De Aar 24 E, -30.67 N
SIS (W/m2)
Mean Annual Cycle
BSRN: 243.7
Heliosat: 249.1
Month
Correlation
Intercept: 1.16
Slope: 1.02
Pearson: 0.986
Kendall: 0.908
Heliosat SIS (W/m2)
BSRN SIS (W/m2)
Bias (Heliosat - BSRN)
mean: 5.37 W/m2
Bias (W/m2)
Histogram of the Bias
#: 48
Bias: 5.37
Abs. Bias: 7.91
RMS: 13.5
RMSE (corr): 12.4
var (corr): 12.5
Frequency
Bias (W/m2)
Correlation of Anomalie
Intercept: 3.57e-15
Slope: 0.48
Correlation: 0.561
Heliosat Anomalie SIS (W/m2)
Anomalie BSRN SIS (W/m2)



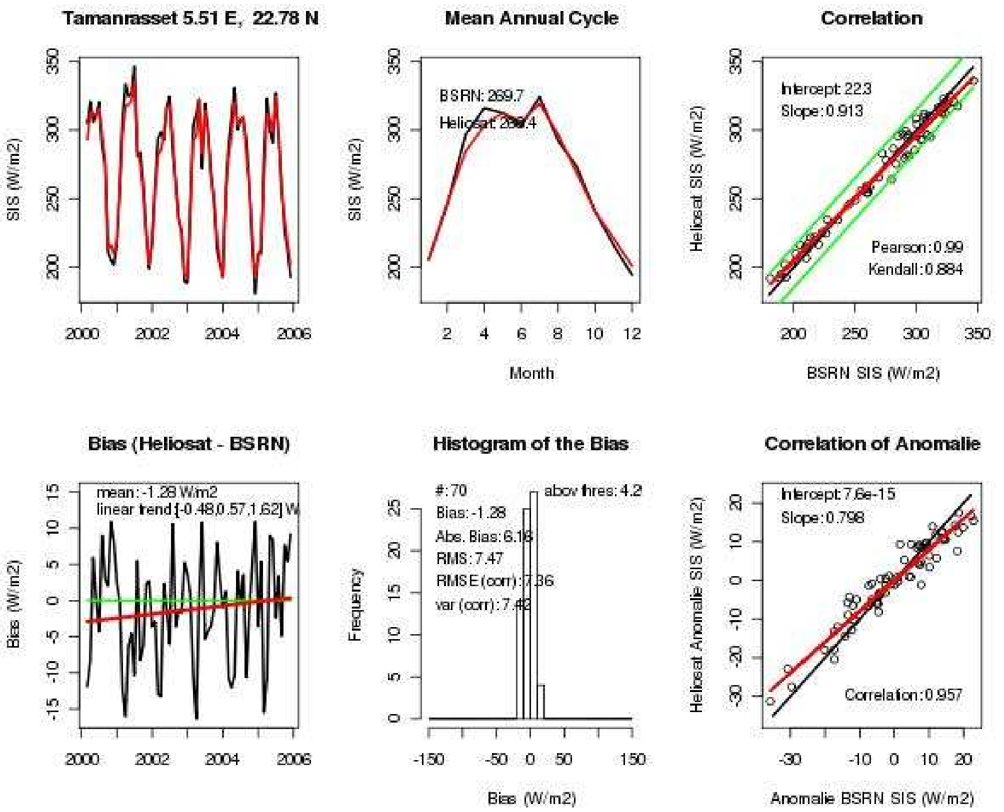
Carpentras 5.06 E, 44.08 N
SIS (W/m2)
Mean Annual Cycle
BSRN: 177.1
Heliosat: 186.2
Month
Correlation
Intercept: 5.7
Slope: 1.02
Pearson: 1.0
Kendall: 0.968
Heliosat SIS (W/m2)
BSRN SIS (W/m2)
Bias (Heliosat - BSRN)
mean: 9.16 W/m2
Bias (W/m2)
Histogram of the Bias
#: 112
Bias: 9.16
Abs. Bias: 9.2
RMS: 10.0
var (corr): 4.07
Frequency
Bias (W/m2)
Correlation of Anomalie
Intercept: -7.8e-16
Slope: 1.03
Correlation: 0.968
Heliosat Anomalie SIS (W/m2)
Anomalie BSRN SIS (W/m2)


Camborne 354.68 E, 50.22 N
SIS (W/m2)
Mean Annual Cycle
BSRN:125.0
Heliosat:132.7
Month
Correlation
Intercept: 2.85
Slope: 1.04
Pearson: 0.997
Kendall: 0.938
Heliosat SIS (W/m2)
BSRN SIS (W/m2)
Bias (Heliosat - BSRN)
mean: 7.69 W/m2
linear trend [-2.74,-1.55,-0.36]
Bias (W/m2)
Histogram of the Bias
#: 60
Bias: 7.69
Abs. Bias: 7.87
RMS: 10.3
RMSE (corr): 6.92
var (corr): 6.98
Frequency
Bias (W/m2)
Correlation of Anomalie
Intercept: -3.28e-15
Slope: 0.77
Correlation: 0.892
Heliosat Anomalie SIS (W/m2)
Anomalie BSRN SIS (W/m2)

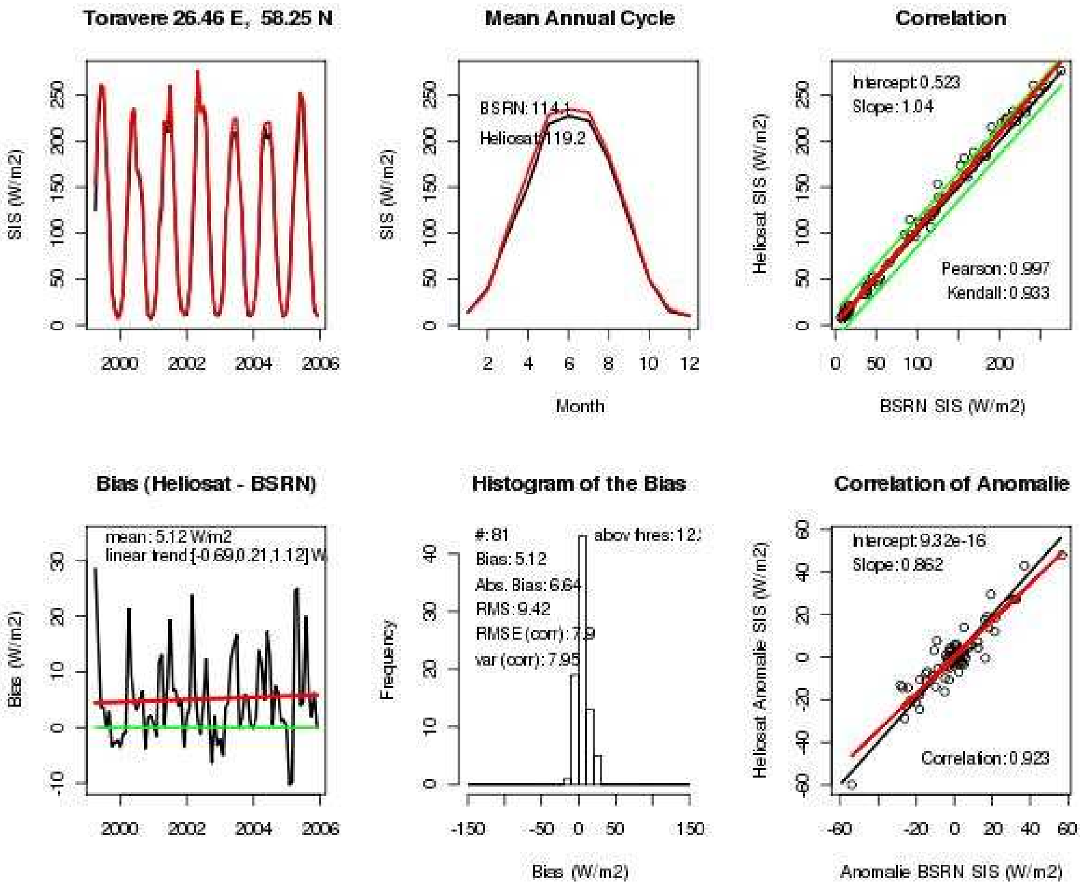

Bermuda 295.33 E, 32.27 N
SIS (W/m2)
Mean Annual Cycle
BSRN: 189.7
Heliosat: 188.1
Month
Correlation
Intercept: -15.2
Slope: 1.07
Pearson: 0.993
Kendall: 0.92
Heliosat SIS (W/m2)
BSRN SIS (W/m2)
Bias (Heliosat - BSRN)
mean: -1.01 W/m2
Bias (W/m2)
Histogram of the Bias
#: 159
Bias: -1.01
Abs. Bias: 7.4
RMS: 9.26
var (corr): 9.23
Frequency
Bias (W/m2)
Correlation of Anomalie
Intercept 0.0116
Slope: 0.929
Correlation: 0.886
Heliosat Anomalie SIS (W/m2)
Anomalie BSRN SIS (W/m2)



Solar Village 46.41 E, 24.91 N
SIS (W/m2)
Mean Annual Cycle
BSRN: 268.2
Heliosat: 268.2
Month
Correlation
Intercept: -4.98
Slope: 1.02
Pearson: 0.998
Kendall: 0.964
Heliosat SIS (W/m2)
BSRN SIS (W/m2)
Bias (Heliosat - BSRN)
mean: 0.00619 W/m2
linear trend [-3.34,-0.30,2.75] W
Bias (W/m2)
Histogram of the Bias
#: 24
abov thres: 0.0
Bias: 0.00619
Abs. Bias: 3.31
RMS: 3.98
RMSE (corr): 3.98
var (corr): 4.07
Frequency
Bias (W/m2)



Tamanrasset 5.51 E, 22.78 N
SIS (W/m2)
Mean Annual Cycle
BSRN: 269.7
Heliosat: 268.4
Month
Correlation
Intercept: 22.3
Slope: 0.913
Pearson: 0.99
Kendall: 0.884
Heliosat SIS (W/m2)
BSRN SIS (W/m2)
Bias (Heliosat - BSRN)
mean: -1.28 W/m2
linear trend [-0.48,0.57,1.62] W
Bias (W/m2)
Histogram of the Bias
#: 70
abov thres: 4.2
Bias: -1.28
Abs. Bias: 6.18
RMS: 7.47
RMSE (corr): 7.36
var (corr): 7.42
Frequency
Bias (W/m2)
Correlation of Anomalie
Intercept: 7.6e-15
Slope: 0.798
Correlation: 0.957
Heliosat Anomalie SIS (W/m2)
Anomalie BSRN SIS (W/m2)


Toravere 26.46 E, 58.25 N
SIS (W/m2)
Mean Annual Cycle
BSRN: 114.1
Heliosat: 119.2
Month
Correlation
Intercept: 0.523
Slope: 1.04
Pearson: 0.997
Kendall: 0.933
Heliosat SIS (W/m2)
BSRN SIS (W/m2)
Bias (Heliosat - BSRN)
mean: 5.12 W/m2
Bias (W/m2)
Histogram of the Bias
#: 81
Bias: 5.12
Abs. Bias: 6.64
RMS: 9.42
RMSE (corr): 7.9
var (corr): 7.95
Frequency
Bias (W/m2)
Correlation of Anomalie
Intercept: 9.32e-16
Slope: 0.862
Correlation: 0.923
Heliosat Anomalie SIS (W/m2)
Anomalie BSRN SIS (W/m2)

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9 Appendix B: Glossary

Abbreviation	Explanation
AC	Anomaly correlation
BSRN	Baseline Surface Radiation Network
CDOP	Continuous Development and Operational Phase
CDR	Climate Data Record
CM SAF	Satellite Application Facility on Climate Monitoring
DWD	Deutscher Wetterdienst
ECMWF	European Centre for Medium-Range Weather Forecast
ECV	Essential Climate Variable
Eumetsat	European Organisation for the Exploitation of Meteorological Satellites,
ERA	ECMWF ReAnalysis
FD	Flux dataset (ISCCP)
FRAC	Fraction of days larger than the target value.
GCOS	Global Climate Observing System
GEWEX	Global Energy and Water Cycle Experiment
ISCCP	International Satellite Cloud Climatology Project
MAD	Mean absolute deviation for the monthly, daily or hourly meas
SD	Standard deviation
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SID	Surface Incoming Direct radiation, commonly called direct irradiance
SIS	Surface Incoming Solar radiation, commonly called global irradiance or surface solar irradiance
SRB	Surface Radiation Budget