EUMETSAT Satellite Application Facility on Climate Monitoring

The EUMETSAT Network of Satellite Application Facilities

CM SAF Climate Monitoring

Product User Manual

Top of Atmosphere Radiation

MVIRI/SEVIRI Data Record

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Applicable documents

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AD 1	CM SAF CDOP2 Project Plan	SAF/CM/DWD/PP/1.6
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Reference documents

Reference	Title	Code
RD 1	Requirements Review 2.6 document. TOA Radiation – TCDR MVIRI/SEVIRI Edition 1 data sets, version 3.0	SAF/CM/RMIB/GERB/RR2.6
RD 2	TOA Radiation MVIRI/SEVIRI Dataset Generation Capability Description Document, version 1.1	SAF/CM/RMIB/DGCDD/MET_TOA
RD 3	TOA Radiation MVIRI/SEVIRI Data Record Algorithm Theoretical Basis Document, version 1.3	SAF/CM/RMIB/ATBD/MET_TOA
RD 4	TOA Radiation MVIRI/SEVIRI Data Record Scientific Validation Report, version 1.1	SAF/CM/RMIB/VAL/MET_TOA
RD 5	GERB Dataset Product User Manual, version 3.0	SAF/CM/RMIB/PUM/GERB_DS

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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). 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 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, in particular WMO SCOPE-CM (Sustained COordinated Processing of Environmental satellite data for Climate Monitoring), the CM SAF - together with the EUMETSAT Central Facility, 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 a true 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 Program). This role provides the CM SAF

with deep contacts to research organizations that form a substantial user group for the CM SAF CDRs,

- 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, http:/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 provides information on the CM SAF Top-Of-Atmosphere (TOA) radiation “MVIRI/SEVIRI Data Record”. The document enables the user to perform an appropriate use of the data including background information of the applied retrieval methods. Two data records are generated with the following CM SAF identifiers:

CM SAF identifier	Content
CM-23311	TOA Reflected Solar radiative flux – All Sky (TRS_AS)
CM-23341	TOA Emitted Thermal radiative flux – All Sky (TET_AS)

These data records of TOA Reflected Solar (TRS) and TOA Emitted Thermal (TET) fluxes are mostly derived from the Meteosat Visible and InfraRed Imager (MVIRI) and the Spinning Enhanced Visible and InfraRed Imager (SEVIRI, Schmetz et al., 2002) instruments on-board the geostationary Meteosat satellites. The observations from the Geostationary Earth Radiation Budget (GERB, Harries et al, 2005) radiometer are used to derive empirical narrowband (NB) to broadband (BB) relations for MVIRI and SEVIRI. Once those relations have been derived, GERB is not needed as input data and the processing of the full Meteosat data record can be done. For climate applications, the TRS and TET radiative fluxes are provided as daily means, monthly means and monthly mean diurnal cycles.

Users may be advised that TRS fluxes are also commonly referred to using several other acronyms, such as Shortwave TOA (SW TOA) fluxes, Reflected Shortwave (RSW) fluxes or Reflected Shortwave Radiation (RSR). Similarly, the TET fluxes are frequently mentioned as Longwave TOA (LW TOA) fluxes or Outgoing Longwave Radiation (OLR). The standard convention CMIP5/OBS4MIP also uses the acronyms RSUT (standing for Radiation Shortwave Up Top of atmosphere) and RLUT (standing for Radiation Longwave Up Top of atmosphere) to respectively refer to TRS and TET fluxes. This naming convention is used within the NetCDF products (see Section 4.2).

This document describes the available products (including example images), gives a basic description of the algorithm and a brief overview of the products’ accuracy. Additionally, a technical description of the data including information on the file format and the data access is provided in the last sections.

3 Description of TOA radiation "MVIRI/SEVIRI Data Record"

3.1 Introduction

At the TOA, the following radiative fluxes are defined: the TOA Incoming Solar (TIS), the TOA Reflected Solar (TRS) and the TOA Emitted Thermal (TET).

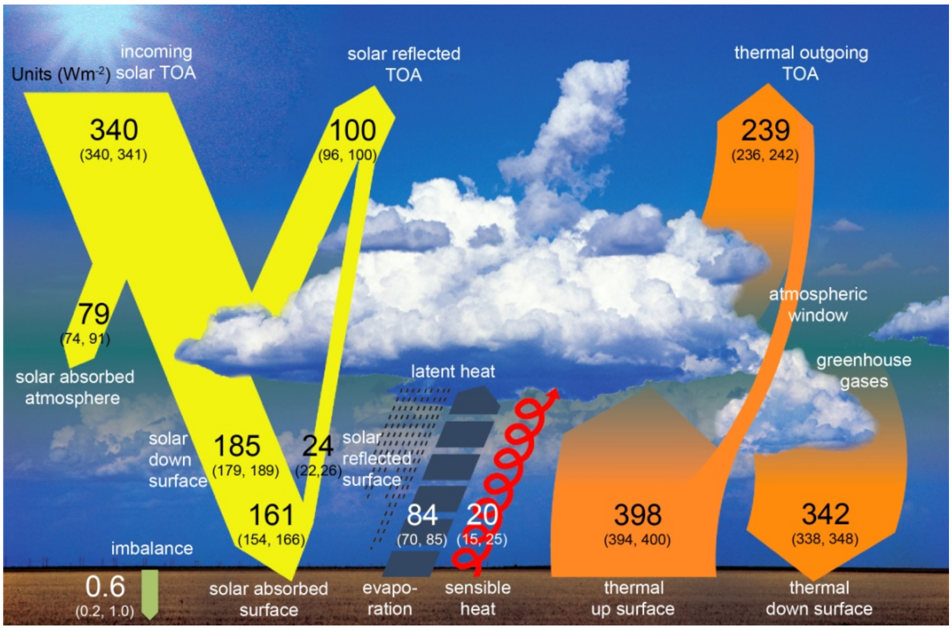

Figure 1: Schematic diagram of the Earth Radiation Budget (from Wild et al., 2013). Numbers indicate best estimates or the magnitudes of the globally averaged energy balance components together with their uncertainty ranges, representing present day climate conditions at the beginning of the twenty first century. Units are Wm^{-2}.

These three components of the Earth Radiation Budget (ERB) are the driver of the climate on our planet. In the frame of climate monitoring, the continuous monitoring of these fluxes is of prime importance to understand climate variability and change. The nature of these quantities, which are defined at TOA, makes the use of satellite observations especially useful.

Over the Meteosat Field Of View (FOV), BB observations of the TRS and TET are available since 2004 from the GERB instruments (Harries et al., 2005) on-board the Meteosat Second Generation (MSG) satellites. The instruments' observations are processed by the GERB team, a consortium including institutions in Germany, the United Kingdom and Belgium. Currently, GERB Edition-1 instantaneous fluxes are generated (Dewitte et al., 2008) and made available to the user community. Within CM SAF, the GERB Edition-1 instantaneous fluxes have been daily and monthly averaged, as well as monthly averaged of the hourly integrated values. These data records have been released in 2013, with product identifier CM-113 (TRS) and CM-115 (TET).

Meteosat observations from around 0° longitude[1] are however available since 1982 and have been used to derive a data record of surface radiation in CM SAF. Given the overlap between the MVIRI and GERB instruments in the period 2004-2006, empirical NB to BB

[1] This is the nominal position of the Meteosat satellites. The operational one might be slightly different as for Meteosat-8 which was located at 3.5° West.

regressions can be derived to “unfilter” the MVIRI channel observations, making the estimation of instantaneous fluxes from 1982 to 2006 possible. From 2004 onward, this estimation can be built on the MVIRI-like visible, water vapour and infrared channels simulated from the NB channels of the SEVIRI instrument (Schmetz et al., 2002). This opens the door to the generation of a homogeneous data record covering more than 30 years. Consequently, it is proposed to use the Meteosat first and second generations’ observations to construct long geostationary-based data records of TRS and TET radiative fluxes.

3.2 Products definition

TRS and TET fluxes are defined as fluxes per unit area at TOA and are expressed in $W.m^{-2}$ units. They are mathematically described as the integral of the directional unfiltered BB radiances (L) over all viewing directions defined by the Viewing Zenith Angle (VZA) and the Relative Azimuth Angle (RAA):

$$F = \int_{VZA=0}^{\frac{\pi}{2}} \int_{RAA=0}^{2\pi} L(VZA, RAA).\cos(VZA).\sin(VZA)\, dVZA\, dRAA$$

TRS and TET fluxes are not defined in terms of wavelength but in terms of source: the TRS contains all the incoming solar radiation that is reflected back to space by the Earth (thus the TRS is directly related to the Earth albedo) while the TET contains all the radiation created by thermal emission in the Earth-atmosphere system which escapes at the TOA (also known as the Outgoing Longwave Radiation).

As the Earth is an ellipsoid, the TOA fluxes obviously decrease with the altitude at which they are defined/measured as the inverse of the square of the distance to the Earth centre. The reference level for the MVIRI/SEVIRI data record is set to 20 km above the mean sea level, which is consistent with CERES EBAF and should allow a direct comparison with climate models.

To compare the MVIRI/SEVIRI data records with other reference data records, users may be advised to first check if the reference levels are identical. If not, the data records should be rescaled to the same reference level. To scale the fluxes from a reference level h_1 to another reference level h_2, the following multiplicative factor should be used:

$$\frac{(R + h_1)^2}{(R + h_2)^2}$$

where R is the radius of the Earth (in the same unit as h_1 and h_2).

3.3 Description of the input data

3.3.1 MVIRI Level 1.5 data

The MVIRI instruments are high resolution radiometers on-board the Meteosat First Generation (MFG) satellites that have been operating from 1977 until 2006. They provide a continuous imaging of the Earth over the Meteosat FOV which is observed from South to North and from East to West. A full Earth scan is performed every 30 minutes. The MVIRI instruments measure radiation using a reflecting telescope within three spectral bands chosen in accordance with Meteosat's primary task of mapping the distribution of clouds and water vapour. These bands are the visible (VIS), the water vapour (WV) and the thermal infrared (IR). They provide a spatial resolution at sub-satellite point of 2.5 km x 2.5 km and 5 km x 5 km respectively for the shortwave (SW) and the longwave (LW) channels.

The MFG series of satellites consists of seven spin-stabilised geostationary satellites, called Meteosat-1 to -7. However, Meteosat-1 failed after two years due to a design fault and its images were never transcribed into the archive. All the MVIRI instruments have been working at the nominal position of 0° longitude and for some of them have been moved afterwards to other locations on the geostationary ring in support of other programs. The Meteosat system is designed as a dual-satellite service, always keeping an additional satellite in orbit as back up.

The MVIRI Level 1.5 data were retrieved from the EUMETSAT Data Centre as images of 5000 x 5000 pixels for the visible channel and 2500 x 2500 pixels for the thermal channels. The values are coded on 8 bits. However, for the VIS images of Meteosat-2 and -3 the digitalization of the detector's signal has been done on only 6 bits. The level 1.5 data are built from the original level 1.0 data by correcting them for undesirable geometrics effects and by rectifying them on a reference geostationary projection.

3.3.2 **SEVIRI Level 1.5 data**

The successor of MVIRI, called SEVIRI, is a line by line scanning radiometer, on-board the MSG satellites, measuring radiation through 12 spectral channels: 11 narrow channels and one broader High-Resolution Visible (HRV) channel. The SEVIRI instrument provides an unprecedented repeat cycle of acquisition of 15 minutes. The 11 narrow channels are composed of 3 solar and 8 thermal infrared channels in which SEVIRI observes the full Earth's disk with a sampling distance of 3 km at nadir. The Meteosat FOV is scanned from South to North and from East to West. Due to data rate limitations, the HRV channel provides images of only half of the Earth's disk in the East-West direction but with a 1 km resolution at sub-satellite point. Among the 11 narrow spectral channels, only the following five are used to generate the MVIRI/SEVIRI data record: the VIS0.6 and VIS0.8 visible bands, the WV6.2 water vapour absorption band and the IR10.8 and IR12.0 thermal infrared bands.

The first satellite of this new generation, MSG1 or Meteosat-8, was launched in August 2002. So far the 4 MSG satellites (Meteosat-8, -9, -10 and -11) have been sent into space. The MSG prime satellites have always been located at a nominal longitude of 0°, except Meteosat-8 which has been operating at a position of 3.5° West.

The SEVIRI Level 1.5 data were retrieved from the EUMETSAT Data Centre in count images of 3712 x 3712 pixels coded on 10 bits. As for MVIRI, these data are retrieved from the original Level 1.0 data by correcting them for undesirable geometrics effects and by geolocating them using the rectified reference projection.

3.4 Summary of user requirements

[RD1] discusses the application areas and user requirements for such geostationary-based data records.

Table 1 summarizes the requirements in terms of stability and Table 2 in terms of accuracy. Table 2 also summarizes the accuracy of the CM-113 and CM-115 products (from [RD5]) as well as documented accuracies of the Clouds and the Earth's Radiant Energy System (CERES; Wielicki et al., 1996) products.

The stability refers to the maximum acceptable change (max-min) of the systematic error over a period of 10 years. Changes of systematic error are primarily caused by switches from one instrument to another and instrumental drift. Stability requirements are only defined for the monthly mean products but, as shown in the Validation Report [RD4], they also characterise the daily mean and monthly mean diurnal cycle products. [RD4] also provides evidence that stability requirements are met over most of the scene types.

Table 1: Stability requirements for CM-23311 and CM-23341 from [RD1].

Products	Threshold	Target	Optimal
TRS all sky MM	4 W/m^2/dec	0.6 W/m^2/dec	0.3 W/m^2/dec
TET all sky MM	4 W/m^2/dec	0.6 W/m^2/dec	0.3 W/m^2/dec[2]

Table 2: Accuracy requirements for CM-23311 and CM-23341 and for the Monthly Mean (MM), the Daily Mean (DM) and the Monthly Mean Diurnal Cycle (MMDC) from [RD1].

Products		Threshold	Target	Optimal	CM-113 and CM-115 accuracy	CERES accuracy	Remarks
TRS CM-23311	**MM**	8 W/m^2	4 W/m^2	2 W/m^2	3.0 W/m^2	4.2 W/m^2	Requirements referring to error: - at 1 standard deviation (RMS error) - at 1° x 1° scale - taking only VZA<60° - does not include error (bias) due to the absolute calibration
	DM	16W/m^2	8 W/m^2	4 W/m^2	5.5 W/m^2	7.8 W/m^2	
	MMDC	16W/m^2	8 W/m^2	4 W/m^2	12.8W/m^2	16.7 W/m^2 (3-hour)	
TET CM-23341	**MM**	4 W/m^2	2 W/m^2	1 W/m^2	2.0 W/m^2	2.0 W/m^2	
	DM	8 W/m^2	4 W/m^2	2 W/m^2	3.6 W/m^2	1.9 W/m^2	
	MMDC	8 W/m^2	4 W/m^2	2 W/m^2	3.1 W/m^2	3.1 W/m^2 (3-hour)	

[2] The new GCOS requirement for TET is 0.2 W/m^2/dec.

3.5 Products features

The main features of the CM-23311 and CM-23341 data records are summarized in Table 3.

Table 3: Main features of the CM-23311 and CM-23341 data records.

Covered period	**32 years**, from 1 February 1983 to 31 January 2015.
VIS channel ageing correction	**Correction** of the MVIRI and SEVIRI ageing using, respectively, the SEVIRI Solar Channel Calibration (SSCC, Govaerts et al., 2004) and Meirink et al. (2013).
Spectral response correction (NB→NB)	MET7-like VIS channels are simulated using **regressions** from NB channels which are **theoretical for MVIRI and empirical for SEVIRI** while MET7-like WV and IR channels are simulated using **theoretical regressions.**
Unfiltering (NB→BB)	**Empirical NB to BB regressions** are used to “unfilter” the MET7-like channel observations. GERB is used “off-line” to tune the regressions.
Fluxes computation (ADM)	Using **CERES TRMM angular dependency models** (ADMs) for the TRS (Loeb et al., 2003) and **theoretical models** for the TET (Clerbaux et al., 2003).
Output quantities	TRS and TET fluxes in **“all sky”** conditions (no clear-sky fluxes in this first edition of the data records).
Temporal characteristics	Fluxes provided as **daily mean**, **monthly mean** and monthly mean of the hourly values (**diurnal cycle**).
Spatial resolution	Data records provided on a regular grid with a spatial resolution of **(0.05°)**^{2}, i.e., about (5.5 km)^2 at sub-satellite point. Internally, TRS and TET are computed as instantaneous fluxes on the geostationary grid at a spatial resolution of **(2.5 km)**^{2} and **(5 km)**^{2} for MFG and of **(3 km)**^{2} for MSG.
Validation	Validation performed at lower resolution (e.g. 1°x1°) by **inter-comparison** with several other data records (CERES EBAF, HIRS OLR CDR, etc.).
Format	A **NetCDF** file format following the CF convention. Information about the data record format is provided in Section 4.

3.6 Processing overview

Figure 2 provides a sketch of the processing into its 4 main processing steps and outlines its main inputs and outputs. Further details on the algorithm are available in the Algorithm Theoretical Basis Document [RD3].

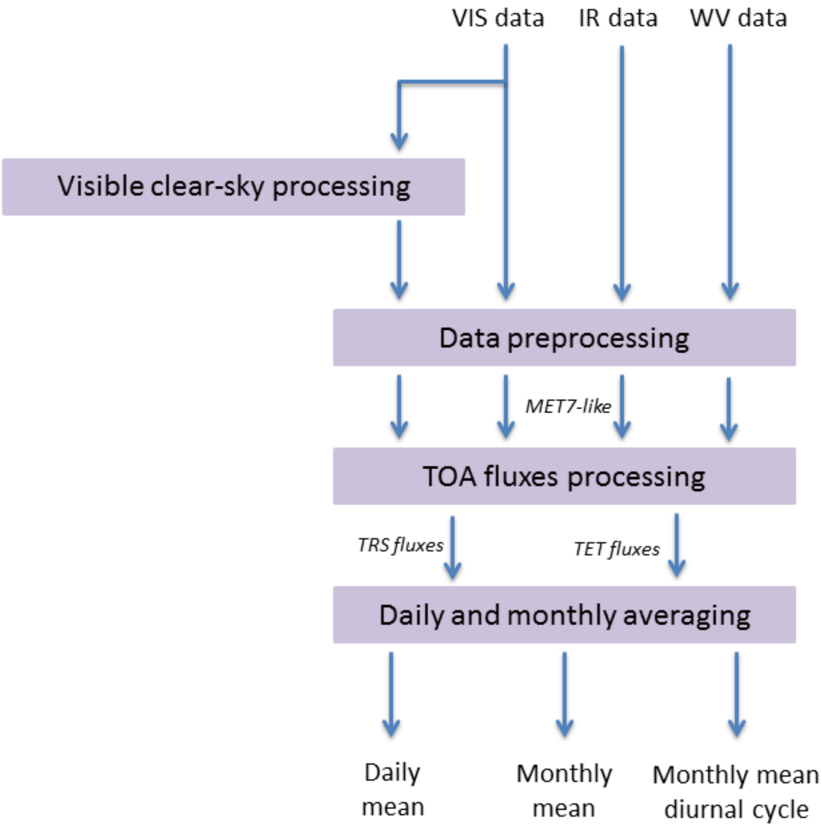

Figure 2: Processing flowchart

- The "**Visible clear-sky processing**" subsystem aims at generating the clear-sky (CS) VIS data that are needed to process the TOA fluxes. In those images, the cloud effect has been filtered by image processing techniques, based on a series of input VIS images covering a period of 61 days around the day of interest. The CS VIS estimates are an important input for cloud detection and characterization.
- The "**Data preprocessing**" subsystem performs several corrections of the input VIS, WV and IR data such as calibration, ageing correction, stripes' interpolation and conversion to equivalent Meteosat-7 ("MET7-like") observations. This preprocessing step is needed as the Meteosat observations are not yet available as Fundamental Climate Data Record (FCDR). In the future, it can be expected that a FCDR will be provided by EUMETSAT.
- In the "**TOA fluxes processing**", the TRS and TET instantaneous radiative fluxes are generated at the time of the imager acquisition from the MET7-like observations through various processing steps: a scene identification (performed only during daytime, i.e. for Solar Zenith Angle (SZA) < 80°), NB to BB relations to "unfilter" the MET7-like radiances, and ADMs to convert BB radiances into fluxes. The TOA fluxes are generated on a geostationary grid at the full resolution, i.e.: (2.5 km)^2, (5 km)^2 and (3 km)^2 at sub-satellite point respectively for the visible MVIRI, the thermal MVIRI and the SEVIRI channels.

- Finally, the "**Daily and monthly averaging**" subsystem performs the averaging of the TRS and TET fluxes in hourly boxes, from which the daily mean, monthly mean and monthly mean diurnal cycle are estimated. A maximum of 3 hours of successive missing data is accepted in the daily averaging; otherwise the daily mean is not issued. A minimum number of 15 days is required to process the monthly mean and monthly mean diurnal cycle. The seasonal change in insolation during the month is also taken into account in the monthly averaging. The data are finally re-gridded from the geostationary grid onto a common regular grid with a spatial resolution of $(0.05°)^2$. This regridding is performed for consistency with other CM SAF products (e.g. CLAAS and SARAH) and also to ease the use of the product.

It should be noted that data from MFG7 (last of the MFG satellites) and MSG1 (first of the MSG satellites) have both been processed during the overlap period (February 2004 – June 2006). This will be used to check that the error characteristics are consistent over the 2 generations of Meteosat satellites.

3.7 Validation approach

Given the absence of "Ground Truth" observations for the TOA fluxes, the validations mostly rely on intercomparisons with other satellite-based data. The GERB data records are not used for validation as they share a large part of the data processing (and observation conditions). Instead, data from instruments on polar platforms (e.g. from CERES and HIRS) are preferred.

The following data records have been used to validate the CM SAF MVIRI/SEVIRI data record: CERES EBAF, CERES SYN1deg-Day, CERES SYN1deg-M3Hour, HIRS OLR CDR (Daily/Monthly), ISCCP FD and ERBS WFOV-CERES. Comparison of multiple sources allows attributing observed problems or artefacts to one of these sources. Validation is performed at a lower spatial resolution of 1°x1° in latitude and longitude (or at the reference resolution, if larger) and in the region between 50°S, 50°N, 50°E and 50°W (which includes the VZA<60° region).

The temporal stability of the MVIRI/SEVIRI data records is evaluated by computing time series of the overall bias between the CM SAF products and the reference data records. Similarly, the accuracy (or processing error) is quantified by computing the RMS error (bias corrected) between the CM SAF products and the reference data records. In general the CERES products and the HIRS OLR CDR products for the TET, are considered as the best references to address the accuracy. The monthly mean and monthly mean diurnal cycle products are especially accurate as they are based on a collection of measurements taken from varying observation directions. This reduces significantly the radiance-to-flux error in the CERES and HIRS monthly means. The additional error introduced in the CM SAF products by missing input data is also investigated. Missing instantaneous MVIRI or SEVIRI observations are temporally interpolated up to 3 hours within the daily processing and this can be a source of error in the daily mean products. When more than 3 hours of successive data is missing, the full day is discarded and no daily mean product is provided. This day is not used in the monthly averaging which is in turn a source of error in the monthly mean product ("sampling problem").

Detailed results of the validation study are presented in the Scientific Validation Report [RD4]. The next section provides a brief summary of the main results.

3.8 Products accuracies

Three sources of error have been identified in the Validation Report [RD4] as affecting the MVIRI/SEVIRI data records: the stability error, the processing error and the missing data error.

The stability error refers to the variability (max-min) in time of the systematic error due to switches from one instrument to another and instrumental drift. The systematic error itself (i.e. the absolute calibration error) is shortly discussed in [RD4].

The processing error is the error resulting from the processing of the MVIRI and SEVIRI observations. This includes the VIS CS preprocessing, the conversion to equivalent Meteosat-7 (“MET7-like”) observations, the conversion to instantaneous radiative fluxes as well as the daily and monthly averaging of these fluxes.

Finally, the missing data error is due to missing data within the MVIRI/SEVIRI data record: either missing images or missing days. A maximum of 3 hours of successive missing images can be interpolated within the daily processing. The interpolation process is of course a source of error in the daily means. When more than 3 successive hours are missing, no daily mean is computed. The resulting missing days are also a source of error in the monthly averaging.

Table 4 gives a summary of the products accuracies from the Validation Report [RD4].

Table 4: Errors affecting the MM, DM and MMDC products from [RD4].

Error sources	**MM**		**DM**		**MMDC**	
	TRS	**TET**	**TRS**	**TET**	**TRS (midday)**	**TET**
Stability error	Stability of all the products better than 4 W/m^2 (max-min) except for the TET during a given period in 1987 (MFG2) **(4)**					
Processing error (at 1 std. dev.)	3.6 W/m^2	2.6 W/m^2	6.5 W/m^2	4.2 W/m^2	11.0 W/m^2 **(3)**	3.4 W/m^2
Additional error due to missing input data (1)(2)	0.3 W/m^2/day	0.2 W/m^2/day	0.5 W/m^2	0.3 W/m^2	0.7 W/m^2/day **(3)**	0.3 W/m^2/day

Remarks

1. The reported errors due to missing data do not affect the products without missing data. For the DM products, the missing data error is the 0.9 percentile of the error over days affected by missing images.
2. The missing data error must be added to the processing error (not a root mean summation of these errors).
3. The reported errors for the MMDC of the TRS are estimated for the time intervals with the highest illumination of the Meteosat FOV (i.e. [09-12] and [12-15] UTC)
4. Those months are January, February and March 1987. They have been removed from the data record but are available on request.

3.9 Products examples

Figures 3, 4 and 5 show examples of the TRS (left) and TET (right) products for the MM, DM and MMDC, respectively.

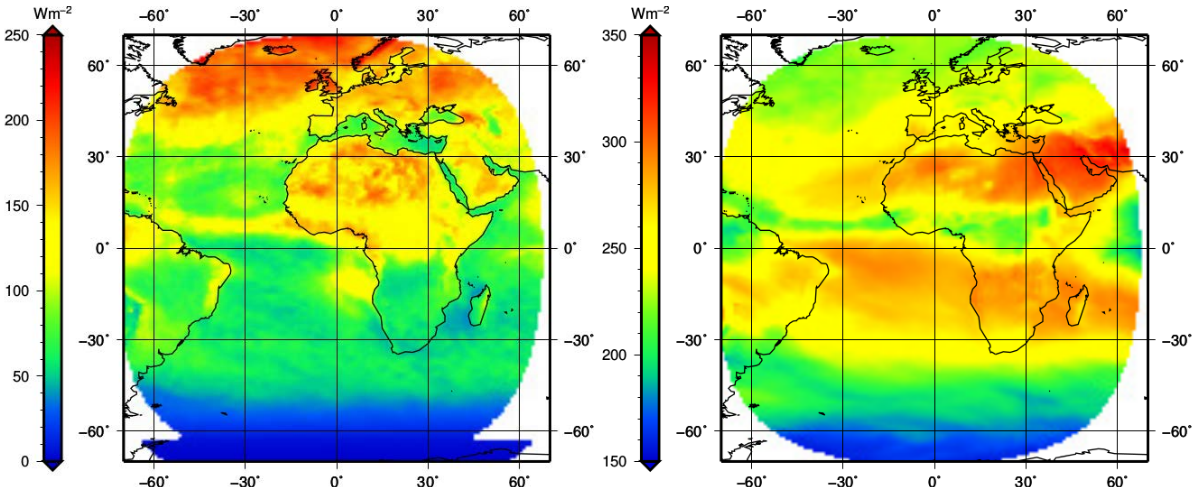

Figure 3: Example of the TRS (left) and TET (right) MM products for June 2005 (MSG1)

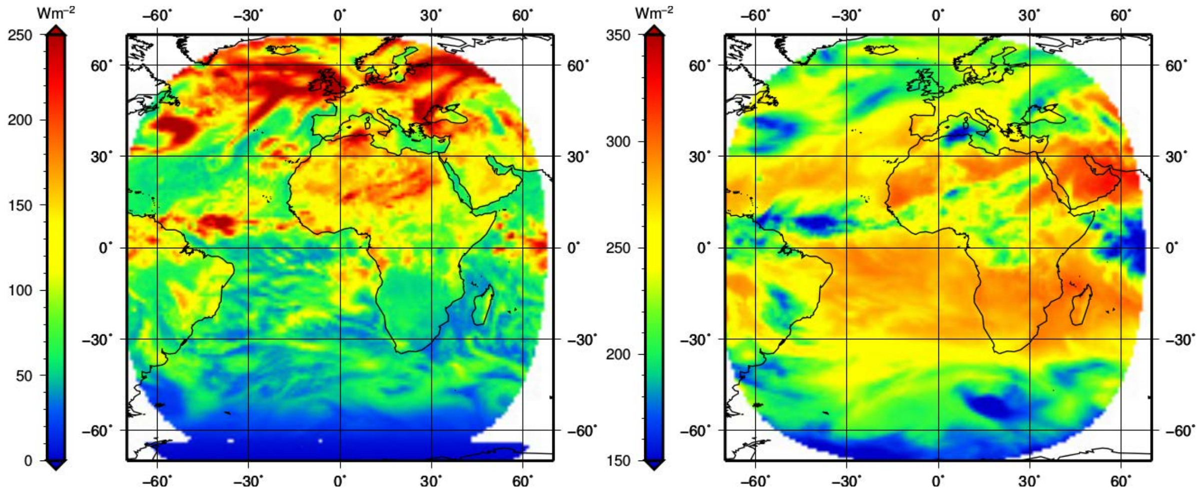

Figure 4: Example of the TRS (left) and TET (right) DM products for the 1st June 2005 (MSG1)

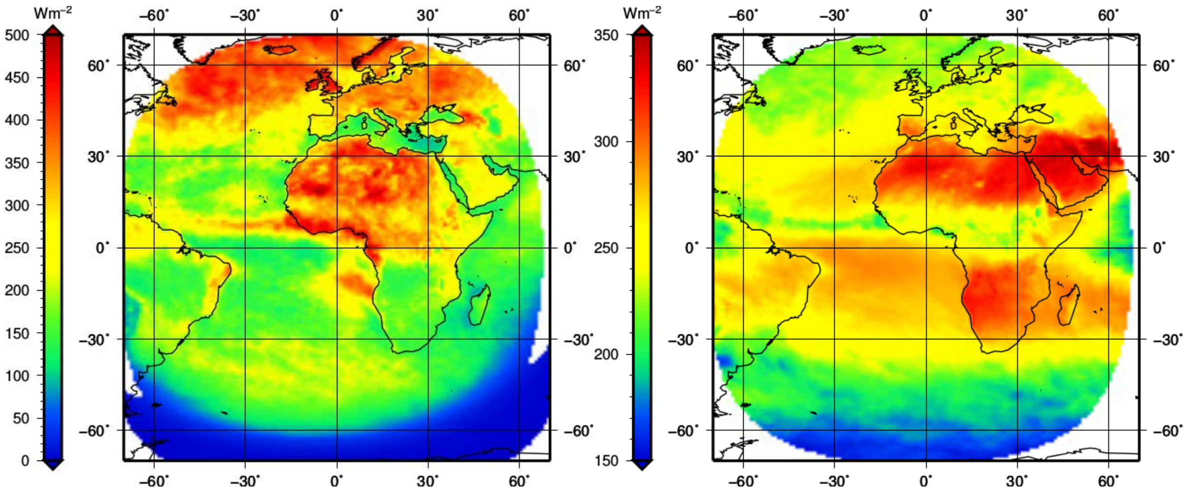

Figure 5: Example of the TRS (left) and TET (right) MMDC products for the [12-15] UTC interval for June 2005 (MSG1)

3.10 General limitations and recommendations

The following points should be considered when using the data.

- The data records are driven by the radiometric levels of the GERB-2 instrument (after application of the “SW calibration update” for this instrument, see Russell, 2006). A close agreement is observed with CERES EBAF for the TRS products (bias of -0.1 W/m^2) but a significant radiometric difference exists for the TET (about -4.9 W/m^2 which is about 2.4%).
- The data are provided up to a VZA of 80° but the TOA flux accuracy is known to decrease rapidly when the angle of observation exceeds 60°. The accuracy values reported in Table 4 are not valid beyond VZA > 60°. This fact should be kept in mind when using the data.
- The data is provided on a regular grid with a 0.05° spacing. However, definition of TOA fluxes at this scale does not make sense especially at high VZA (atmospheric path, cloud parallax …). The fine spatial resolution is aimed to allow an easy and accurate data regridding on larger areas, e.g. the grid box of climate model.
- Although several quality check processes have been applied, it was not possible to look at each individual Meteosat images. Artefacts (such as “stray light” contamination or inaccurate image rectification) in the input images may have been missed and could have affected the final products (sometime reduced during the daily/monthly averaging). Should the user suspect problems in some products please report to the CM SAF team through the helpdesk.
- For this first edition of the MVIRI/SEVIRI TOA radiation data records the backup satellites are not considered. This introduces a large number of gaps in the instantaneous data record. When a gap exceeds 3 hours the full day is discarded (no daily mean products) and this day is not considered in the monthly averaging. This can bias the monthly mean products. Information about missing data is provided to the users via the field “VAR_*nhobs*” in the data files.
- For the MFG satellites there is frequent data interruption around midnight for +/-1 month around the 21 March and Sept. each year (eclipse condition, when the satellite is in the shadow of the Earth). This has few effect on the TRS products but can alter the TET diurnal cycle as the [23-24] and [00-01] fluxes may be interpolated, instead of observed, for those intervals.

- The reference level for the MVIRI/SEVIRI data record is set to 20 km above the mean sea level, which is consistent with climate models and CERES EBAF. To compare with other data records, users may be advised to first check if the reference levels are identical. If not, the data records should be rescaled to the same reference level based on the method given in Section 3.2.
- From 1st Feb. 2004 to 30 June 2006, the data records include overlapping data issued from Meteosat-7 (MFG7) and Meteosat-8 (MSG1). In general, users are advised to use the MFG7 data (as it is based on a broader VIS channels) but the overlapping MSG1 data could be useful if consistency with the subsequent MSG data is important.
- For the Met-2 and -3 satellites, the recalibration of the WV and IR channels with HIRS is not yet available from EUMETSAT. Instead the operational calibration was used with reduced stability of the instrument measurements. Although the effect on the TET products is still within requirements, this fact must be considered by users of the data before 1989. As an exception, the TET for the months of Jan., Feb. and March 1987 (MFG2) are likely to be out of the stability requirement, with a thermal flux bias of about 15 W/m^2. These months have been removed from the data record (where they are thus identified as undefined) to ensure that the user does not use “bad” data unknowingly. However, these data are available on request.
- For the Met-2 to -6 satellites, the spectral response correction is based on the published spectral response curves. Those curves are known to be inaccurate, especially for the VIS channel (Govaerts, 1999; Decoster et al., 2013a, 2013b, 2014a; Decoster, 2014b) and this issue is being addressed in the FIDUCEO H2020 project.
- As GSICS recalibration of the SEVIRI WV 6.2 µm,IR 10.8 µm and 12 µm channels was not (yet) available for the full MSG era, the operational SEVIRI calibration is used in this work. Although some bias is reported for the thermal channels, the biases (e.g. wrt IASI) remain quite stable and do not change significantly during decontamination of the instrument. Therefore, it is not expected that the use of the GSICS recalibration would significantly improve the stability and the TET products.
- Information about cloud phase is needed for an accurate selection of the SW Angular Dependency Model (ADM). With Meteosat, the cloud phase retrieval suffers from the limited information available in the 3 channels of MVIRI. In particular, the misidentification of super cooled water clouds as ice clouds and the misidentification of transparent clouds as water clouds. The effect on the TRS products is however expected to remain small.
- The scene identification process is highly unreliable over snow covered regions as they exhibit VIS reflectances similar to the ones of clouds. The frequency of snow is however limited in the Meteosat FOV and the effect on the TRS products is expected to remain small.
- For permanent snow/ice surfaces, the bright desert ADMs are used since they are the closest models in terms of albedo. Empirical snow ADMs are now available from Kato & Loeb (2005) but are not used due to the difficulty to detect the snow with MVIRI. Improvement of the TRS over snow covered surfaces is addressed in Bertrand et al. (2008).
- The NB to BB regressions and the ADM selection are based on constant surface type map (Bertrand et al., 2006). This could introduce flux error in region of seasonally varying vegetation like the Sahel and also in regions that have experienced significant changes during the last decades.
- For clear ocean in the sun glint region (SGA < 15°) the TRS instantaneous flux is not based on the observation but instead on the CERES TRMM flux models (Loeb et al., 2003). Similarly, in twilight conditions (85° < SZA < 100°), a statistical model of the

TRS is used (Kato and Loeb, 2003). Those "model" fluxes are used in the averaging processes. The effect on the MM and DM products is in general negligible, but can be significant for some hourly intervals of the MMDC TRS products.

- Clerbaux et al. (2003b) have shown that the geostationary TET fluxes may exhibit some bias (about 1%) in clear sky conditions in mountainous areas as the angular dependency models do not account for azimuthal anisotropy. Indeed, from a geostationary orbit, the Northern hemisphere is always observed from the South while it is the reverse in the Southern hemisphere.
- It is expected that the ADM for the thermal radiation will underestimate the anisotropy in case of high semi-transparent clouds. This results in overestimation of the thermal flux in the centre of the FOV (VZA < 50°) and underestimation on the disk edges (VZA > 50°). Similar effect is observed in the GERB ED01 data record. This effect is especially apparent over the warm tropical oceans (see the comparison with CERES EBAF in the Validation Report [RD4]).
- In case of missing data the TRS flux is obtained by interpolation in terms of TOA albedo which is known to increase at high SZA. This could introduce a small underestimation of the flux in case of missing data close to the SZA=85° limit. With geostationary observations, the viewing geometry is obviously fixed. This is likely to introduce some systematic error in the diurnal cycle products.

4 Data format description

This section describes the output format for the MVIRI/SEVIRI products. Product types are:

- TOA Reflected Solar (TRS), which contains the TOA Incoming Solar (TIS) as ancillary field.
- TOA Emitted Thermal (TET)

Each product is provided on a regular grid with a spatial resolution of $(0.05°)^2$, i.e. $(5.5\ \text{km})^2$ at sub-satellite point. The time resolution is either:

- Daily mean
- Monthly mean
- Monthly mean diurnal cycle

All products are coded in NetCDF (Network Common Data Form), version 4, format (http://www.unidata.ucar.edu/software/netcdf/) and following the CF (Climate and Forecast) Metadata Convention version 1.5 (http://cf-pcmdi.llnl.gov/).

4.1 Filename convention

The product filenames follow the CM SAF filename convention and are consequently built following the structure:

PROtsyyyymmddhhmmVerGrSourcLvAr

Character	Meaning
PRO	Three-character coding of product type, i.e. “TRS” or “TET”
t	Time interval of product, i.e. “d” for daily and “m” for monthly
s	Statistics, i.e. “m” for mean and “d” for mean diurnal cycle
yyyymmddhhmm	Date. For the monthly products (mm and md), the first day of the month is taken for the day value (“dd”). The time value (“hhmm”) is “0000” for all products.
Ver	Version number or release number, i.e. “001”
Gr	Grid, i.e. “23” for a regular lat-lon grid at a 0.05° x 0.05° resolution
Sourc	Data source, i.e. “10001” for MVIRI/SEVIRI on Meteosat
Lv	Processing level, i.e. “01”
Ar	Area, i.e. “MH” for the METEOSAT disk (70°S-70°N, 70°W-70°E)

Examples:

- TRSdm200906010000001231000101MH.nc is a file containing the daily mean TRS product for the 1st June 2009
- TETmm200906010000001231000101MH.nc is a file containing the monthly mean TET product for June 2009
- TRSmd200906010000001231000101MH.nc is a file containing the TRS monthly mean diurnal cycle for June 2009

4.2 Data file contents

A NetCDF file contains dimensions, variables and attributes, which are all identified by a specific name (and an ID number). These components can be used together to capture the meaning of data and relations among data fields. The specific content of the NetCDF files is described in the following subsections.

The names of the 3-dimensional data fields within each NetCDF product are fully compliant to the standard convention CMIP5/OBS4MIP. TRS products are provided under the name "radiation shortwave up top of atmosphere" (rsut) and TET products under the name "radiation longwave up top of atmosphere" (rlut). The TSI 3-dimensional data field within the TRS files is provided under the name "radiation shortwave down top of atmosphere" (rsdt).

- **Dimensions:**

Each NetCDF file contains the following dimensions:

Table 5: NetCDF dimensions

Name	Description
lon	Number of data points along the X axis (*x* = 2800)
lat	Number of data points along the Y axis (*y* = 2800)
time	Number of data points along the time axis, i.e. *time*=1 for MM and DM products and *time*=24 for MMDC products
lon_err	Number of data points along the X axis at a 1 degree resolution (*x* = 140)
lat_err	Number of data points along the Y axis at a 1 degree resolution (*y* = 140)

- **Global variables:**

Each NetCDF file contains the following global variables:

Table 6: NetCDF global variables

Name	Description
float lat(lat)	Geographical latitude of grid-box centre [degrees_north]
float lon(lon)	Geographical longitude of grid-box centre [degrees_east]
float time(time)	Start of averaging/composite time period [days counted from 1970-01-01]
float lat_err(lat_err)	Geographical latitude of grid-box centre at a 1 degree resolution (used to compute the errors against CERES products) [degrees_north]
float lon_err(lon_err)	Geographical longitude of grid-box centre at a 1 degree resolution (used to compute the errors against CERES products) [degrees_east]

- **Specific 3-dimensional variables:**

3-dimensional variables consist of the products themselves along with related information. For example, each TRS product is provided along with the TIS information. Also included is the number of hourly integrations that were used for the averaging of the MM and MMDC products. For the DM products, this field is not provided since a fixed number of 24 hourly integrations is always required to enable the daily processing. Two other fields (RMS and bias) are used to give an insight into the accuracy of the product by inter-comparison with CERES EBAF products. Each NetCDF file contains a subset of the following 3-dimensional variables:

Table 7: NetCDF specific 3-dimensional variables

Name	Description
float [3] *rlut (time, lat, lon)*	TET data mean value within the grid box [W/m^2]
float [3] *rsut (time, lat, lon)*	TRS data mean value within the grid box [W/m^2]
float [3] *rsdt (time, lat, lon)*	TIS data mean value within the grid box (provided along with TRS products only) [W/m^2]
float VAR_nhobs (time, lat, lon)	Number of hourly integrations counted during the averaging period; VAR corresponds to the variable name (rsut or rlut). The field is only provided in the MM and MMDC products since it is always 24 for the DM.
float VAR_bias (time, lat_err, lon_err)	Bias estimated against the CERES EBAF products at 1° resolution (*lat_err*=*lon_err*=140); VAR corresponds to the variable name (rsut or rlut). The field is only provided in the MM products.
VAR_rms (time, lat_err, lon_err)	RMS estimated against the CERES EBAF products at 1° resolution (*lat_err*=*lon_err*=140); VAR corresponds to the variable name (rsut or rlut). The field is only provided in the MM products.

[3] This field might be provided as an integer in order to save space, please refer to the NetCDF file.

- **Global attributes:**

Global attributes are common to all products. They feature general information such as the algorithm and version used to generate the product. Global attributes are summarized in Table 8.

Table 8: Global NetCDF attributes

Name	Description
title	Dataset title, i.e. “TOA Reflected Solar Flux” or “TOA Emitted Thermal Flux” followed by “Daily Mean”, “Monthly Mean” or “Monthly Mean Diurnal Cycle”
cmsaf_product_id	CM SAF product identifier, i.e. "CM-23311” or “CM-23341”
satellite	Processed Meteosat satellite (character’s string: MFG2, …, MSG3)
time_resolution	Time resolution, i.e. “daily mean“, “monthly mean“ or “monthly mean diurnal cycle“
version	Product version according to configuration management, i.e. “001”
Conventions	Conventions followed, i.e. "CF-1.5"
creation_date	Date on which the data was created
institution	Institution where the data were produced, i.e. “CMSAF_RMIB”
contact_email	Email contact for information about the data
references	References that describe the data or methods used to produce it

- **Specific attributes:**

The specific attributes feature additional information related to the product such as methods and parameters specific to the algorithm, for example data units or scale factor and offset used to convert compressed data to real data. Specific NetCDF attributes are summarized in Table 9.

Table 9: Specific NetCDF attributes

Name	Description
long_name	Long descriptive name
standard_name	Standard name that references a description of a variable's content in the CF standard name table
start_time	Start of averaging/composite time period [coded as yyyymmdd_hhmmss]
end_time	End of averaging/composite time period [coded as yyyymmdd_hhmmss]
scale_factor	Factor by which the data have to be multiplied before their use.
add_offset	Number that has to be added to the data before their use and after having multiplied by the scale_factor
tsi[31]	Daily TSI values (up to 31) used to estimate the incoming solar flux field (only for the *rsut* variable)
units	Physical units of the data
resolution	Spatial resolution of the data.
valid_min	Minimum valid value
valid_range	Valid range of the data [min,max]
_FillValue	This number represents missing/undefined data. These data needs to be filtered before any processing.

5 Data ordering via the Web User Interface (WUI)

User services are provided through the CM SAF homepage www.cmsaf.eu. The user service includes information and documentation about the CM SAF and the CM SAF products, information on how to contact the user help desk and allows to search the product catalogue and to order products.

On the main webpage, 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 a central and most up to date documentation. However, some of the key features and services are briefly described in the following sections.

5.1 Product ordering process

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 you selected product type and time period you want to obtain, you can choose your preferred type of data transfer. This is either via a temporary ftp account (the default setting), or by CD/DVD or email. Your order will be confirmed via email, and you will get another email once the data have been prepared. If you selected the ftp data transfer, this second email will give you information on how to access the ftp server.

5.2 Contact User Help Desk staff

You can contact the User Help Desk staff in case you have questions. You find contact information (e-mail address contact.cmsaf@dwd.de, telephone and fax number) on the CM SAF main webpage (www.cmsaf.eu) or the Web User Interface main page.

5.3 Feedback/User Problem Report

Users of the CM SAF products and services are encouraged to provide feedback on the CM SAF product and services to the CM SAF team. EUMETSAT CM SAF is a user driven service and is committed to consider the needs and requirements of its users in the planning for product improvements and additions. Users can either contact the User Help Desk (e-mail address contact.cmsaf@dwd.de) or use the “User Problem Report” page. Users are also invited to provide their specific requirements on future products for their applications. 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.

5.4 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.

6 Copyright and Disclaimer

The user of CM SAF data agrees to respect the following regulations:

6.1 Copyright

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 in publications, presentations, web pages etc., ***EUMETSAT's copyright credit must be shown by displaying the words "copyright (year) EUMETSAT" on each of the products used.***

6.2 Acknowledgement and Identification

When exploiting EUMETSAT/CM SAF data you are kindly requested to acknowledge this contribution accordingly and make reference to the CM SAF, e.g. by stating "The work performed was done (i.a.) by using data from EUMETSAT's Satellite Application Facility on Climate Monitoring (CM SAF)". It is highly recommended to clearly identify the product version used.

6.3 Re-distribution of CM SAF data

Please do not re-distribute CM SAF data to 3rd parties. The use of the CM SAF products is granted free of charge to every interested user, but CM SAF has an essential interest to know how many and what users the CM SAF has. This helps to ensure of the CM SAF operational services as well as its evolution according to users needs and requirements. Each new user shall register at CM SAF in order to retrieve the data.

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8 Glossary

AD	Applicable Document
ADM	Angular Dependency Model
ATBD	Algorithm Theoretical Basis Document
BB	Broadband
CDOP	Continuous Development and Operations Phase
CERES	Clouds and the Earth’s Radiant Energy System
CF	Climate and Forecast
CLAAS	CLoud property dAtAset using SEVIRI
CM SAF	Satellite Application Facility on Climate Monitoring
CS	Clear-sky
DEEP-C	Diagnosing Earth's Energy Pathways in the Climate system
DGCDD	Dataset Generation Capability Description Document
DM	Daily Mean
DWD	Deutscher Wetterdienst (German MetService)
EBAF	Energy Balanced And Filled
ECMWF	European Centre for Medium Range Forecast
ECV	Essential Climate Variable
ERB	Earth Radiation Budget
ERBS	Earth Radiation Budget Satellite
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FCDR	Fundamental Climate Data Record
FMI	Finnish Meteorological Institute
FOV	Field Of View
GERB	Geostationary Earth Radiation Budget Instrument
GSICS	Global Space-based Inter-Calibration System
HIRS	High-resolution Infrared Radiation Sounder
HRV	High-Resolution Visible
IASI	Infrared Atmospheric Sounding Interferometer
IOP	Initial Operations Phase
IR	Infrared
ISCCP	International Satellite Cloud Climatology Project

KNMI	Koninklijk Nederlands Meteorologisch Instituut
LW	Longwave
LW TOA	Longwave TOA
MeteoSwiss	Meteorological Service of Switzerland
MFG	Meteosat First Generation
MM	Monthly Mean
MMDC	Monthly Mean Diurnal Cycle
MOP	Meteosat Operationnal Program
MSG	Meteosat Second Generation
MVIRI	Meteosat Visible and InfraRed Imager
NB	Narrowband
NetCDF	Network Common Data Form
NMHS	National Meteorological and Hydrological Services
OLR	Outgoing Longwave Radiation
PUM	Product User Manual
RAA	Relative Azimuth angle
RD	Reference Document
RLUT	Radiation Longwave Up Top of atmosphere
RMIB	Royal Meteorological Institute of Belgium
RMS	Root Mean Square
RSR	Reflected Shortwave Radiation
RSUT	Radiation Shortwave Up Top of atmosphere
RSW	Reflected Shortwave
SAF	Satellite Application Facility
SARAH	Surface Solar Radiation DataSet - Heliosat
SBDART	Santa Barbara DISORT Atmospheric Radiative Transfer model
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SMHI	Swedish Meteorological and Hydrological Institute
SSCC	SEVIRI Solar Channels Calibration
SW	Shortwave
SW TOA	Shortwave TOA
SZA	Solar Zenith Angle
TCDR	Thematic Climate Data Records

TET	Top Of the Atmosphere Emitted Thermal
TIS	Top of the Atmosphere Incoming Solar
TOA	Top Of the Atmosphere
TRMM	Tropical Rainfall Measurement Mission
TRS	Top of the Atmosphere Reflected Solar
UKMO	UK Met-Office
VIS	Visible
VZA	Viewing Zenith Angle
WFOV	Wide Field Of View
WUI	Web User Interface
WV	Water Vapour