EUMETSAT Satellite Application Facility on Climate Monitoring

EUMETSAT CM SAF CLIMATE MONITORING

Validation Report

ICDR SEVIRI Radiation based on SARAH-2 methods

Surface Incoming Shortwave Radiation (SIS)   **CM-5210**

Surface Direct Irradiance (SDI)   **CM-5230**

Sunshine Duration (SDU)   **CM-5280**

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TABLE OF CONTENTS

	Validation Report **ICDR SEVIRI Radiation** **based on SARAH-2 methods**	Doc.No.: SAF/CM/DWD/ICDR/SEV/RAD/VAL
![EUMETSAT CM SAF CLIMATE MONITORING logo]		Issue: 1.3 Date: 31.10.2018

List of Figures

List of Tables

Applicable Documents

Reference	Title	Code
AD 1	CM SAF Product Requirement Document	SAF/CM/DWD/PRD/3.0

Reference Documents

Reference	Title	Code
RD 1	Algorithm Theoretical Baseline Document (ATBD) ICDR SEVIRI Radiation based on SARAH-2 methods	SAF/CM/DWD/ICDR/SEV/RAD/ATBD/1.0
RD 2	Product User Manual (PUM) ICDR SEVIRI Radiation based on SARAH-2 methods	SAF/CM/DWD/ICDR/SEV/RAD/PUM/1.0
RD 3	Algorithm Theoretical Baseline Document (ATBD), Meteosat Solar Surface Radiation and effective Cloud Albedo Climate Data Sets METEOSAT_HEL, The MAGICSOL method	SAF/CM/DWD/ATBD/METEOSAT_HEL
RD 4	Validation Report ICDR SEVIRI Radiation	SAF/CM/DWD/ICDR/SEV/RAD/VAL/1.1

Executive Summary

An ICDR (Interim Climate Data Record) is meant to provide near-real time information in line with a corresponding CDR (Climate Data Record). The new "ICDR SEVIRI Radiation based on SARAH-2 methods" (ICDR SEVIRI Radiation) is the near-real time continuation of the CDR Surface Solar Radiation Data Set - Heliosat, Edition 2.1 (SARAH-2.1). The ICDR SEVIRI Radiation consists of the Solar Surface Irradiance (SIS, CM-5210), Surface Direct Irradiance (SDI, CM-5230) and the Sunshine Duration (SDU, CM-5280). The ICDR SEVIRI Radiation is based on the SEVIRI instruments on board the Meteosat satellite series (starting in 2018 using Meteosat-10). All ICDR SEVIRI Radiation parameters are validated and the results are shown in this report.

The radiation parameters of the ICDR SEVIRI Radiation have been validated using ground based observations from the Baseline Surface Radiation Network (BSRN) as a reference. For the sunshine duration station measurements from the CLIMAT and ECAD data bases are used.

The mean absolute differences of the monthly mean ICDR SEVIRI SIS and the SDI parameters in comparison with the BSRN surface reference measurements are 4.8 W/m^2 and 9.9 W/m^2 (for SID) / 19.1 W/m^2 (for DNI), respectively.

The daily mean data of the surface incoming solar radiation (global irradiance) have a mean absolute difference of 11.3 W/m². The mean absolute difference of the daily mean direct radiation irradiance parameters is 18.9 W/m^2 (for SID) and 34.5 W/m^2 (for DNI). Overall, these accuracies are in line with the requirements from the PRD and are consistent with those from the corresponding SARAH-2.1 data records.

The validation of the ICDR SEVIRI Radiation 30-minutes instantaneous data versus BSRN reveals mean absolute differences in the range from 48 to 108 W/m^2.

Further the ICDR SEVIRI radiation data is checked for consistency with its corresponding CDR (SARAH-2.1). Therefore the CDR and the ICDR are both validated with reference to the same BSRN stations. The consistency is checked through analyzing the time series of the CDR+ICDR combination for the years 2014 to 2018. The ICDR SEVIRI radiation parameters fit well to the corresponding SARAH-2.1 CDR.

1   The EUMETSAT SAF on Climate Monitoring (CM SAF)

The importance of climate monitoring with satellites was recognized in 2000 by EUMETSAT Member States when they amended the EUMETSAT Convention to affirm that the EUMETSAT mandate is also to "contribute to the operational monitoring of the climate and the detection of global climatic changes". Following this, EUMETSAT established within its Satellite Application Facility (SAF) network a dedicated center, the SAF on Climate Monitoring (CM SAF, http://www.cmsaf.eu).

The consortium of CM SAF currently comprises the Deutscher Wetterdienst (DWD) as host institute, and the partners from the Royal Meteorological Institute of Belgium (RMIB), the Finnish Meteorological Institute (FMI), the Royal Meteorological Institute of the Netherlands (KNMI), the Swedish Meteorological and Hydrological Institute (SMHI), the Meteorological Service of Switzerland (MeteoSwiss), the Meteorological Service of the United Kingdom (UK MetOffice) and the Centre national de la recherche scientifique (CNRS) of France. Since the beginning in 1999, the EUMETSAT Satellite Application Facility on Climate Monitoring (CM SAF) has developed and will continue to develop capabilities for a sustained generation and provision of Climate Data Records (CDR's) derived from operational meteorological satellites.

In particular the generation of long-term data records is pursued. The ultimate aim is to make the resulting data records suitable for the analysis of climate variability and potentially the detection of climate trends. CM SAF works in close collaboration with the EUMETSAT Central Facility and liaises with other satellite operators to advance the availability, quality and usability of Fundamental Climate Data Records (FCDRs) as defined by the Global Climate Observing System (GCOS). As a major task the CM SAF utilizes FCDRs to produce records of Essential Climate Variables (ECVs) as defined by GCOS. Thematically, the focus of CM SAF is on ECVs associated with the global energy and water cycle.

Another essential task of CM SAF is to produce data records that can serve applications related to the new Global Framework of Climate Services initiated by the WMO World Climate Conference-3 in 2009. CM SAF is supporting climate services at national meteorological and hydrological services (NMHSs) with long-term data records but also with data records produced close to real time, so-called Interim Climate Data Records (ICDRs), that can be used to prepare monthly/annual updates of the state of the climate, and to apply a climate monitoring. Both types of products together allow for a consistent description of mean values, anomalies, variability and potential trends for the chosen ECVs. CM SAF ECV data records also serve the improvement of climate models both at global and regional scale.

As an essential partner in the related international frameworks the CM SAF assumes the role as main implementer of EUMETSAT's commitments in support to global climate monitoring. This is achieved through:

- Application of highest standards and guidelines as lined out by GCOS for the satellite data processing,

- Processing of satellite data within an international collaboration benefiting from developments at international level and pollinating the partnership with own ideas and standards,

- Intensive validation and improvement of the CM SAF climate data records,

- Taking a major role in data record assessments performed by research organisations such as WCRP (World Climate Research Programme),

- Maintaining and providing an operational and sustained infrastructure that can serve the community within the transition of mature CDR products from the research community into operational environments.

A catalogue of all available CM SAF products is accessible via the CM SAF webpage, www.cmsaf.eu. Here, detailed information about product ordering, add-on tools, sample programs and documentation is provided.

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 35 year long (1983-2017) continuous surface radiation climate data record based on observations from the Meteosat First and Second Generation satellites: Surface Solar Radiation Data record – Heliosat Edition 2.1 (SARAH-2.1, doi: 10.5676/EUM_SAF_CM/SARAH/V002_01).

Table 2-1: *Overview of CM SAF data used in this report.*

Parameter	ICDR SEVIRI Radiation based on SARAH-2 methods	SARAH-2.1
SIS	CM-5210	CM-23205
SDI (SID,DNI)	CM-5230	CM-23295
SDU	CM-5281	CM-23283

Starting 2018 the "Interim Climate Data Record (ICDR) SEVIRI based on SARAH-2 methods" is available that contains the surface incoming solar radiation (SIS), the surface incoming direct radiation (SDI) and the sunshine duration (SDU). The validation of these ICDRs (see Table 2-1) is described in this document.

Data from the visible channels of the SEVIRI instruments on-board EUMETSAT's geostationary METEOSAT satellites of the Second Generation are used. The SIS and SDI parameters are processed using methods similar to the ones used to generate the corresponding SARAH-2.1 Climate Data Record, in order to allow for a seamless continuation of specific CDR parameters using the ICDR.

The used algorithm is based on a climate version of the Heliosat algorithm to obtain information about the effective cloud albedo (Cano et al. 1986; Posselt et al. 2012, Mueller et al., 2015). The effective cloud albedo is used as input for the Spectral Mesoscale Atmospheric Global Irradiance Code (SPECMAGIC), which calculates the clear sky radiation and considers the effect of the effective cloud albedo on the irradiance. SPECMAGIC is a sophisticated eigenvector look-up table method (Mueller et al. 2009). Heliosat is extended by the addition of a self-calibration method accounting for changes in the satellites (switches, degradation) and a modification in the determination of the surface albedo. Details of the retrieval method can be found in the ATBD [RD.1]. More information on the products can be found in the PUM [RD.2].

In this document the ICDR SEVIRI Radiation is validated with high-quality surface measurements given by the Baseline Surface Radiation Network (BSRN). The ICDR

sunshine duration is validated with corresponding station-based measurements from CLIMAT and ECAD.

Example maps of the ICDR SEVIRI SIS, SDI and SDU data records are presented in Figure 2-1. The effect of clouds on radiation is very well depicted (especially for direct radiation). Quantitative information on the quality of the ICDR SEVIRI Radiation is provided in the following sections. In Section 3 the validation procedure is described and the validation results including a stability analysis versus the corresponding Climate Data Record SARAH-2.1 are presented in Section 4. Conclusions are drawn in Section 5.
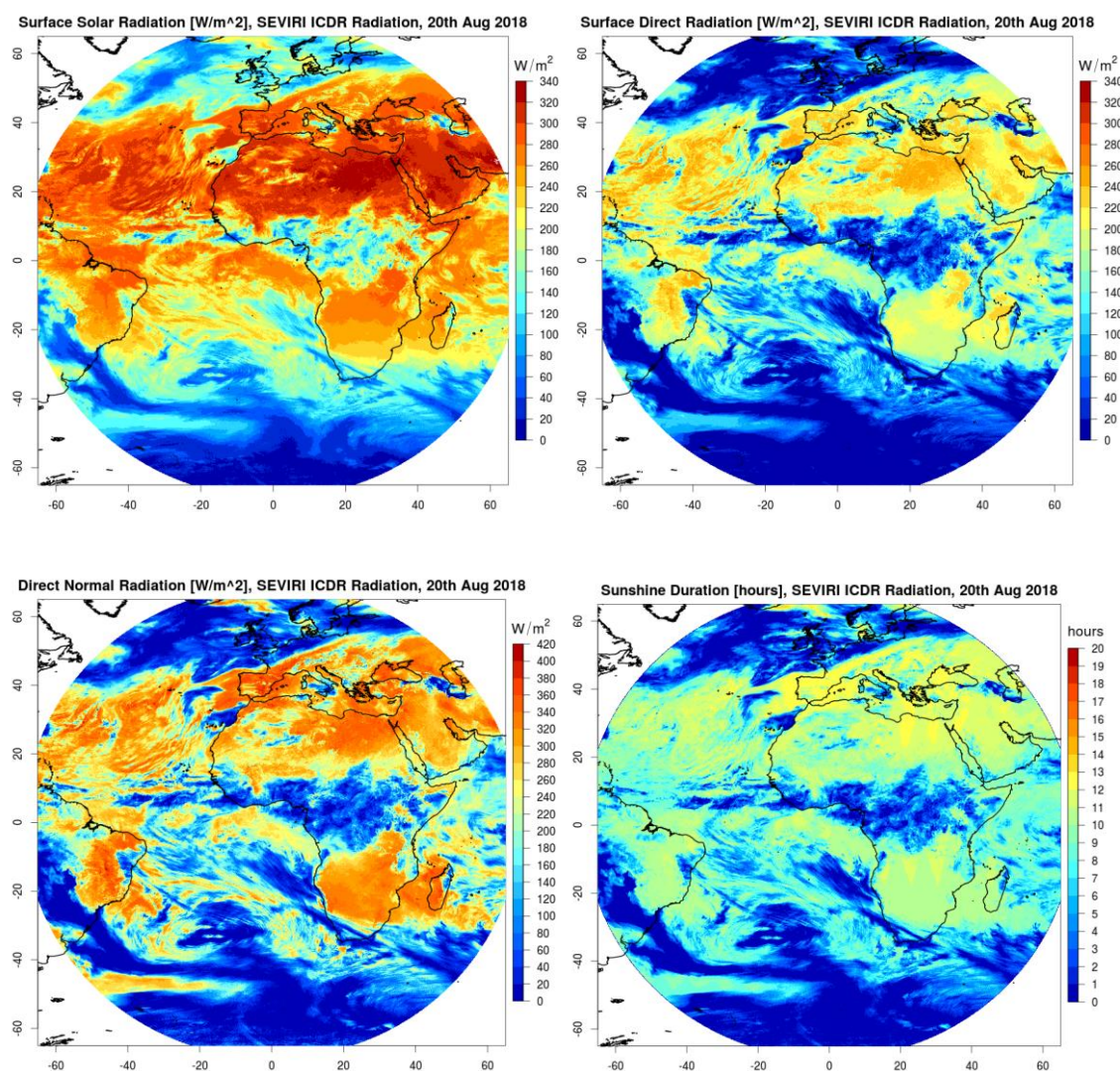
Figure 2-1: *Daily means of SIS (top left), and of the SDI Parameters SID (top right) and DNI (bottom left), and SDU (bottom right) from the ICDR SEVIRI Radiation for 2018-08-20.*

3 Validation procedure

3.1 Validation data

The validation of the data from the ICDR SEVIRI Radiation based on SARAH-2 methods for the surface incoming solar radiation (SIS) and the surface incoming direct solar radiation parameters (SDI) 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 Table 3-1.

Table 3-1: *List of BSRN stations used for the validation of the ICDR SEVIRI data.*

Station	Country	Code	Latitude [°N]	Longitude [°E]	Elevation [m]
Cabauw	Netherlands	Cab	51.97	4.93	0
Carpentras	France	Car	44.05	5.03	100
Cener	Spain	Cnr	42.82	-1.60	471
De Aar	South Africa	Daa	-30.67	23.99	1287
Florianopolis	Brasil	Flo	-27.53	-48.52	11
Gobabeb	Namibia	Gob	-23.56	15.04	407
Palaiseu Cedec	France	Pal	48.71	2.21	156
Payerne	Switzerland	Pay	46.81	6.94° E	491
Tamanrasset	Algeria	Tam	22.78	5.51	1385
Toravere	Estonia	Tor	58.25	26.46	70

The BSRN data has been obtained from the BSRN archive at the Alfred Wegener Institute (AWI), Bremerhaven, Germany (www.bsrn.awi.de). In a first step the BSRN data has been quality controlled using the tests suggested by (Long and Shi 2008). To ensure a high quality of the reference data record, only those BSRN measurements that pass the limit tests are considered in the calculation of the daily and monthly averages. To derive monthly- and daily-averaged values from the surface measurements, the method M7 proposed by (Roesch et al. 2010) was employed to reduce the impact of missing values. By applying method M7, averages for each 15-min UTC interval are calculated from the 1-min mean BSRN data for each day and month, respectively. To derive the daily / monthly means the 96 bins (96 x 15 min = 24 h) for the corresponding day / month are averaged; the averages are only valid if all bins contain valid values. Deriving the monthly mean diurnal cycle of the shortwave fluxes allow more accurate estimates of monthly means, in particular for incomplete observations. The uncertainty of the temporally averaged global irradiance based on BSRN measurements is estimated to be ±10 W/m2 at hourly time scale and ±4 W/m2 at monthly time scale

(Raschke et al. 2012). To validate the instantaneous SEVIRI ICDR Radiation data with BSRN measurements, the 1-min BSRN data are temporally averaged using a centered 11-min rolling mean to account for the grid-box to point comparison problem.

To assess the quality of the satellite data with the BSRN surface observations, the difference in the spatial representativeness between these two observing systems needs also to be considered. Depending on the local spatial distribution of surface radiation the impact can be in the range of 4 W/m2 for monthly mean data (Hakuba et al. 2013) and even larger for daily mean surface radiation data. Due to its higher temporal and spatial variability it must be assumed that the level of uncertainty of the direct normal radiation is larger than the level of uncertainty for the irradiance.

For evaluation of the Sunshine Duration (SDU), data from the European Climate Assessment & Datasets (ECA&D) and from the CLIMAT climate observation station network were used in this study. ECA&D (Klein et al., 2002) is gathering long-term daily observational series from meteorological stations all over Europe. Some automatic quality control and homogeneity checks are applied to the data. Due to some national restrictions only a part of the ECA&D data is downloadable. In contrast, the main application for CLIMAT data is climate analyses and these data are therefore monthly totals. The CLIMAT data undergo routine quality control at DWD. Additionally some basic visual checks were applied to extract suspicious stations. CLIMAT and ECA&D sunshine duration data are only available for land-based stations. ECA&D and CLIMAT station data are available for a relatively high number of stations, but despite quality checks, there is no guarantee that these data are bias free. Stations were removed from the analysis if they reported apparently erroneous data, such as fixed zeros, permanently high values throughout the year or obvious jumps in the time series. CLIMAT data were accessed via the DWD Climate Data Centre.

Table 3-2: *Accuracy [W/m^2] (SDU: [h]) and decadal stability [W/m^2/decade] (SDU: [h/dec]) requirements (threshold (Thr), target (Tar) and optimal (Opt)) for monthly and daily averaged, and 30-min instantaneous data from the SEVIRI ICDR Radiation data (SIS, SDI (SID and DNI), SDU);*

	SIS [W/m^2]			SID [W/m^2]			DNI [W/m^2]			SDU [h]		
accuracy	Th	Ta	Op	Th	Ta	Op	Th	Ta	Op	Th	Ta	Op
monthly	15	8	5	15	10	8	20	15	12	30	20	10
daily	20	15	12	25	20	15	30	25	20	2.0	1.5	1.0
instantaneous	50	30	20	80	60	40	100	80	60	/	/	/

To achieve a sufficient level of consistency between the new SEVIRI ICDR Radiation and its corresponding Climate Data Record, both needs to be compared and the common time series CDR+ICDR needs to be analyzed.

3.2 Statistical measures

The validation employs several statistical measures and scores to evaluate the quality of the SIS and SDI data records. Beside the commonly used bias and standard deviation, here also the (mean) absolute deviation is used. Bias and standard deviation alone do not provide sufficient information of the climate quality of a data record. For each data record the number of months (or days) that exceed the target accuracy to characterize the quality of the data records are provided. In the following chapters the applied quality measures are described. Thereby, the variable 'y' describes the data record to be validated (e. g. ICDR SEVIRI) and 'o' denotes the reference data record (i. e., BSRN). The individual time step is marked with 'k' and 'n' is the total number of time steps.

Bias

The bias (also called mean error) is defined as the mean difference between the average of two data records, resulting from the arithmetic mean of the difference over the members of the data records. It indicates whether the data record on average over- or underestimates the reference data record.

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

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 data record.

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

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 data record.

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

14

Fraction of time steps above the validation target values

A measure for the uncertainty of the derived data record is the fraction of the time steps that are outside the requested target value 'T'. The target values are given by the threshold / target accuracies of the corresponding CM SAF product, plus the non-systematic error (uncertainty) of the BSRN measurements (Ohmura et al. 1998).

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

15

4   Validation results

In this section the validation results of the new ICDR SEVIRI Radiation are presented. This includes the Surface Incoming Solar Radiation (SIS), the surface incoming direct irradiance (SDI) parameters SID and DNI, the Sunshine Duration (SDU). For the evaluation of the quality of the ICDR SEVIRI Radiation data, also comparisons with its corresponding Climate Data Record SARAH-2.1 are included. For each parameter and temporal resolution the time period considered is 2014-2018 for SARAH-2.1 and 2018 for the ICDR.

For the comparison with the BSRN data the daily and monthly means from the ICDR and corresponding TCDR are compared with the respective daily and monthly means derived from the BSRN measurements. The means of the BSRN stations have been derived independently using the complete temporal resolution (minutes) of the BSRN station measurements. The comparison results are shown by the mean bias, mean absolute difference, anomaly correlation, standard deviation and fraction of months above a given threshold for the individual stations and for all stations together.

For the validation of the 30-min instantaneous data the BSRN station data is averaged of a time window of ±11 minutes in order to account for the issue of comparing points to grid-boxes.

In order to match the threshold / target accuracy the mean absolute deviation should be below the threshold / target accuracy and 90% of the monthly (daily) means should be below the threshold / target accuracy plus the uncertainty of the surface measurements. Further the correlation and standard deviation are provided.

The result section is divided into the SIS and SDI validation results of monthly, daily and instantaneous data. The validation of SDU is presented in the last part of the result section.

4.1   Monthly Means

The results of the validation of the monthly mean ICDR SEVIRI SIS and SDI (SID and DNI) parameters are summarized in Table 4-1. To be able to get an overview of the consistency between the ICDR and underlying TCDR, Table 4-1 also includes the validation results of the corresponding SARAH-2.1 Climate Data Record (CDR) for the time period 2014-2017 for the same BSRN stations.

The results show that the mean absolute difference (MAD) of the ICDR SEVIRI SIS is 5.07 W/m^2, which documents the high accuracy of the ICDR SEVIRI radiation that is at the same quality level than the corresponding. The anomaly correlation with the BSRN data is high for both ICDR and TCDR. It should be noted that there is an overall small positive bias of the ICDR relative to the CDR and the BSRN stations. However it should be kept in mind that the analyzed time periods are differing.

Table 4-1: *Results of the comparison between the monthly mean SIS and SDI parameters derived from BSRN measurements and the corresponding ICDR SEVIRI Radiation and SARAH-2.1. Included are the number of analyzed months, the bias, the mean absolute bias and the standard deviation.*

	data	Nmon	Bias [W/m2]	MAD [W/m2]	SD [W/m2]
SIS	**ICDR**	52	3.74	5.07	5.37
	SARAH-2.1	412	1.65	5.26	7.15
SID	**ICDR**	46	2.33	10.04	13.4
	SARAH-2.1	407	-0.52	9.26	13.6
DNI	**ICDR**	46	2.89	21.7	25.9
	SARAH-2.1	408	-1.54	18.3	24.4

An illustration of the mean bias and the MAD with reference to the BSRN stations is shown in Table 4-1. The box-whisker plots represent the range between the 25% and 75% percentiles (1st and 3rd quartile) by the colored boxes; the whiskers extend to 1.5 times the interquartile range or the maximum value, whichever is smaller. Overall the new ICDR SEVIRI Radiation data is close to the data given by the SARAH-2.1 CDR. As already seen in Table 4-1, the ICDR SEVIRI Radiation tends to an overestimation relative to BSRN and relative to SARAH-2.1 for the radiation parameters SIS, SID an DNI by about 2-3 W/m2 also at the individual stations. Deviations can be larger at specific stations, e.g. at dessert stations. Parts of this difference might be also explained by the different time periods and months considered. The mean absolute deviations and standard deviations are similar for the ICDR and SARAH-2.1 radiation parameters.

By looking at Figure 4-1 to Figure 4-3 it is visible that the general behavior of the ICDR and its corresponding CDR is quite similar at the individual stations, which means that both data records have similar spatial error characteristics. This in turn means that the ICDR and its corresponding CDR have a high degree of consistency. Further information on the consistency are given in Section 4.5.
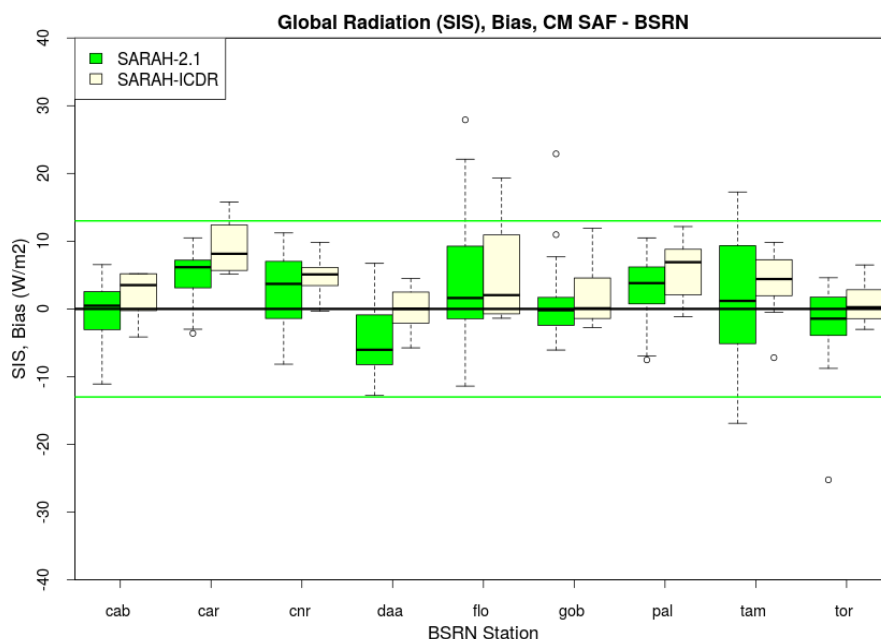
Figure 4-1: *Results of the validation of the monthly mean global radiation (SIS) of ICDR SEVIRI Radiation (2018) and SARAH-2.1 (2014-2017) with reference to BSRN measurements; Shown it the bias as boxplots for the individual BSRN stations used; Green lines denote the corresponding ICDR SEVIRI target accuracy.*
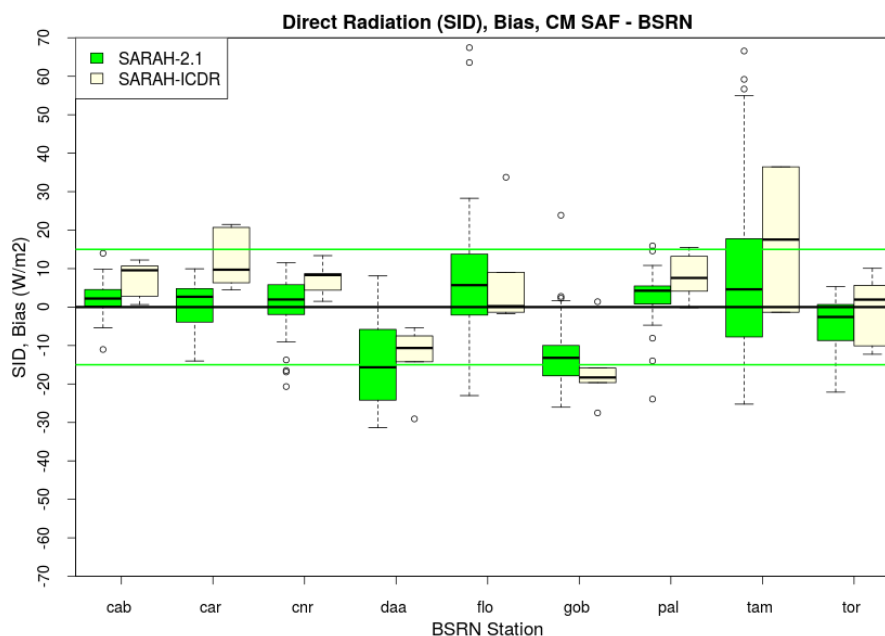
Figure 4-2: *Results of the validation of the monthly mean direct radiation (SID) of ICDR SEVIRI Radiation (2018) and SARAH-2.1 (2014-2017) with reference to BSRN measurements; Shown it the bias as boxplots for the individual BSRN stations used; Green lines denote the corresponding ICDR SEVIRI target accuracy.*
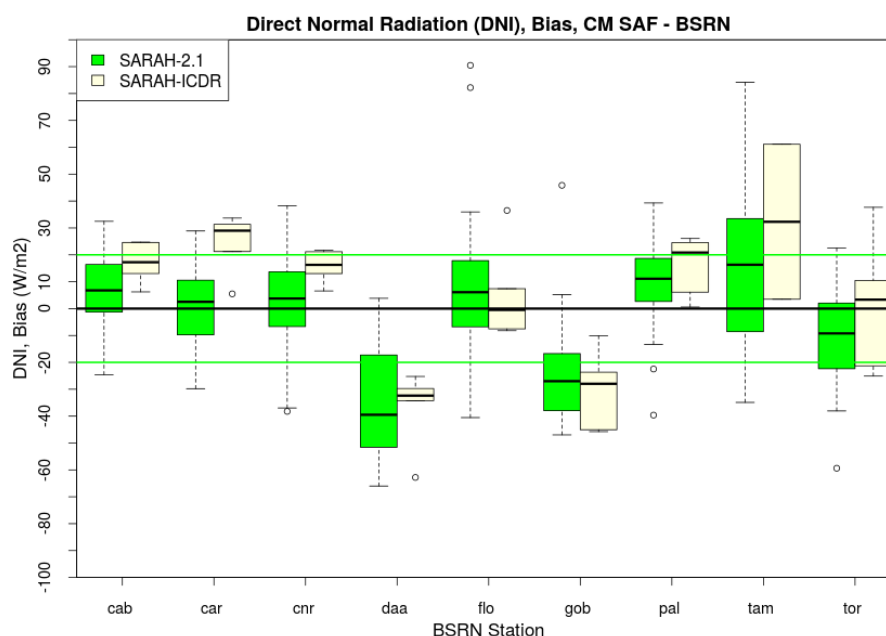
Figure 4-3: *Results of the validation of the monthly mean direct normal radiation (DNI) of ICDR SEVIRI Radiation (2018) and SARAH-2.1 (2014-2017) with reference to BSRN measurements; Shown it the bias as boxplots for the individual BSRN stations used; Green lines denote the corresponding ICDR SEVIRI target accuracy.*

4.2   Daily means

Table 4-2 provides the validation result for the daily means of the ICDR SEVIRI Radiation data and for the corresponding SARAH-2.1 climate data record. As expected, the mean biases are similar to the values derived for the monthly means, while the mean absolute difference values for the daily means are about twice as high compared to those for the monthly means. For the measure of MAD, the ICDR SEVIRI Radiation parameters perform better than its corresponding CDR, which might be a result of the new integrated water vapor input in daily resolution (compared to monthly resolution in the case of SARAH-2.1). The correlations between the ICDR and CDR and the BSRN stations are overall very high. The fraction of deviations above the target accuracy is increasing from the global radiation to the direct radiation parameters. The largest absolute deviations are found for the direct normal radiation (DNI) at dessert stations (see Figure 4-6).

As for the monthly means, it can be assumed that the spatial error characteristics are consistent between the ICDR SEVIRI Radiation at its corresponding CDR SARAH-2.1.

Table 4-2: *Results of the comparison between the daily mean SIS and SDI parameters derived from BSRN measurements and the corresponding ICDR SEVIRI Radiation and SARAH-2.1. Included are the number of analyzed months, the bias, the mean absolute bias and the standard deviation.*

	data	Nday	Bias [W/m2]	MAD [W/m2]	SD [W/m2]	Cor	$Frac_{day}$ > Thresh.
SIS	**ICDR**	1528	3.32	9.7	13.5	0.97	6.87
	SARAH-2.1	12047	1.55	11.6	16.3	0.96	9.84
SID	**ICDR**	1344	0.98	16.1	22.9	0.95	17.0
	SARAH-2.1	11740	-0.57	19.6	28.0	0.92	23.3
DNI	**ICDR**	1329	1.76	31.8	41.9	0.95	33.0
	SARAH-2.1	11856	-1.38	36.0	48.6	0.92	36.1

The mean bias of the daily means from the ICDR SEVIRI Radiation and the SARAH-2.1 climate data record are shown in Figure 4-4 to Figure 4-6 applying boxplots.

Figure 4-4: *Results of the validation of the daily mean global radiation (SIS) of ICDR SEVIRI Radiation (2018) and SARAH-2.1 (2014-2017) with reference to BSRN measurements; Shown it the bias as boxplots for the individual BSRN stations used; Green lines denote the corresponding ICDR SEVIRI target accuracy.*
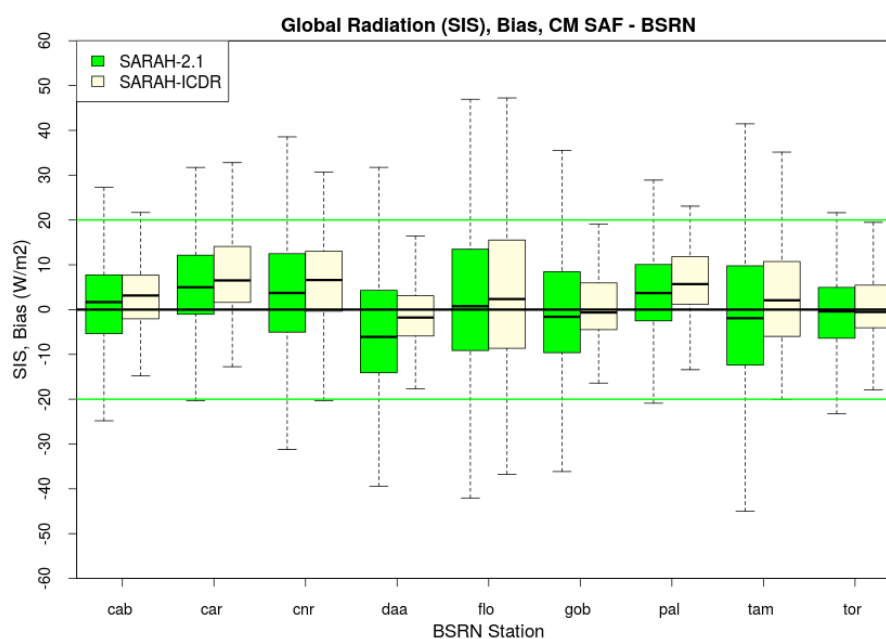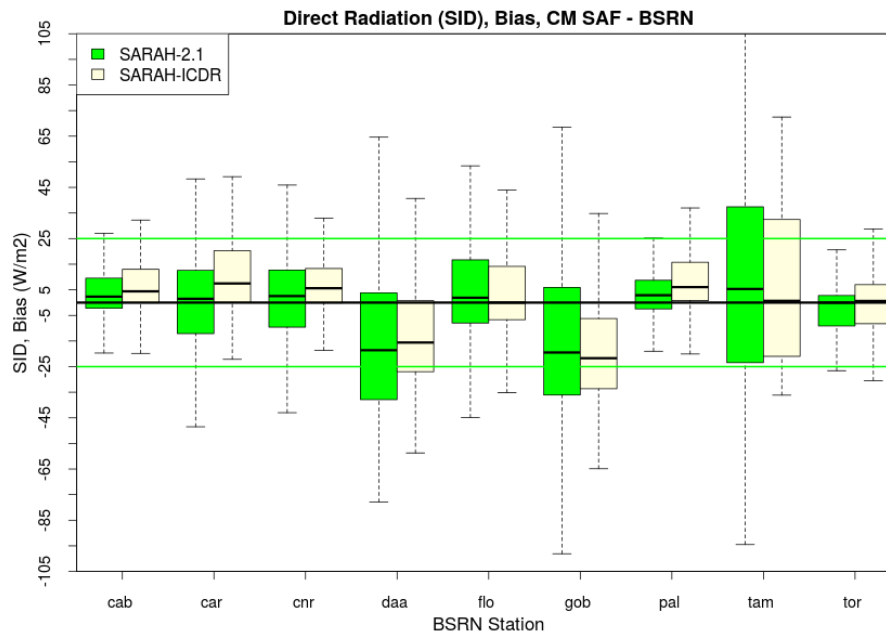
Figure 4-5: *Results of the validation of the daily mean direct radiation (SID) of ICDR SEVIRI Radiation (2018) and SARAH-2.1 (2014-2017) with reference to BSRN measurements; Shown it the bias as boxplots for the individual BSRN stations used; Green lines denote the corresponding ICDR SEVIRI target accuracy.*
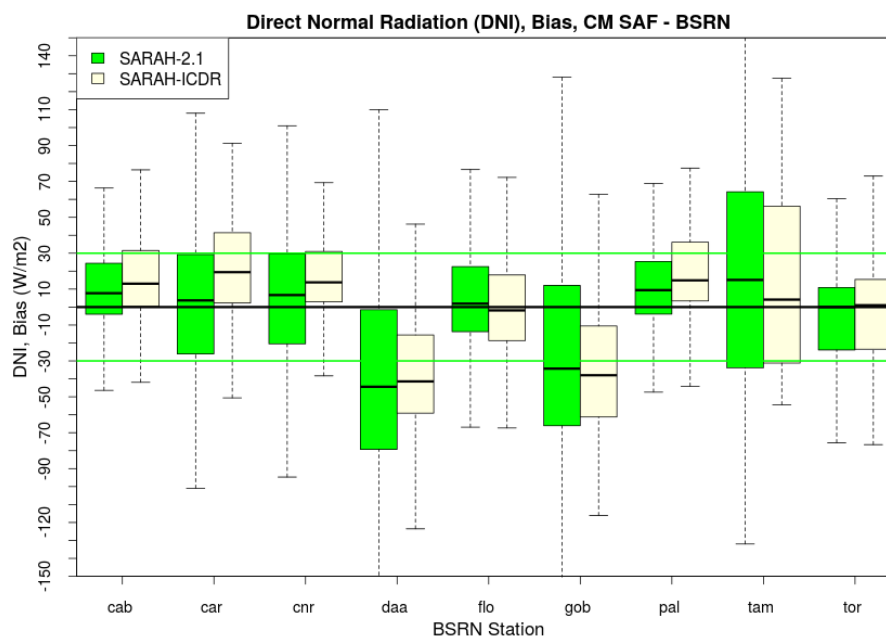
Figure 4-6: *Results of the validation of the daily mean direct normal radiation (DNI) of ICDR SEVIRI Radiation (2018) and SARAH-2.1 (2014-2017) with reference to BSRN measurements; Shown it the bias as boxplots for the individual BSRN stations used; Green lines denote the corresponding ICDR SEVIRI target accuracy.*

4.3 Instantaneous data

Table 4-3 provides the validation result for the 30-min instantaneous ICDR SEVIRI Radiation data (2018) and for the corresponding SARAH-2.1 climate data record (2014-2017). As expected, the validation results show larger deviation of the instantaneous data relative to the monthly and daily means. Here, the spatial and temporal variability of the surface incoming solar radiation leads to substantial uncertainties when comparing point to gridded data, which is particularly affecting the validation of the direct radiation. The Table 4-3 provides information on the bias, the mean absolute deviations and the correlation coefficient.

It should be mentioned that the values in Table 4-3 correspond to the daytime only comparisons of the satellite and station data. The full-day values are additionally shown in the Figure 4-7 to Figure 4-9, which show the scatter of the ICDR SEVIRI Radiation and the BSRN measurements.

Table 4-3: *Results of the comparison between the 30-min instantaneous daytime surface solar irradiance derived from BSRN measurements and the CM SAF SEVIRI ICDR Radiation. Included are the number of analyzed time steps, the bias, the mean absolute deviation and the correlation.*

	data	N	Bias [W/m2]	MAD [W/m2]	Cor
SIS	**ICDR**	37499	6.83	48.9	0.98
	SARAH-2.1	289156	4.19	51.1	0.98
SID	**ICDR**	32426	2.14	54.4	0.95
	SARAH-2.1	285357	-0.98	60.2	0.95
DNI	**ICDR**	32610	4.13	107.5	0.93
	SARAH-2.1	288088	-1.74	115.3	0.93

Figure 4-7 to Figure 4-9 show the Scatterplots of the validation of the instantaneous ICDR SEVIRI data (2018) and the SARAH-2.1 data (2014-2017) for the parameters SIS, SID an DNI for the ICDR SEVIRI Radiation (left side) and the SARAH-2.1 climate data record (right side). Even though the spread relatively large for the 30-min data, the distribution is overall close to the 1:1-line. An exception is DNI, which shows the tendency of underestimating high radiation values and overestimating low radiation values resulting in a too small slope of the regression line (see Figure 4-9). The underestimation of direct radiation might be also partly explained by the circumsolar radiation affecting surface measurements of the direct radiation (Blanc et al., 2014).

A reason for these deviations might be related to the point to grid-box comparisons issue at the short time range. At the instantaneous time scale, there might be many cases where at a point clear sunshine occurs, while in the 25 km^2 grid box, some clouds exist. This would imply an underestimation of the satellite product. The opposite case (full shadow at the station, and some clear sky in corresponding grid-box) will be frequent as well, which results in an overestimation of the low direct radiation values.
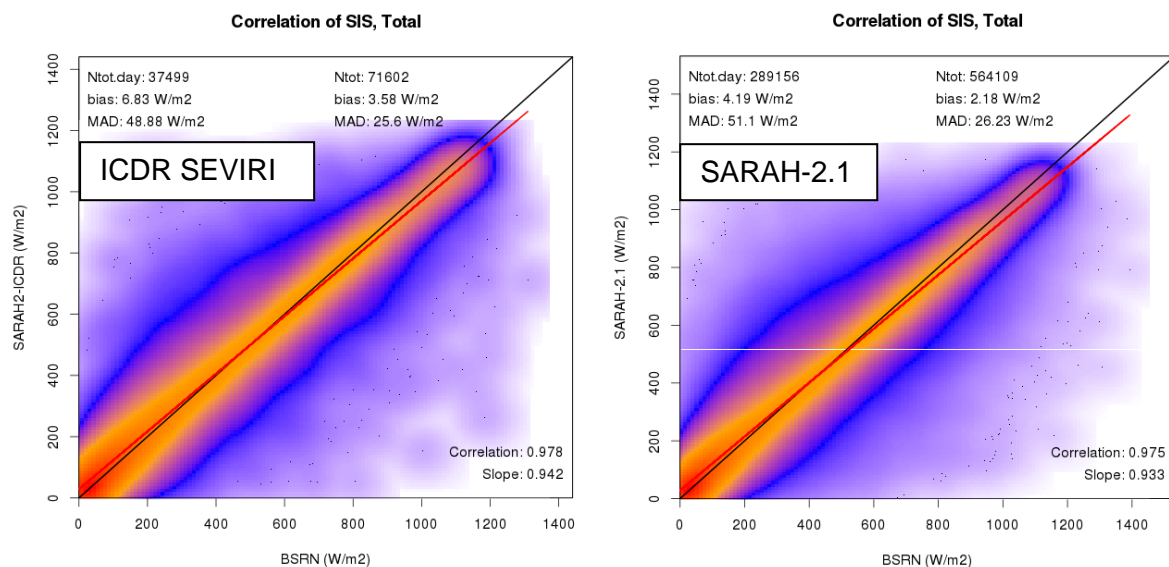
Figure 4-7: *Results of the validation on the 30-min instantaneous global radiation (SIS) of the ICDR SEVIRI (left) (2018) and the SARAH-2.1 CDR (right) (2014-2017) with reference to BSRN surface measurements. Additionally shown are bias [W/m2], MAD [W/m2] and correlations.*
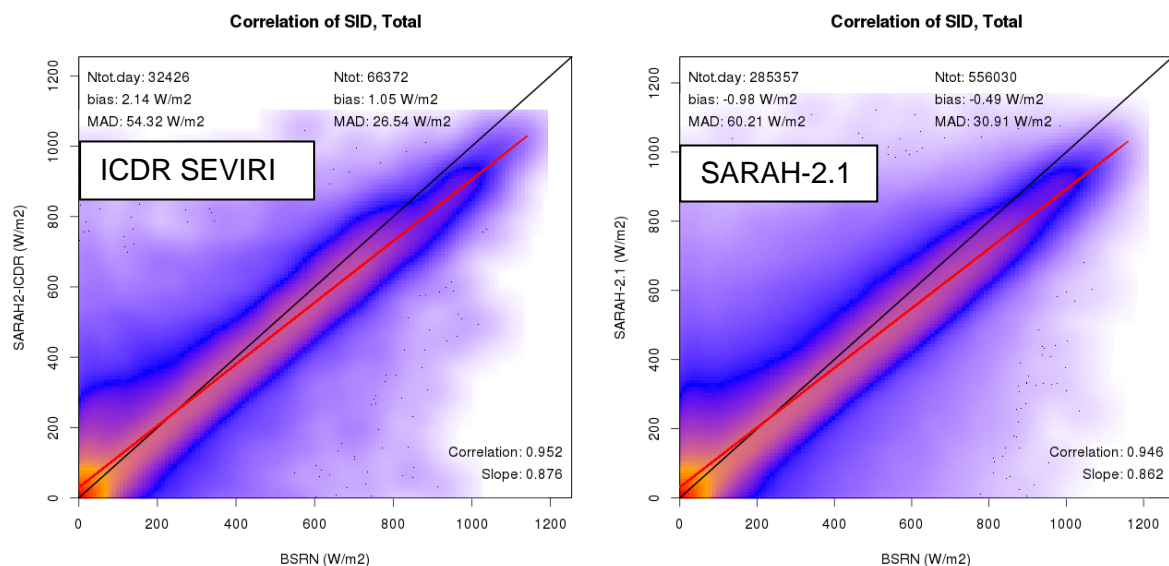
Figure 4-8: *Results of the validation on the 30-min instantaneous direct radiation (SID) of the ICDR SEVIRI (left) (2018) and the SARAH-2.1 CDR (right) (2014-2017) with reference to BSRN surface measurements. Additionally shown are bias [W/m2], MAD [W/m2] and correlations.*
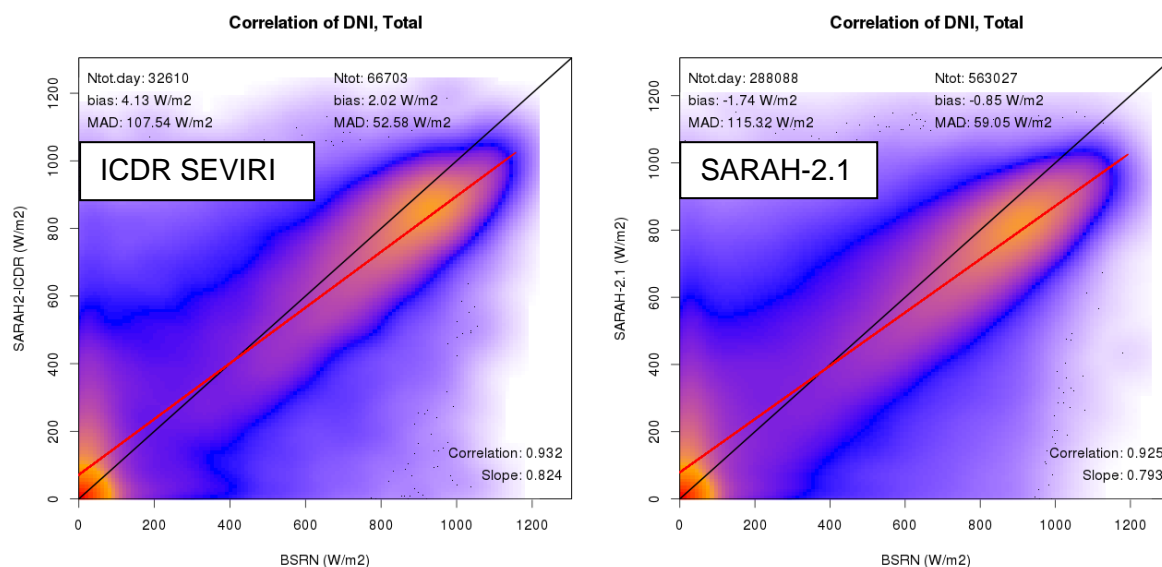
Figure 4-9: *Results of the validation on the 30-min instantaneous direct normal radiation (DNI) of the ICDR SEVIRI (left) (2018) and the SARAH-2.1 CDR (right) (2014-2017) with reference to BSRN surface measurements. Additionally shown are bias [W/m2], MAD [W/m2] and correlations.*

4.4 Sunshine Duration

The sunshine duration (SDU) is defined by the World Meteorological Organisation to occur at a direct irradiance larger than 120 W/m^2. Table 4-4 summarizes the results of the validation of SDU for daily and monthly sum of sunshine. There is overall small positive bias of the ICDR SEVIRI and SARAH-2.1 SDU with reference to station observations by CLIMAT (monthly) and ECA&D (daily), of 11 h and 0.5 h for monthly and daily sums, respectively. The MAD is in the order of 17 h and less than 1 h for monthly and daily SDU, respectively. Overall the validation results are very similar for the ICDR SEVIRI and the corresponding CDR SARAH-2.1, which documents their consistency.

**Table 4-4:** *Results of the comparison between the sunshine duration monthly and daily sums derived from CLIMAT and ECA&D station data, respectively, and the ICDR SEVIRI (2018) and SARAH-2.1 (2014-2017) sunshine duration data.*

Data	Time resolution	N	Bias [h]	MAD [h]	SD [h]
ICDR		1972	11.4	16.8	20
SARAH-2.1	Monthly	19416	11.3	17.0	20
ICDR		39685	0.4	0.9	1.3
SARAH-2.1	Daily	319552	0.5	0.9	1.3

Figure 4-10 shows that the mean absolute deviation of monthly sunshine duration sums is below 20 hours at most stations for the new ICDR SEVIRI Radiation. Higher deviations occur in West Africa and in the Sahel region. Reasons for the higher differences there, might be due to the partly high aerosol load in that regions and due to reduced station data quality.
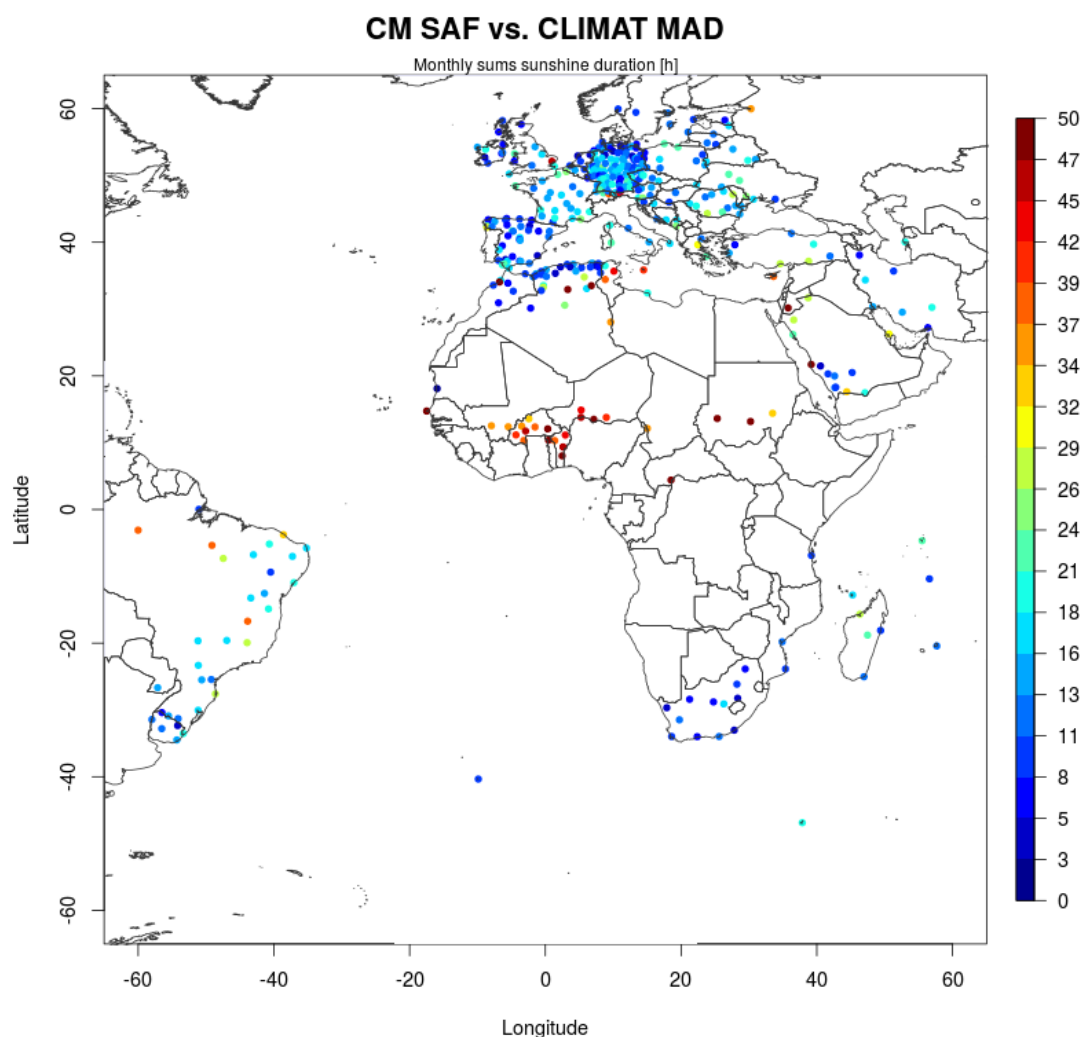
Figure 4-10: *Mean absolute differences (MAD) for the comparison of sunshine duration monthly sums of CLIMAT station data and the ICDR SEVIRI.*

4.5 CDR + ICDR consistency

The concept of long-term climate data record (CDR) and its near-real time continuation using similar algorithms should allow for the valid analysis of anomalies, and in ideal case, the real-time updates of trend assessments. In the past, the CDR and the at that time so-called "CM SAF operational products" used different algorithm for data generation, which lead to larger inconsistencies between the climate data record and the near-real time information. The old concept still allowed anomaly estimations, but a consistent time series that enables for example the analysis of variability and trends over time was not achievable.

Since the new CDR+ICDR concept became operational, the consistency has been improved (see RD 4). In order to demonstrate the consistency achieved, the time series of the SARAH-2.1 CDR for 2014-2017 continued by the new SEVIRI ICDR Radiation (until June 2018) is analyzed by plotting the bias of the satellite data to the BSRN station data over time.

The time series of the bias of SIS, SID and DNI are shown in Figure 4-11 to Figure 4-13. The Figures show that there is no discontinuity or "jump" in the CDR/ICDR combined bias time series for any of the parameters. This underlines the high consistency of the CDR+ICDR SEVIRI Radiation initially documented in RD 4.
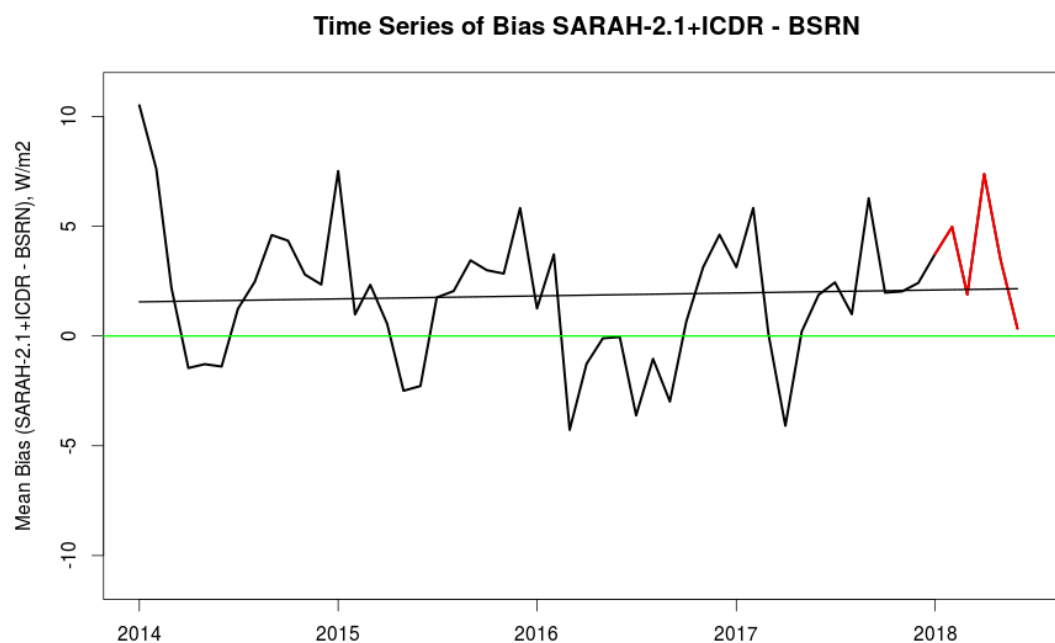
Figure 4-11: *Monthly time series of the bias of the combined SARAH-2.1 and ICDR SEVIRI global radiation (SIS) data for the time period 2014-01 to 2018-06 including its linear trend (black line); The ICDR time period is shown in red.*
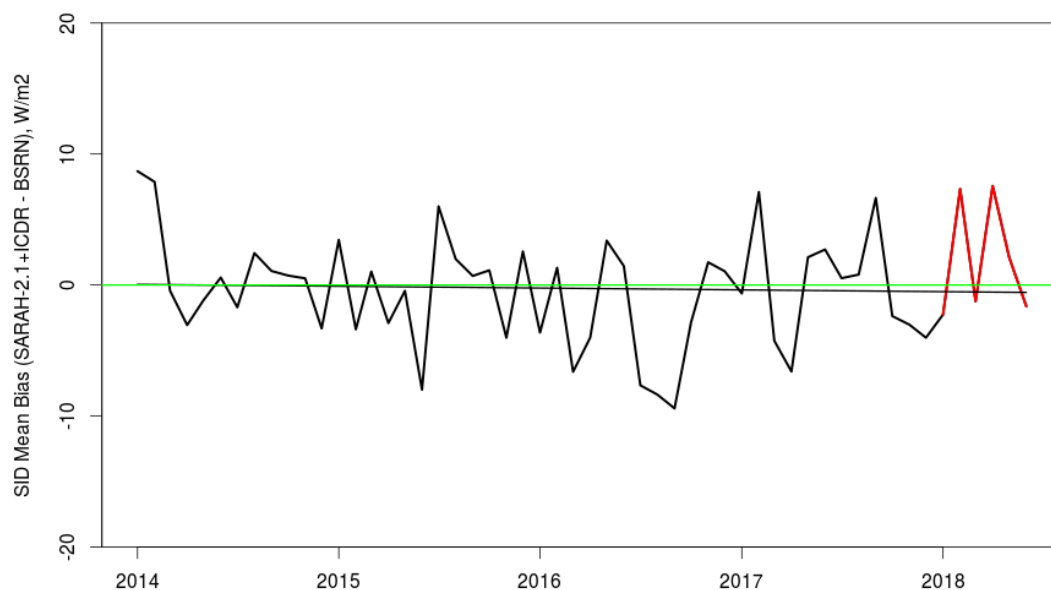
Figure 4-12: *Monthly time series of the bias of the combined SARAH-2.1 and ICDR SEVIRI direct radiation (SID) data for the time period 2014-01 to 2018-06 including its linear trend (black line); The ICDR time period is shown in red.*
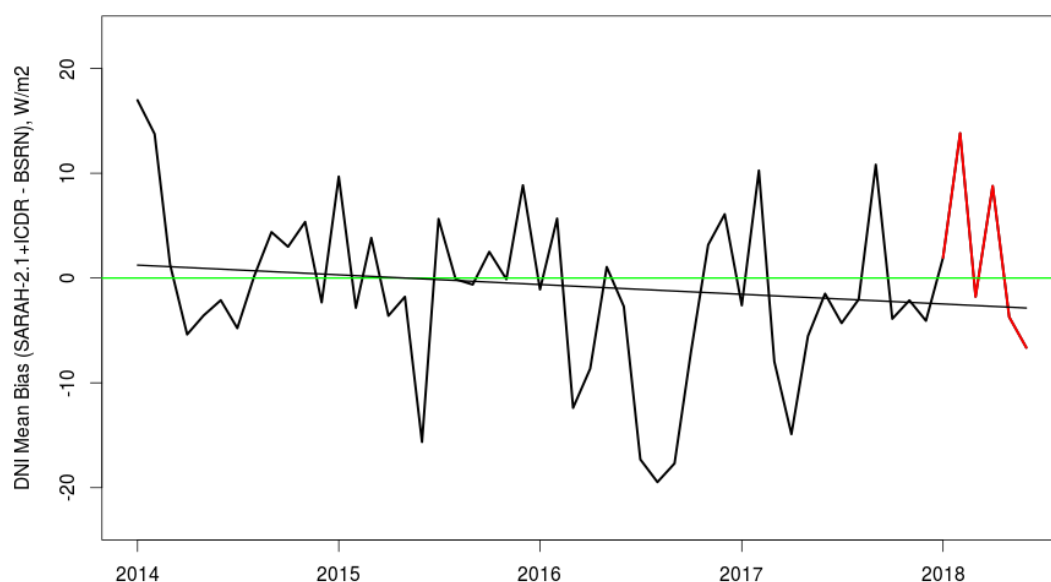

Figure 4-13: *Monthly time series of the bias of the combined SARAH-2.1 and ICDR SEVIRI direct normal radiation (DNI) data for the time period 2014-01 to 2018-06, including its linear trend (black line); The ICDR time period is shown in red.*

4.6   Summary

This Validation Report of the ICDR SEVIRI Radiation based on SARAH-2 methods describes the quality of the ICDR data record. It has been shown by validation with surface measurements from the BSRN that the accuracy of the ICDR SEVIRI Radiation is in line with the requirements and in a similar range as the corresponding SARAH-2.1 Climate Data Record. The ICDR allows continuing the Climate Data Record with high accuracy and reasonable consistency, that now has been possible since the new CDR+ICDR concept is applied.

There is a general small positive bias of the ICDR radiation parameters SIS and SDI in the order of 2-4 W/m^2 with reference to high-quality BSRN station measurements. DNI has almost a zero bias, but its mean absolute deviations are larger than the one of SID and SIS. The mean absolute bias for SIS is found to be 5.07 and 9.7 W/m^2 for the monthly and daily means, respectively. In general, the validation measures of the ICDR are close to the CDR results, which show the good consistency between the ICDR and the CDR. The monthly sum of sunshine duration of the ICDR SEVIRI has a small positive bias of 16 hours, which is in line with corresponding bias of the SARAH-2.1 SDU.

The daily data shows a larger spread than the monthly data. While the biases are similar to the monthly data, the mean absolute deviations are about twice as large as for monthly data. The MAD values range from about 10 to 30 W/m^2 (from SIS to DNI) for the ICDR SEVIRI daily means. The correlation with reference to BSRN measurements ranges from 0.92 to 0.97. The mean absolute deviation of the sunshine duration daily sums is less than 1h.

The validation of the 30-min instantaneous ICDR data shows larger deviations than the daily mean data. While there is little effect on the bias, the mean absolute deviations of the instantaneous data range from 50 to 100 W/m^2 (from SIS to DNI). A substantial part of this deviation is attributable to the uncertainty of validating point to grid-box data at high temporal resolution. Huang et al. (2016) estimates this effect to be on average in the range of 40 W/m^2 for global irradiance at the instantaneous time scale.

The consistency of the ICDR SEVIRI Radiation to its corresponding Climate Data Record SARAH-2.1 is of high importance and the main factor triggering the CDR+ICDR concept applied at the CM SAF. The consistency is shown by the fact that the deviations to the individual BSRN stations of the ICDR and the CDR are very similar. This means that the spatial behavior is consistent. The temporal consistency is shown by analyzing the CDR+ICDR combined time series of the bias with reference to the BSRN stations. There it is shown that no inconsistency or "jump" in the bias time series occurs during the switch from CDR to ICDR (in 2018). This consistency is achieved by applying the same basic algorithms for the generation of the ICDR SEVIRI Radiation and for the corresponding SARAH-2.1 climate data record.

Based on the validation results it is concluded that the ICDR SEVIRI Radiation based on SARAH-2 methods is suitable for the accurate analysis of anomalies. Even though the consistency is found to be high, the user should take care when analyzing trends based on the combined data set of CDR and ICDR, as inhomogeneities cannot be fully excluded

during the transition phase between both data records. If trends need to be determined with highest confidence, it is recommended to solely use the CDR.

5   References

Blanc, P., B. Espinar, N. Geuder, C. Gueymard, R. Meyer, R. Pitz-Paal, B. Reinhardt, D. Renné, M. Sengupta, L. Wald and S. Wilbert, 2014: Direct normal irradiance related definitions and applications: The circumsolar issue. Solar Energy, 110, 561-577.

Bojanowski, J. S., A. Vrieling, and A. K. Skidmore, 2014: A comparison of data sources for creating a long-term time series of daily gridded solar radiation for Europe. Solar Energy, 99, 152-171.

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.

Decoster, I., and Coauthors, 2014: Spectral Aging Model Applied to Meteosat First Generation Visible Band. Remote Sensing, 6, 2534-2571.

Gilgen, H., A. Roesch, M. Wild, and A. Ohmura, 2009: Decadal changes in shortwave irradiance at the surface in the period from 1960 to 2000 estimated from Global Energy Balance Archive Data. Journal of Geophysical Research, 114.

Hagemann, S., A. Loew, and A. Andersson, 2013: Combined evaluation of MPI-ESM land surface water and energy fluxes. Journal of Advances in Modeling Earth Systems, n/a-n/a.

Hakuba, M. Z., D. Folini, A. Sanchez-Lorenzo, and M. Wild, 2013: Spatial representativeness of ground-based solar radiation measurements. Journal of Geophysical Research: Atmospheres, 118, 8585-8597.

Huang, G., X. Lin, C. Huang, S. Liu, Y. Ma and H. Chen, 2016: Representativeness errors of point-scale ground-based solar radiation measurements in the validation of remote sensing products. Remote Sensing of Environment, 181, 198-206.

Klein Tank, A.M.G. and Coauthors, 2002. Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment. Int. J. of Climatol., 22, 1441-1453.

Long, C. N., and Y. Shi, 2008: An Automated Quality Assessment and Control Algorithm for Surface Radiation Measurements. The Open Atmospheric Science Journal, 2, 23 - 37.

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.

Mueller, R., U. Pfeifroth, J. Trentmann, and R. Cremer, 2015: Digging the METEOSAT treasure - 3 Decades of Solar Surface Radiation. Remote Sensing 7(6), 8067-8101.

Norton, M., A. M. G. Amillo, and R. Galleano, 2015, Comparison of solar spectral irradiance measurements using the average photon energy parameter, Solar Energy, 120, 337-344, doi:10.1016/j.solener.2015.06.023.

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.

Posselt, R., R. Müller, R. Stöckli, and J. Trentmann, 2011: CM SAF Surface Radiation MVIRI Data Set 1.0 - Monthly Means / Daily Means / Hourly Means. EUMETSAT Satellite Application Facility on Climate Monitoring (CM SAF).

Posselt, R., R. W. Mueller, R. Stöckli, and J. Trentmann, 2012: Remote sensing of solar surface radiation for climate monitoring — the CM-SAF retrieval in international comparison. Remote Sensing of Environment, 118, 186-198.

Raschke, E., S. Kinne, and P. W. Stackhouse, 2012: GEWEX Radiative Flux Assessment (RFA) Volume 1: Assessment.

Roesch, A., M. Wild, A. Ohmura, E. G. Dutton, C. N. Long, and T. Zhang, 2010: Assessment of BSRN radiation records for the computation of monthly means. Atmospheric Measurement Techniques Discussions, 3, 4423-4457.

Sanchez-Lorenzo, A., M. Wild, and J. Trentmann, 2013: Validation and stability assessment of the monthly mean CM SAF surface solar radiation dataset over Europe against a homogenized surface dataset (1983–2005). Remote Sensing of Environment, 134, 355-366.

6 Glossary

Abbreviation	Explanation
AC	Anomaly correlation
BSRN	Baseline Surface Radiation Network
CAL	Effective Cloud Albedo
CDOP	Continuous Development and Operational Phase
CDR	Climate Data Record
CLIMAT	Climate station data
CM SAF	Satellite Application Facility on Climate Monitoring
DNI	Direct Normal Irradiance
DWD	Deutscher Wetterdienst
ECAD	European Climate Assessement Dataset
ECV	Essential Climate Variable
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FD	Flux dataset (ISCCP)
FRAC	Fraction of days larger than the target value
GCOS	Global Climate Observing System
GEBA	Global Energy Balance Archive
GEWEX	Global Energy and Water Cycle Experiment
ICDR	Interim Climate Data Record
ISCCP	International Satellite Cloud Climatology Project
MAD	Mean absolute deviation for the monthly, daily or hourly means
PRD	Product Requirements Document
SARAH	Surface Solar Radiation Dataset – Heliosat
SD	Standard deviation
SDI	Surface Direct Radiation
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