EUMETSAT Satellite Application Facility on Climate Monitoring

Product User Manual

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**

Reference Number:	SAF/CM/DWD/ICDR/SEV/RAD/PUM/
Issue/Revision Index:	1.3
Date:	31.10.2018

Document Signature Table

	Name	Function	Signature	Date
Author	Jörg Trentmann Uwe Pfeifroth	CM SAF Scientists		31.10.2018
Editor	R. Hollmann	CM SAF Science Coordinator		31.10.2018
Approval	CM SAF SG			04.12.2018
Release	M. Werscheck	Project Manager		17.01.2018

Distribution List

Internal Distribution	
Name	**No. Copies**
DWD / Archive	1

External Distribution		
Company	**Name**	**No. Copies**
Public		1

Document Change Record

Issue/ Revision	Date	DCN No.	Changed Pages/Paragraphs
1.0	27.04.2018	SAF/CM/DWD/ICDR/SEV/RAD/ VAL	First Version
1.1	16.05.2018	SAF/CM/DWD/ICDR/SEV/RAD/ VAL	Editorial changes to CDOP-3 document style
1.2	20.08.2018	SAF/CM/DWD/ICDR/SEV/RAD/ VAL	Update due to new ICDR SEVIRI parameters
1.3	31.10.2018	SAF/CM/DWD/ICDR/SEV/RAD/ VAL	Update after ORR to implement ORR RIDs

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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	Validation Report - ICDR SEVIRI Radiation based on SARAH-2 methods	SAF/CM/DWD/ICDR/SEV/RAD/VAL/ 1.2
RD 2	Algorithm Theoretical Baseline Document (ATBD) - ICDR SEVIRI Radiation based on SARAH-2 methods	SAF/CM/DWD/ICDR/SEV/RAD/ATBD/ 1.2

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 centre, 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), and 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 (CDRs) 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 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 that can be used to prepare monthly / annual updates of the state of the climate. 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

This CM SAF Product User Manual (PUM) provides relevant information to the user on the Interim Climate Data Record (ICDR) SEVIRI Radiation based on SARAH-2 methods. This ICDR corresponds to the SARAH-2.1 thematic climate data record (TCDR) (Pfeifroth et al., 2017) and can be used to extend the temporal coverage of SARAH-2.1, which currently is available until 2017. The new ICDR is available from 2018 onwards.

The document enables the user to perform an appropriate use of the data. This manual describes available products including example images, gives basic algorithm descriptions and a brief overview of the accuracy. It also discusses potential difficulties affecting the scientific interpretation. Additionally, a technical description of the data including information on format as well as on access and handling tools (e.g. mapping and display tools) is provided in the final sections.

CM SAF data products are distinguished between operational monitoring products and data records (Schulz et al., 2009). Operational monitoring products are disseminated with appropriate timeliness for climate monitoring (i.e. 5 days after observation at the latest for the ICDR SEVIRI) to support operational climate monitoring applications of National Meteorological and Hydrological Services and other services and applications.

The concept of Climate Data Records (CDRs) and regularly updated so-called Interim Climate Data Records (ICDRs) aims to provide near-real time information with the highest possible consistency to the corresponding long-term climate data record. This consistency is achieved by applying similar methods to generate the ICDR as is used for the CDR generation. However, due to the timeliness restrictions, the ICDR quality and consistency might be reduced, e.g. due to sensor degradations, orbital changes or inter-satellite biases, that instantaneously might influence the ICDR quality.

This Product User Manual describes the ICDR SEVIRI Radiation based on SARAH-2 methods available from 2018 onwards.

3 Description of ICDR SEVIRI Radiation based on SARAH-2 methods

The ICDR SEVIRI Radiation based on SARAH-2 methods provides data records of the solar surface irradiance (SIS), the surface direct irradiance (SDI) and the sunshine duration (SDU). The applied method, i. e., MAGICSOL is described in detail in the Algorithm Theoretical Baseline document RD 2 (SAF/CM/DWD/ICDR/SEV/RAD/ATBD/1.2). The data records are available on a regular 0.05°x0.05° grid as daily and monthly averages and as 30-min instantaneous data. The spatial coverage includes the Meteosat disk up to a scanning angle of 68 degree. Details on the validation and the performance of the ICDR SEVIRI are documented in the Validation Report RD 1 (SAF/CM/DWD/ICDR/SEV/RAD/VAL/1.3).

The generation of the ICDR SEVIRI Radiation based on SARAH-2 methods closely follows the processing used to generate the CM SAF SARAH-2 climate data record with few adjustments necessary to allow the online processing. These adjustments include

- the use of satellite data from the previous 30 days for the statistical determination of the clear-sky reflectivity and the maximum reflectivity (instead of satellite data from the current month in SARAH-2) and
- the use of daily data from the operational ECMWF analysis system for the integrated water vapor (instead of monthly ERA-Interim water vapor data in SARAH-2).

The ICDR SEVIRI Radiation based on SARAH-2 methods is designed to extent the CM SAF SARAH-2 climate data record in time with as much consistency as possible. The validation report documents the small systematic differences between the ICDR SEVIRI Radiation based on SARAH-2 methods and the SARAH-2.1 climate data record. Overall we conclude that the ICDR SEVIRI Radiation based on SARAH-2 methods can be used to assess anomalies of the surface solar radiation with high accuracy using the SARAH-2.1 climate data record as climatological reference.

3.1 Processing of Meteosat images

The processing of the METEOSAT data is done in satellite projection. The results are transferred to the regular latitude-longitude-grid using a subroutine of SPECMAGIC (Mueller et al., 2009). For the retrieval of the effective cloud albedo, the Heliosat algorithm is used (Hammer et al., 2003). The original version of the Heliosat method has been modified to generate a data record that meets climate quality. The effective cloud albedo derived with the modified Heliosat version is used in combination with the clear sky surface radiation model SPECMAGIC (Mueller et al., 2009; Mueller et al., 2012) to derive the surface radiation products from the MVIRI and SEVIRI instruments on board the geostationary Meteosat satellites number 2 to 10. The derived parameters and methods are described in more detail in the following sections. The complete model (cloudy and clear sky) is called MAGICSOL and described in more detail in the ATBD (SAF/CM/DWD/ICDR/SEV/RAD/ATBD, RD 2).

The Heliosat method does not require calibrated radiances as input, but is directly based on image counts. From the Heliosat algorithm the effective cloud albedo is derived. Together with information about the atmospheric clear sky state (water vapour, aerosols, ozone) the effective cloud albedo is used as input for the SPECMAGIC method to calculate the direct irradiance and the solar surface irradiance.

In the following sub-sections a brief description of each individual surface radiation product is given with associated information on averaging methods, validation procedures and known limitations.

3.2 Surface Incoming Solar Radiation (SIS)

3.2.1 Product definition

The surface incoming solar (SIS) radiation is the radiation flux (irradiance) reaching a horizontal plane at the Earth surface in the 0.2 – 4 µm wavelength region. It is expressed in W/m².

3.2.2 Basic Retrieval approach

The surface incoming solar radiation (SIS) is retrieved using the Heliosat method. The Heliosat method is based on the conservation of energy. As a consequence the basic relation between the solar irradiance and the effective cloud albedo is as follows:

$$SIS = SIS_{CLS} \cdot (1 - CAL) \quad \textbf{(Equation 3-1)}$$

Here, SIS is the solar surface irradiance, SIS_{CLS} the clear sky irradiance and CAL is the effective cloud albedo, also called cloud index, n, in former publications (e. g. Cano et al, 1986). For effective cloud albedo values above 0.8, Equation 3-1 is modified in order to consider the saturation and absorption effects within optically thick clouds. The modification of the equation for small and large values of CAL is based on ground measurements and is described in detail in the ATBD [RD 2] and given in the Appendix, Section 7.3, of this document.

When CAL is known, SIS can be calculated from the clear sky solar irradiance. The algorithm to calculate the clear sky solar surface irradiance uses RTM based LUTs for the calculation of SIS_{CLS}.

The radiative transfer model (RTM) libRadtran (Mayer and Kylling, 2005) was used for the generation of the LUT. The LUT contains SIS values for a wide range of atmospheric states and 32 spectral bands. The SIS value for the actual atmospheric state is then calculated by interpolation between the states. The atmospheric states cover different values for water vapour, ozone, aerosol optical depth, aerosol single scattering albedo, and asymmetry parameter. Several aerosol types were included (Hess et al., 1998). Additionally, Modified Lambert Beer (MLB)-LUTs are used (Mueller et al., 2004). A specific aerosol optical thickness and aerosol type can be assigned to each pixel depending on the provided aerosol background map. The aerosol optical thickness and type is assigned to each pixel depending on the aerosol map derived from the aerosol information provided by the European Centre for Medium-Range Weather Forecasts (ECMWF), see Benedetti et al., 2009 and Morcrette et al., 2009 for further details. Vertically integrated water vapour amounts (daily means) are taken from ECMWF high-resolution operational analysis. The interpolation between the LUTs is done with a linear interpolation scheme.

3.2.3 Details on processing, gridding and averaging

Daily averages are calculated following a method by Möser (1983) (also published in Diekmann et al., 1988), as follows:

$$SIS_{DA} = SIS_{CLSDA} \frac{\sum_{i=1}^{n} SIS_i}{\sum_{i=1}^{n} SIS_{CLS\,i}} \qquad \text{Equation 3-2}$$

SIS_{DA} is the daily average of SIS. SIS_{CLSDA} is the daily averaged clear sky SIS, SIS_i the calculated SIS for satellite image i and SIS_{CLSi} the corresponding calculated clear sky SIS. n is the number of images available during a day.

The applied equation for averaging accounts for data gaps (missing values) and zero values. However, the larger the number of available images per day, the better the daily cycle of cloud coverage can be resolved, increasing the accuracy of the daily average of SIS. A minimum number of three available pixels per day is required to derive the daily mean for this specific pixel. The monthly average is calculated from the daily means of this month on pixel basis as arithmetic mean with a required number of 20 existing daily means.

3.2.4 Input data

- CAL from METEOSAT processing, available for each pixel in satellite resolution
- Daily vertically-integrated water vapour from the operational high-resolution ECMWF analysis, the pixel value is derived by spatial interpolation.
- A monthly ozone climatology based on ERA-Interim (Dee et al., 2011) was used.
- Lookup tables.
- Surface albedo from SARB/CERES (see section 7.2 for details), only needed for the clear sky model.

Information about the aerosol optical thickness and type is derived from the aerosol information MACC (Monitoring Atmospheric Composition and Climate Reanalysis) provided by the European Centre for Medium-Range Weather Forecasts (ECMWF). The MACC data results from a data assimilation system for global reactive gases, aerosols and greenhouse gases. It consists of a forward model for aerosol composition and dynamics (Morcrette et al., 2009) and the data assimilation procedure described in detail in (Benedetti et al., 2009). MACC has been evaluated to perform better than Kinne et al., 2013, and the GADS/OPAC climatology (Hess et al., 1998, Köpke et al. 1997) within the used processing system; see Mueller and Träger-Chatterjee (2014) for further details. Monthly long term means on 0.5x0.5 degree latitude-longitude grid. The pixel value is derived by spatial interpolation and assignment of the respective monthly mean.

3.2.5 Product example

Figure 3-1 provides an illustration of the SIS product.

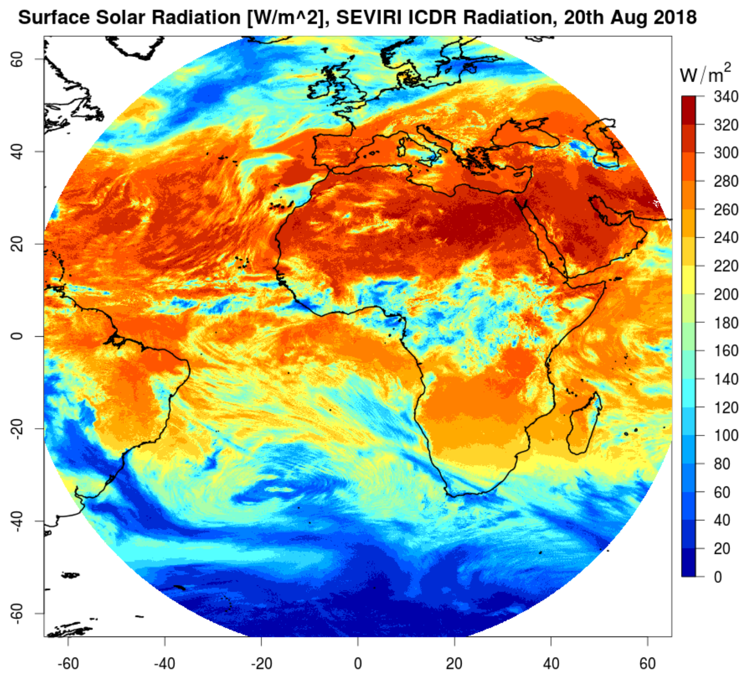

Figure 3-1: Illustration of the SIS product. Daily mean surface irradiance from 20th August 2018.

3.2.6 Validation

The Product Requirement Document (PRD) [AD 1] lists specific product requirements which have to be fulfilled by the products. The achieved accuracy for the SIS product is summarized in Table 3-1. The validation has been performed against reference ground measurements from the Baseline Surface Radiation Network (BSRN).

The detailed results of the validation are presented in the CM SAF Validation Report [RD 1: SAF/CM/DWD/ICDR/SEV/RAD/VAL/]. Here the main validation results are given in Table 3-1.

Table 3-1: Summary of validation results for SIS: N Number of comparisons. Bias: mean of the differences for monthly / daily means, MAD: mean of absolute deviations for monthly / daily means. Cor: Correlation between BSRN and satellite-derived data. For comparison the values of the corresponding validation for the SARAH-2.1 data record for the time period 2014-2017 is also shown.

SIS	**N**	**Bias [W/m^2]**	**MAD [W/m^2]**
SARAH-ICDR			
Monthly Mean	52	3.7	5.1
Daily mean	1582	3.3	9.7
SARAH-2.1			
Monthly mean	412	1.7	5.3
Daily mean	12047	1.6	11.6

3.2.7 Comparison with CM SAF SARAH-2 CDR

To ensure a high consistency with the CM SAF SARAH-2.1 CDR the surface solar irradiance biases with reference to BSRN are analysed over time. Figure 3-2 shows the bias time series of the CDR+ICDR combined data. It is seen that there is no discontinuity or “jump” in the time series, which underlines the consistency achieved. However, as seen in Table 3-1, there is a slightly larger positive bias of the ICDR relative to the CDR – keeping in mind that the analysis time periods differ.

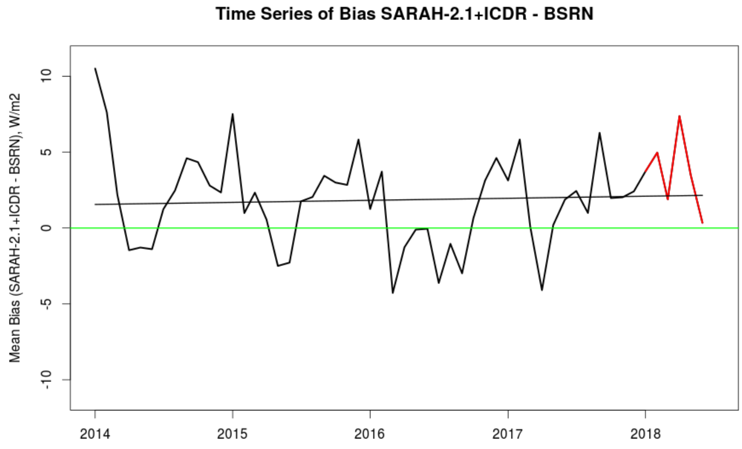

Figure 3-2: Bias time series of SIS of the combined CDR SARAH-2.1 and ICDR SEVIRI Radiation data with reference to BSRN station measurements for the time period 2014 to June 2018.

3.2.8 Limitations

Below is a list of known deficiencies and limitations of the SIS product:

- The high clear sky reflection over bright surfaces (e. g., desert regions) reduces the contrast between clear sky reflection and cloudy-sky reflection. This leads to higher uncertainties in CAL and errors in the calculation of SIS.
- The accuracy of aerosol information is not well defined in several regions of the world due to missing ground measurements. Any uncertainty in the aerosol information affects the accuracy of SIS, especially in regions that are dominated by cloud free sky. For the current data record a monthly climatology has been used. Monthly, daily and hourly variations in the aerosol optical depth are therefore not considered.
- The use of the satellite data from last previous 30 days for the determination of the clear sky reflection and the maximum reflectivity (in contrast to the use of the satellite data from the current month) may induce differences between SARAH-2.1 SIS and the SIS from the ICDR SEVIRI Radiation based on SARAH-2 methods.

3.3 Surface Direct irradiance (SDI)

3.3.1 Product definition

The surface direct irradiance contains two direct radiation products, the direct normalized irradiance (DNI) and the surface incoming direct radiation (SID). The direct normal irradiance (DNI) is the radiation flux (irradiance) at the surface normal to the direction of the sun in the 0.2 - 4 µm wavelength region. It is expressed in W/m^2. It is derived by normalisation of the direct irradiance, SID, with the cosine of the solar zenith angle (see (Equation 3-4). SID is the radiation flux (irradiance) reaching a horizontal plane in the 0.2 – 4 µm wavelength region at the surface directly without scattering.

3.3.2 Algorithm outline

3.3.2.1 Clear sky

The algorithm for the calculation of SDI under clear sky conditions is described in detail in Mueller et al., 2009 and also documented in the public license gnu-MAGIC project, http://sourceforge.net/projects/gnu-magic. It is a fast method to calculate solar irradiance (including the direct irradiance) for large areas, which uses an eigenvector hybrid LUT approach for the fast and accurate calculation of SDI. The aerosol optical thickness and type is assigned to each pixel depending on the aerosol map derived from the aerosol information provided by the European Centre for Medium-Range Weather Forecasts (ECMWF). Daily vertically-integrated water vapour columns are taken from the high-resolution operational ECMWF analysis. The interpolation within the LUTs is done with a linear interpolation scheme. The atmospheric input and interpolation routine is identical for SIS and SDI, with exception of a background surface albedo map, which is not needed for SDI.

3.3.2.2 Cloudy sky situations

For the consideration of clouds on the clear sky irradiance a formula of Müller et al. (2009) is used, which describes the relation of the direct irradiance (all sky) SID_{allsky} to that of the clear sky direct irradiance SID_{clear}:

$$SID_{allsky} = SID_{clear} \cdot ((1 - CAL) + 0.38 \cdot CAL))^{2.5} \qquad \text{(Equation 3-3)}$$

where CAL is the effective cloud albedo. This formula is an adaptation from the diffuse model of Skartveit et al., 1998. The direct irradiance is set to zero for CAL values above 0.6. DNI is subsequently derived from SID by normalisation with the solar zenith angle:

$$DNI = SID / \cos(SZA) \qquad \text{(Equation 3-4)}$$

where SID is the direct irradiance and SZA is the solar zenith angle.

3.3.3 Details on processing, gridding and averaging

The calculation of the temporal averages of the SDI climate data records is conducted with the same method as for the surface irradiance products (see section 3.3.2).

3.3.4 Input data

The input is identical to that of SIS with exception of the background surface albedo map which is not needed for SDI. The input data is therefore described in section 3.2.4. CAL, total water vapor column, ozone content, aerosol information and look-up tables are used according to section 3.2.4.

3.3.5 Product example

Figure 3-3 provides examples of the SDI data records, DNI and SID.

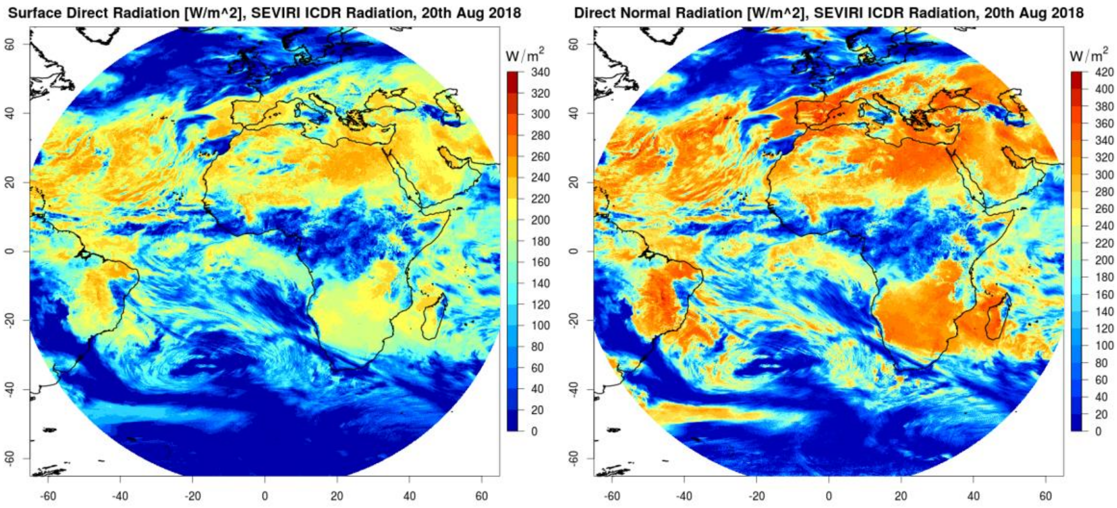

Figure 3-3 Illustration of the SID (left) and DNI (right) Interim Climate Data Record; Shown are daily means for 20th August 2018.

3.3.6 Validation

The Product Requirement Document (PRD) [AD 1] lists specific product requirements which have to be fulfilled by the products. The achieved accuracy for the SDI data records are shown in Table 3-2. The detailed results of the validation are presented in the CM SAF Validation Report [RD 1: SAF/CM/DWD/ICDR/SEV/RAD/VAL/].

Table 3-2: Summary of validation results for SDI parameters (SID and DNI): N Number of comparisons. MAD: mean of absolute deviations for monthly/daily means.

SID	N	Bias [W/m²]	MAD [W/m²]
ICDR SEVIRI			
Monthly Mean	52	2.3	10.0
Daily mean	1344	1.0	16.1
SARAH-2.1			
Monthly mean	407	-0.5	9.3
Daily mean	11740	-0.6	19.6
DNI			
ICDR SEVIRI			
Monthly mean	46	2.9	21.7
Daily mean	1329	1.8	31.8
SARAH-2.1			
Monthly mean	408	-1.5	18.3
Daily mean	11856	-1.4	36.0

3.3.7 Comparison with CM SAF SARAH-2 CDR

To ensure a high consistency with the CM SAF SARAH-2.1 CDR, the mean surface solar irradiance derived from the ICDR SEVIRI Radiation based on SARAH-2 methods and the CM SAF SARAH-2.1 are compared. Figure 3-4 shows the bias time series of the combined surface solar radiation derived from the ICDR SEVIRI Radiation based on SARAH-2 methods and the SARAH-2.1 climate data record for the time period 2014 to June 2018.

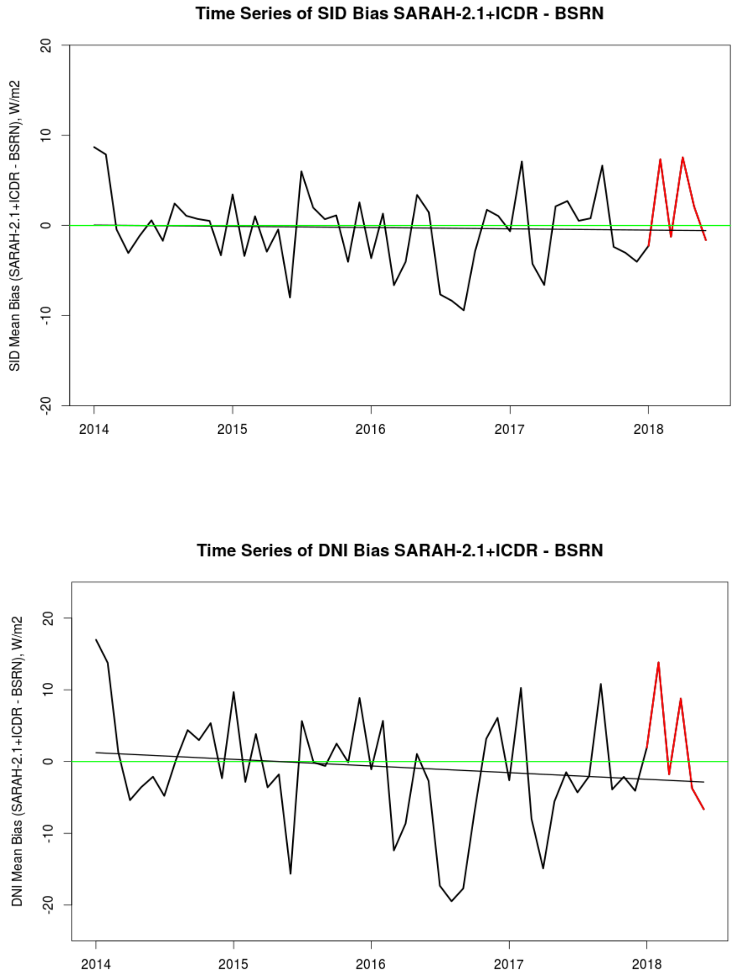

Figure 3-4: Bias time series of the SDI parameters SID (top) and DNI (bottom) of the combined CDR SARAH-2.1 and ICDR SEVIRI Radiation data with reference to BSRN reference stations for the time period 2014 to June 2018.

3.3.8 Limitations

Below is a list of some of known deficiencies and limitations of the SDI product (see also SIS limitations)

- The relatively high clear sky reflection over bright surfaces reduces the contrast between clear sky reflection and cloudy sky reflection. This leads to higher uncertainties and errors in the calculation of CAL and subsequent of SID and DNI.
- The accuracy of aerosol information is not known in several regions of the world due to missing ground measurements.

- SDI is quite sensitive to the AOD (aerosol optical depth) in clear sky situations, which introduces a certain amount of uncertainty as the accuracy of monthly AOD can only be expected to be +/- 0.1. Moreover, for the current data record, a monthly climatology has been used. Monthly, daily and hourly variations in the aerosol optical depth are therefore not considered, which increases the uncertainty in daily and hourly values significantly. However, due to missing ground based measurements it is not evident nor proven that information about the temporal variation of aerosols gained from satellite would perform significantly better for the generation of a long term data records of monthly and daily means than a best-of aerosol climatology. Indeed, Kinne et al. (Kinne et al., 2006) discussed the limited accuracy of aerosol information retrieved from satellites. Moreover, dynamic aerosol information with appropriate coverage does not exist for the complete period of the data record. Hence, uncertainties in SDI introduced by uncertainties in the AOD are mainly related to the lack of accurate and homogeneous input alternatives of aerosol information (especially over land) with high spatial and temporal resolution. However, due to the relative large sensitivity of SDI on aerosol optical depth the limited accuracy of the aerosol information is a significant reason for the lower accuracy of SDI relative to SIS.

- The use of the satellite data from the previous 30 days for the determination of the clear sky reflection and the maximum reflectivity (in contrast to the use of the satellite data from the current month) may induce differences between SARAH-2.1 SDI data records and the SDI data from the ICDR SEVIRI Radiation based on SARAH-2 methods

3.4 Sunshine Duration (SDU)

3.4.1 Product definition

The daily or monthly sunshine duration is the time per day or month at which DNI exceeds the threshold of 120 W/m^2, as defined by the WMO.

3.4.2 Algorithm outline

Basis for the retrieval of satellite-based sunshine duration (SDU) are the SARAH-2 DNI data and the WMO threshold for bright sunshine, which is defined by DNI ≥ 120 W/m^2. SDU is derived by the ratio of sunny slots to all available slots during daylight multiplied by the length of the day.

The day length is calculated depending on the date, longitude and latitude. The day length is restricted by a threshold of the solar elevation angle (SEA) of 2.5°. The sunny slots are weighted depending on the number of surrounding cloudy and sunny grid points, which is discussed in more detail in ATBDs section 6.1 [RD2]. The number of daylight slots describes the maximum number of Meteosat observations (slots) per grid point and per day during daylight. Daylight is defined by the time where the SEA exceeds 2.5°.

A sunny slot corresponds to a DNI value of 120 W/m^2 or larger. The ICDR SEVIRI Radiation data provides instantaneous DNI data every 30 minutes. Therefore, without weighting, one sunny slot would correspond to a 30 minutes time window. In reality this is only the case in bright weather situations. If there are clouds in the surrounding area of a grid point, there is a probability that not the whole 30 minutes are sunny. This is also valid in the opposite case, when a cloudy grid point has sunny grid points in its near surroundings. This fact should be accounted for in the retrieval of SDU by using the information of the 24 surrounding grid points. In addition the information of two successive time steps is incorporated.

3.4.3 Details on processing, gridding and averaging

The output of the algorithm described in section 3.4.2 are daily sums of SDU. To derive SDU monthly sums the daily sums of each month are summed up.

3.4.4 Input data

Basis for the retrieval of satellite-based sunshine duration (SDU) are the SARAH-2.1 DNI data.

3.4.5 Product example

Figure 3-37 provides an example of the SDU data records.

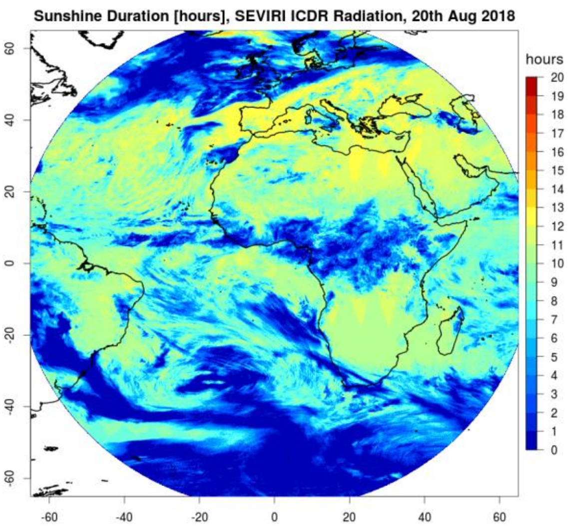

Figure 3-7 Illustration of the SDU climate data records; Daily sum [hours] for 20 August 2018.

3.4.6 Validation

The achieved accuracy for the SDU data record is shown in Table 3-3. Please see section 3.2.6 for validation limitations.

The detailed results of the validation are presented in the CM SAF Validation Report [RD.1: SAF/CM/DWD/VAL/METEOSAT_HEL].

Table 3-3: Summary of the validation results of the sunshine duration monthly and daily sums using CLIMAT and ECA&D station data as reference, respectively.

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

Overall the validation results of SDU based on the ICDR are very similar to ones of the SARAH-2.1 CDR, which demonstrate their consistency.

3.4.7 Limitations

Below some of the known deficiencies and limitations of the SDU product (see also SDI limitations) are reported.

In regions, such as the Sahara desert, DNI can exceed 120 W/m^2 even if the solar elevation angle is lower than 2.5°, which leads to unnatural artefacts in SDU. These artefacts occur mainly in regions with high solar insolation and very low cloud cover.

The retrieval algorithm for SDU includes two constants, which were derived empirically using comparisons with measurements from about 250 Station from Germany. The derivation procedure for theses constants is planned to be extended for the next release to a wider range of trustworthy stations.

4 Data description

This section describes the output formats for the surface radiation parameters. Each surface radiation parameter is gridded onto a regular lat/lon grid with a size of 0.05x0.05° (WSG 84). The time resolution includes 30-min instantaneous values, daily mean values, and monthly mean values for SIS and SDI; SDU is available as daily and monthly sums.

4.1 Product Names

Product types are:

- Surface incoming solar radiation (SIS), also known as global irradiance.
- Surface direct radiation (SDI, consisting of SID and DNI).
- Sunshine Duration (SDU)

Time resolutions:

- Monthly mean value (for SDU: monthly sum)
- Daily mean value. (for SDU: daily sum)
- 30 min instantaneous values.

4.2 Data Format and Ordering

CM SAF‘s climate monitoring products of surface radiation are provided as NetCDF-4 (Network Common Data Format, http://www.unidata.ucar.edu/software/netcdf/) files. The NetCDF software functions as an I/O library, callable from C, FORTRAN, C++, Perl, Python or other language for which a NetCDF library is available. The library stores and retrieves data in self-describing, machine-independent data records. Each NetCDF data record can contain multidimensional, named variables (with differing types that include integers, reals, characters, bytes, etc.), and each variable may be accompanied by ancillary data, such as units of measure or descriptive text.

A NetCDF consists of dimensions, variables, and attributes. These components can be used together to capture the meaning of data and relations among data. The dimensions of the CM SAF radiation CDRs are longitude, latitude and time (see Table 7-1). Each NetCDF file contains one variable (SIS, DNI, SID or SDU) at the given time resolution (instantaneous, daily or monthly means (sums for SDU)) together with the data values for the dimensions (see Table 7-2). The variables as well as the dimension variables are accompanied by attributes following the NetCDF Climate and Forecast (CF) Metadata Convention 1.4 (http://cfconventions.org/). The attributes that are included in the CM SAF surface radiation data records are listed in Table 7-3.

All data records are provided in separated files, one file for each time step, with the exception of the 30-min instantaneous data, which are provided with all time steps per day in a single file. The data records cover monthly, daily and 30-min instantaneous values.

Below a list of relevant product acronyms ($product) and acronyms for the averaging period ($mean):

SIS: Surface Incoming Shortwave Radiation**.** Also called solar surface irradiance

DNI: Direct Normal Irradiance at surface

SID: Surface incoming direct radiation

SDU: Sunshine Duration

As additional data layer the corresponding daily and monthly mean clear-sky surface radiation data are available.

mm: Monthly mean

dm: Daily mean

in: instantaneous

ms: Monthly sum

ds: Daily sum

Within the CAL daily mean NetCDF files an additional layer called “CAL_nobs” is included that gives the number of the available observations in the visible spectral range per pixel, at the given day.

Ordered files will follow the following naming convention:

$Product$mean$Year$MonthDayHour$Version

Further details on the naming are given in the Web User Interface and the naming convention document available at the CM SAF web page: www.cmsaf.eu -> Products -> “Naming convention” item.

4.3 Data ordering via the Web User Interface (WUI)

Information on the CM SAF services are provided through the CM SAF homepage www.cmsaf.eu. The web page includes information and documentation on the CM SAF and the CM SAF products, information on how to contact the user help desk. It provides also the link to the WUI (http://wui.cmsaf.eu), which allows to search the product catalogue and to order products.

On the WUI "webpage" (http://wui.cmsaf.eu), a detailed description how to use the web interface for product search and ordering is given. The user is referred to this description since it is the central and most up to date documentation. However, some of the key features and services are briefly described in the following sections.

Copyright note:

All intellectual property rights of the CM SAF products belong to EUMETSAT. The use of these products is granted to every interested user, free of charge. If you wish to use these products, EUMETSAT's copyright credit must be shown by displaying the words "copyright (year) EUMETSAT" on each of the products used.

You need to be registered and logged in to order products. A login is provided upon registration, all products are delivered free of charge. After the selection of the product, the desired way of data transfer can be chosen. This is usually via a temporary ftp account. Each order will be confirmed via email, and the user will get another email once the data have been prepared. If the ftp data transfer was selected, this second email will provide the information on how to access the ftp server.

4.4 Data volume:

The data amount depends on the data request of the user, in detail on the size of the selected region and the length of the covered time period. The user will be informed about the data volume of his request within the WUI ordering process. Below the maximum values for one parameter covering the complete Meteosat disk and time period are given:

Monthly Means: up to 30 MB per month per parameter

Daily Means: ~500 MB per month per parameter

30-min Instantaneous: up to 5 GB per month per parameter

4.5 Contact User Help Desk staff

In case of questions the contact information of the User Help Desk (e-mail address contact.cmsaf@dwd.de, telephone and fax number) are available via the CM SAF main webpage (www.cmsaf.eu or the main page of the Web User Interface.

4.6 Feedback/User Problem Report

Users of CM SAF products and services are encouraged to provide feedback on the CM SAF product and services to the CM SAF team. Users can either contact the User Help Desk (see chapter 4.5) or use the "User Problem Report" page. A link to the "User Problem Report" is available either from the CM SAF main page (www.cmsaf.eu) or the Web User Interface main page.

4.7 Service Messages / log of changes

Service messages and a log of changes are also accessible from the CM SAF main webpage (www.cmsaf.eu) and provide useful information on product status, versioning and known deficiencies.

5 Tools and Auxiliary data

This section describes currently available tools to read, display, re-project and modify the CM SAF products. All tools and auxiliary data shortly described here, are accessible from the CM SAF main webpage (www.cmsaf.eu).

All tools and auxiliary data described are free of charge. They come with no warranty and are based on best effort basis. When encountering problems, please contact the User Help Desk (section 4.5).

5.1 Climate data operators (CDO)

To allow easy access to CM SAF data records the possibility to import CM SAF data has recently been integrated into the ‚climate data operators' (CDO) which is a well-established conversion tool in the climate modelling community (https://code.zmaw.de/projects/cdo).

This package was originally developed for processing and analysis of data produced by a variety of climate and numerical weather prediction models (e. g. for file operations, simple statistics, arithmetic, interpolation or the calculation of climate indices). Besides the conversion between different file formats, cdo offers possibilities for pre-processing the data for validation studies, especially interpolation to other grid types and selection of regions, including methods for interpolation of non-continuous data records such as e. g. cloud types.

The CM SAF Meteosat climate data records are provided on a regular latitude longitude grid, whereby the latitude and longitude are given and described in the NetCDF-files. CDO employs this information for spatial operations on these final products. A link to this tools is available on the CM SAF web site (www.cmsaf.eu/tools/). CDO has been used for the averaging of CAL, for the generation of SARAH-2.1 monthly means, and for modifications of the NetCDF metadata settings.

Please refer to the CDO-manual for detailed instructions how to import and process CM SAF products.

5.2 CM SAF R Toolbox

The CM SAF R Toolbox is a set of R-based tools for the preparation, analysis and visualization of CM SAF NetCDF data [Fig. 1]. It was developed in the framework of a EUMETSAT/ CM SAF workshop in 2015 with the intention to have an easy-to-use tool, which helps unexperienced R-user to start working with CM SAF NetCDF formatted data.

The tools are mainly based on prepared R-scripts, which guide the user through all options. By this, the tools can be used without any scripting knowledge and the user gets a first impression of the usage of R. CM SAF data are provided via ftp as tar-files, which can contain multiple time steps in separate NetCDF files. The CM SAF R Toolbox contains an R-script for the preparation of ordered CM SAF data, which includes to untar, unzip and merge the data and the option to sub-select the data in time and space. The output of this first step is a single ready-to-use NetCDF file including all time steps. For the analysis and manipulation of NetCDF data the Toolbox offers an R-script, which acts as an interface to the ‘cmsaf’ R-package.

The ‘cmsaf’ R-package is a collection of more than 50 operators, which are developed to handle CM SAF data. This R-package is the core of the functionality of the CM SAF R Toolbox. The ‘cmsaf’ R-package can be used without the Toolbox and it is freely available via all CRAN mirrors of the R-project. So far, the ‘cmsaf’ R-package was downloaded more than 10.000 times worldwide.

For visualization of CM SAF NetCDF data the Toolbox offers an R-based graphical interface for interactive plots and a set of specialized prepared R-scripts for the plotting of spatial data or 1D-timeseries.

5.3 Auxiliary Data

This section gives an overview of available auxiliary data records which will be helpful for further processing and interpretation of CM SAF products. All auxiliary data records are accessible via the webpage www.cmsaf.eu in the folder ‘Data Access’. Table 5-1 lists the available auxiliary data records and their respective coverage. Further a NetCDF-file with information on the true time of observation for the 30-min instantaneous data is available on the cmsaf-webpage (cmsaf.eu -> Products -> Auxiliary Data).

Table 5-1: Table of available auxiliary data records. AOD=Aerosol Optical Depth, ssa=single scattering albedo, gg=asymmetry parameter, the aerosol data is available as ASCII files from the CM SAF web page in the menu >add on products<.

Region	Surface albedo [-]	Aerosols [AOD,ssa,gg]	Water vapour [mm]
CM SAF full disc area ("MA") (METEOSAT)	X	X	x
Global ("GL").		x	x

6 References

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

Benedetti, A., Morcrette, J.-J., Boucher, O., Dethof, A., Engelen, R.J., Fisher, M., Flentje, H., Huneeus, N., Jones, L., Kaiser, J.W., Kinne, S., Mangold, A., Razinger, M., Simmons, A.J., Suttie, M., 2009: Aerosol analysis and forecast in the European Centre for Medium-Range Weather Forecasts Integrated Forecast System: 2. Data assimilation, Journal of Geophysical Research, 114, D13205.

Betts Alan K., Martin Köhler and Yuanchong Zhang, 2009: Comparison of river basin hydrometeorology in ERA-Interim and ERA-40 reanalyses with observations, Journal of Geophysical Research, 114, D02101, doi:10.1029/2008JD010761.

Dee, D. P., et al., 2011, The ERA-Interim reanalysis: configuration and performance of the data assimilation system, Quarterly Journal of the Royal Meteorological Society, 137(656), 553-597, doi:10.1002/qj.828.

Diekmann, F.-J. et al., 1988: An operational estimate of global solar irradiance at ground level from METEOSAT data: results from 1985 to 1987, Meteorol. Rdsch., 41, 65-79.

Dürr, B. , Zelenka A., Müller R.W., and R. Philipona, 2010, Validation of MeteoSwiss and CM-SAF satellite based global solar irradiance over the Alps, International Journal of Remote Sensing, 21, 5549-5571.

EUM TD 04: “Meteosat Data Collection and Retransmission System”, Technical Description, Revision 5, 1998

EUM TD 05: „The Meteosat System”, Revision 4, November 2000

EUM TD 06: “The Meteosat Archive - User Handbook”, November 2001

Hammer A., Heinemann D., Hoyer C., Kuhlemann R., Lorenz E., Müller R., and Beyer H. G., 2003: Solar energy assessment using remote sensing technologies, Remote Sens. Environ., 86, 423-432.

Hess, M., P. Koepke, and I. Schult, 1998: Optical Properties of Aerosols and Clouds: The Software Package OPAC. Bull. Amer. Meteor. Soc., 79, 831-844.

Kato, S., T. P. Ackerman, J. H. Mather, and E. E. Clothiaux, 1999: The k-distribution method and correlated-k approximation for a shortwave radiative transfer model, Journal of Quantitative Spectroscopy and Radiative Transfer, 62(1), 109-121, doi:http://dx.doi.org/10.1016/S0022-4073(98)00075-2.

Kinne, S., Schulz M., Textor C. et al., 2006: An AeroCom initial assessment – optical properties in aerosol component modules of global models, Atmos. Chem. Phys., 6, 1815-1834.

Kinne, S., D. O'Donnel, P. Stier, S. Kloster, K. Zhang, H. Schmidt, S. Rast, M. Giorgetta, T. F. Eck, and B. Stevens (2013), MAC-v1: A new global aerosol climatology for climate studies, J. Adv. Model. Earth Syst., 5, 704–740, doi:10.1002/jame.20035.

Mayer, B. and Kylling, A., 2005: Technical note: The libRadtran software package for radiative transfer calculations - description and examples of use. Atmos. Chem. Phys., 5, 1855-1877.

Möser, W., 1983: Globalstrahlung aus Satellitenmessungen. Mitteilungen aus dem Institut für Geophysik und Meteorologie der Universität zu Köln, Köln.

Mueller R.W. et al, 2004: Rethinking satellite based solar irradiance modelling – The SOLIS clear sky module, Remote Sens. Environ., 91, 160-174.

Mueller, R. W., C. Matsoukas, A. Gratzki, H.D. Behr and R. Hollmann, 2009: The CM SAF operational scheme for the satellite based retrieval of solar surface irradiance – A LUT based eigenvector approach, Remote Sens. Environ., 113, 1012-1024.

Mueller, R.; Behrendt, T.; Hammer and A.; Kemper, A., 2012: A New Algorithm for the Satellite-Based Retrieval of Solar Surface Irradiance in Spectral Bands. Remote Sens., 4, 622-647.

Mueller, R. and Träger-Chatterjee, C., 2014: Brief accuracy assessment of aerosol climatologies for the retrieval of solar surface radiation, Atmosphere, 5,959-972.

Mueller, R., U. Pfeifroth and C. Träger-Chatterjee, 2015: Towards Optimal Aerosol Information for the Retrieval of Solar Surface Radiation using Heliosat. Atmosphere 6(7), 863-878.

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.

Morcrette, J. J., Boucher, O., Jones, L., Salmond, D., Bechtold, P., Beljaars, A., Benedetti, A., Bonet, A., Kaiser, J. W., Razinger, M., Schulz, M., Serrar, S., Simmons, A. J., Sofiev, M., Suttie, M., Tompkins, A. M. and Untch, A., 2009: Aerosol analysis and forecast in the European Centre for Medium-Range Weather Forecasts Integrated Forecast System: Forward modelling, J. Geophys. Res., 114, D06206.

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.

Posselt, R., R. Mueller, J. Trentmann, R. Stockli and M.A. Liniger, 2014: A surface radiation climatology across two Meteosat satellite generations, Remote Sensing of Environment, 142, 103-110.

Skartveit A., Olseth J., Tuft M., 1998: An hourly diffuse fraction model with correction for variability and surface albedo. Solar Energy, 63, 173–183.

7 Appendix

7.1 Appendix A: Description of the netCDF file format

The netCDF metafile definitions follows the cf 1.4 convention, please see

http://cfconventions.org/ for details

Table 7-1: Dimensions in the NetCDF files

Dimension	Size	Description
Lon	2601	Longitude (WSG 84)
Lat	2601	Latitude (WSG 84)
Time	1 (48)	Time (for instantaneous data)

Table 7-2*:* Variables in the netCDF SIS, SID, DNI NetCDF files

Variable	Type	Dimension	Description
lat	Float	(lat)	Longitude [°E]
lon	Float	(lon)	Latitude [°N]
time	Double	(time)	Time [hours since 01.01.1983]
SIS, SID, DNI, SDU	Short	(lon,lat,time)	Radiation variable

Table 7-3*:* Selected variable attributes in the NetCDF files

Attribute name	Type	Description
units	string	the units of the variable
long_name	string	a more descriptive variable name
standard_name	string	a pre-defined variable name according to the standard name table in order to enable users of data from different sources to determine whether quantities were in fact comparable
Coordinates	string	identifies the coordinate variables

_FillValue	same as variable	This value is considered to be a special value that indicates undefined or missing data; it is used to pre-fill disk space allocated to the variable.
missing_value	same as variable	deprecated, included for backward compatibility, describes the same as the [_FillValue]
platform	string	Name of satellite platform used (Note: for monthly data only the platform of the first day of month is included; See daily mean for more details)
comments	string	Miscellaneous information about the data or methods used to produce it.

7.2 Appendix B: SARB/CERES albedo

http://www-surf.larc.nasa.gov/surf/pages/bbalb.html

The albedo is calculated in a two step process. The first step is to determine scene type for a given 10 minute region. The SARB group uses the 17 scene types as specified by the International Geosphere/Biosphere Programme, plus "Tundra", "Sea Ice" and "Fresh Snow" scenes. Each has an associated spectral albedo which is used by SPECMAGIC.

7.3 Appendix C: Complete equations for the effective cloud albedo - solar irradiance relation

The effective cloud albedo is related to the solar irradiance via the clear sky index. The clear sky index is defined as:

$$k=SIS/\,SIS_{CLS}$$

Here SIS_{CLS} is the solar irradiance for cloud free skies. The relation between the effective cloud albedo CAL and the clear sky index is mainly given by:

$$k = 1\text{-}CAL$$

This relation is defined by physics, in detail by the law of energy conservation (Dagested, 2005). However, above a CAL value of 0.8 empirical corrections are needed in order to consider:

- The effect of statistical noise, which could lead to CAL values above 1 and below 0 (occurs very seldom, however has to be considered).
- The effect of saturation occurring in optically thick clouds.

In these regions the n-CAL relation was determined from the statistical regression using the ground-based measurements at European sites and fitted to get the best performance at all the ground sites. The equations given below provide the complete n-CAL relation for all possible CAL values. It is important to note that the empirical fit has been performed in the 80s and used since then without refitting.

$$
\begin{aligned}
CAL < -0.2 &: k = 1.2, \\
-0.2 \leq CAL \leq \ 0.8 &: k = 1 - CAL, \\
0.8 < CAL \leq \ 1.1 &: k = \ 2.0667 - 3.6667 \cdot CAL + 1.6667 \cdot CAL^2, \\
CAL > \ 1.1 &: k = 0.05
\end{aligned}
$$

As a consequence of the definition of the clear sky index, the surface solar irradiance for the full-sky situation (G) is given by,

$$SIS = k \cdot SIS_{CLS} \ ,$$

where SIS_{CLS} is the clear sky surface solar irradiance calculated using the MAGIC code (Mueller et al., 2004, 2009, 2012).

7.4 Glossary – List of Acronyms in alphabetical order

Abbreviation	Explanation
AVHRR	Advanced Very High Resolution Radiometer
AOD	Aerosol Optical Depth
BSRN	Baseline Surface Radiation Network
CAL	Effective Cloud Albedo
CDOP	Continuous Development and Operational Phase
CDO	Climate Data Operators
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
ERA	ECMWF ReAnalysis
FD	Flux dataset (ISCCP)
FRAC	Fraction of days larger than the target value.
GADS/OPAC	Global Aerosol Data Set / Optical Properties of Aerosols and Clouds
GCOS	Global Climate Observing System
GERB	Geostationary Earth Radiation Experiment
GEWEX	Global Energy and Water Cycle Experiment
HRIT	High Rate Information Transmission
ICDR	Interim Climate Data Record
ISCCP	International Satellite Cloud Climatology Project
K	Clear sky index
LUT	RTM based Look-Up-Table
MAB	Mean of absolute bias values over several days or months

MACC	Monitoring Atmospheric Composition and Climate Reanalysis
MVIRI	Meteosat Visible-InfraRed Imager
NCEP	National Center for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
PRD	Product Requirement Document
PUM	Product User Manual
RTM	Radiative Transfer Model
SARAH	Surface Solar Radiation Data records – Heliosat
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
SSA	Single Scattering Albedo
SZA	Solar Zenith Angle