EUMETSAT Satellite Application Facility on Climate Monitoring

# Algorithm Theoretical Basis Document

# ICDR SEVIRI Clouds - based on CLAAS-2 methods

| | |
|---|---|
| **Fractional Cloud Cover** | **CM-5010** |
| **Cloud Top level** | **CM-5030** |


| | |
|---|---|
| Reference Number: | SAF/CM/DWD/ICDR/SEV/CLD/ATBD |
| Issue/Revision Index: | 1.0 |
| Date: | 27.04.2018 |

## Document Signature Table

| | Name | Function | Signature | Date |
|---|---|---|---|---|
| Authors | Martin Stengel<br>Stephan Finkensieper | CM SAF scientist<br>CM SAF scientist | | 11.01.2018 |
| Editor | Rainer Hollmann | Science Coordinator | | 11.01.2018 |
| Approval | | CM SAF Steering Group | | 27.04.2018 |
| Release | Martin Werscheck | Project Manager | | 27.04.2018 |

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## Document Change Record

| Issue/ Revision | Date | DCN No. | Changed Pages/Paragraphs |
|---|---|---|---|
| 1.0 | | SAF/CM/DWD/ICDR/SEV/CLD/ATBD/ | Initial version |
| | | | |
| | | | |

## Table of Contents

## List of Figures



## List of Tables

## Applicable documents

| Reference | Title | Code |
|---|---|---|
| **AD 1** | CM SAF Product Requirements Document | SAF/CM/DWD/PRD/3.0 |

## Reference documents

| Reference | Title | Code |
|---|---|---|
| **RD 1** | MSG Level 1.5 Image Data Format Description | EUM/MSG/ICD/105 v7, 4 Dec. 2013 |
| **RD 2** | Algorithm Theoretical Basis Document SAFNWC/MSG "Cloud Products" (CMa-PGE01 v3.2, CT-PGE02 v2.2 & CTTH-PGE03 v2.2) | SAF/NWC/CDOP/MFL/SCI/ATBD/01, Issue 3, Rev. 2, 15 Feb. 2012 |
| **RD 3** | Product User Manual SEVIRI cloud products CLAAS Edition 2 | SAF/CM/KNMI/PUM/SEV/CLD Issue 2, Rev. 1, 10. June 2016 |
| **RD 4** | Validation Report SEVIRI cloud products CLAAS Edition 2 | SAF/CM/KNMI/VAL/SEV/CLD Issue 2, Rev. 1, 10. June 2016 |
| **RD 5** | Algorithm Theoretical Basis Document SEVIRI cloud products CLAAS Edition 2 | SAF/CM/KNMI/PUM/SEV/CLD Issue 2, Rev. 3, 17. June 2016 |
| **RD 6** | Validation Report ICDR SEVIRI Clouds – based on CLAAS-2 methods | SAF/CM/DWD/ICDR/SEV/CLD/VAL Issue 1, Rev. 0, 11. January 2018 |
| **RD 7** | Product User Manual ICDR SEVIRI Clouds – based on CLAAS-2 methods | SAF/CM/DWD/ICDR/SEV/CLD/PUM Issue 1, Rev. 0, 11. January 2018 |

# 1 The EUMETSAT SAF on Climate Monitoring

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 (CDRs) derived from operational meteorological satellites.

In particular the generation of long-term data sets is pursued. The ultimate aim is to make the resulting data sets 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 sets that can serve applications related to the new Global Framework of Climate Services initiated by the WMO World Climate Conference-3 in 2009. CM SAF is supporting climate services at national meteorological and hydrological services (NMHSs) with long-term data records but also with data sets 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 sets 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 set assessments performed by research organisations such as WCRP. 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, www.cmsaf.eu/. Here, detailed information about product ordering, add-on tools, sample programs and documentation is provided.

# 2 Executive summary

This Algorithm Theoretical Basis Document (ATBD) provides information on the processing algorithms and chain implemented for the generation of the ICDR SEVIRI Clouds, which provides a routinely generated continuation (see Figure 2-1) of a product subset (CFC and CTO) of CLAAS-2 (CM SAF CLoud property dAtAset Using SEVIRI, edition 2; Benas et al., 2017 and [RD 3], [RD 4] and [RD 5]). Additional information about the ICDR SEVIRI Clouds can be found in the Validation Report ([RD 6]) and the Product User Manual Document ([RD 7]).

As CLAAS-2, the ICDR SEVIRI Clouds products are derived from inter-calibrated measurements of the Spinning Enhanced Visible Infra-Red Imager (SEVIRI) mounted on the Meteosat Second Generation (MSG) satellites. The cloud property algorithms applied are part of the MSG v2012 software package by the NWCSAF (SAF for support to Nowcasting and Very Short Range Forecasting, documented in [RD 2] and Derrien and Le Gléau (2005).

Although the algorithms in CLAAS-2 and ICDR SEVIRI Clouds are identical, certain input data and intercalibration procedures had to be changed to facilitate a routine operation. Furthermore, a critical bug affecting monthly mean cloud top parameters has been fixed. Where applicable, these changes are highlighted in the respective section.

The document seamlessly describes all elements of the production of the final ICDR SEVIRI Clouds products which are structured in the following three topics.

1. A description of the data sources and a summary of SEVIRI instrument characteristics are given, including a description of the inter-calibration applied to MSG measurements.
2. A report on the derivation of the cloud products by MSG v2012 algorithms. Note that significant parts of the MSG v2012 algorithms have already been documented in the ATBDs [RD 2], which will be referred to in this document when appropriate.
3. An elaboration on the production of the daily/monthly means and monthly mean diurnal cycle products (Level-3 data) based on the Level-2 products provided by MSG v2012.

Basic accuracy requirements are defined in the product requirements document [AD 1].

The ICDR SEVIRI Clouds products contain the following cloud properties:

Fractional Cloud Cover [CM-5010, CFC, Section 5.1 and Section 6.2.1]

Cloud Top level [CM-5030, CTO, Section 5.2 and Section 6.2.2]

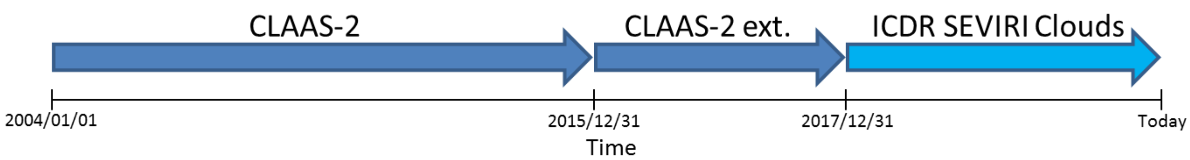


**Figure 2-1** Schematic view of ICDR SEVIRI Clouds continuing the CLAAS-2 records series.

# 3 Processing of measured SEVIRI radiances (Level-1.5)

## 3.1 The SEVIRI instrument

SEVIRI is a passive optical imaging radiometer with 12 spectral channels at visible and infrared wavebands. SEVIRI instruments are mounted on the geostationary MSG satellites and measure from 2004 onwards. MSG 1, MSG 2, MSG 3 and MSG 4 measurement images are to align to each other and centred at 0°/0° longitude/latitude. The region seen by a SEVIRI instrument is shown in Figure 6-1. It covers Africa, Europe, partly South America, the Atlantic Ocean and the Middle East. All four SEVIRI instruments on MSG 1, MSG 2, MSG 3 and MSG 4 are identical in construction. Table 3-1 lists the main characteristics of the SEVIRI instrument. In the following the measurement principle is explained in the following.

An MSG satellite spins around its vertical axis with 100 rpm, the SEVIRI instrument uses this spin to scan the earth line-by-line in east-west direction. After each line, the scan mirror is moved on step in South-North direction and the next line is scanned. The acquisition time of one image is 12 minutes, together with onboard calibration and scan mirror retrace a nominal repeat cycle of 15 minutes is achieved.

For each of the 12 spectral channels three detectors acquire three lines of an image simultaneously. The HRV channel however has 9 detectors and 9 lines are obtained per revolution. In Table 3-2 SEVIRI's channels and their characteristics can be found. After each scan a black body calibration is applied for the infrared channels as well as a measurement of the deep space radiance. The deep space radiance corresponds to zero input radiance and is subtracted from the measured signal. The black body calibration is undertaken by moving a black body into the telescope in the intermediate focal plane. The accuracy of SEVIRI was determined prior to the launch in space. The infrared channels measure brightness temperature with an accuracy of < 1 K for a target of 300 K while the bias for the VIS channels ranges from 0.08 to 0.52 W/(m² sr µm), for more details see Table 3-3.

After acquiring an image, the data are sent to the EUMETSAT ground segment where they are further processed into Level 1.5 data as described in the next section. After this processing step the images are ready to be disseminated to the user.

**Table 3-1** SEVIRI instrument features.

| |
|---|
| line-by-line scanning radiometer |
| 12 spectral channels 0.4 -13.4 µm, image every 15 min. |
| Scan duration 12 min. |
| blackbody calibration at every scan (15 min.) |
| spatial resolution: 3 km at sub-satellite point |
| radiometric bias: <1 K for IR and 1.5 – 11 W $m^{-2}$ $sr^{-1}$ $mm^{-1}$ for VIS channels |

**Table 3-2** SEVIRI channel characteristics (source: EUMETSAT, 2010)

| Channel ID | Absorption Band / Channel Type | Nominal Centre Wavelength (µm) | Spectral Bandwidth (µm) | Dynamic Range | Spectral Bandwidth As % of energy actually detected within spectral band |
|---|---|---|---|---|---|
| HRV | Visible High Resolution | Nominally 0.75 | 0.6 to 0.9 | 0 - 459 W/m2 sr m (scaled at centre frequency) | Precise spectral characteristics not critical |
| VIS 0.6 | VNIR Core Imager | 0.635 | 0.56 to 0.71 | 0 - 533 W/m2 sr m | 98.0 % |
| VIS 0.8 | VNIR Core Imager | 0.81 | 0.74 to 0.88 | 0 - 357 W/m2 sr m | 99.0 % |
| IR 1.6 | VNIR Core Imager | 1.64 | 1.50 to 1.78 | 0 - 75 W/m2 sr m | 99.0 % |
| IR 3.9 | IR / Window Core Imager | 3.92 | 3.48 to 4.36 | 0 - 335 K | 98.6 % |
| IR 6.2 | Water Vapour Core Imager | 6.25 | 5.35 to 7.15 | 0 - 300 K | 99.0 % |
| IR 7.3 | Water Vapour Pseudo-Sounding | 7.35 | 6.85 to 7.85 | 0 - 300 K | 98.0 % |
| IR 8.7 | IR / Window Core Imager | 8.70 | 8.30 to 9.10 | 0 - 300 K | 98.0 % |
| IR 9.7 | IR / Ozone Pseudo-Sounding | 9.66 | 9.38 to 9.94 | 0 - 310 K | 99.0 % |
| IR 10.8 | IR / Window Core Imager | 10.80 | 9.80 to 11.80 | 0 - 335 K | 98.0 % |
| IR 12.0 | IR / Window Core Imager | 12.00 | 11.00 to 13.00 | 0 - 335 K | 98.0 % |
| IR 13.4 | IR / Carbon Dioxide Pseudo-Sounding | 13.40 | 12.40 to 14.40 | 0 - 300 K | 96.0 % |

**Table 3-3** SEVIRI channel noise budgets expressed in K for IR channels and W/(m² sr µm) as reported in Schmid (2000)

| **Channel (µm)** | HRV | 0,6 | 0,8 | 1,6 | 3,9 | 6,2 | 7,3 | 8,7 | 9,7 | 10,8 | 12 | 13,4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Noise** | 0,52 | 0,39 | 0,36 | 0,08 | 0,24 | 0,4 | 48 | 0,15 | 0,24 | 0,13 | 0,21 | 0,29 |
| **Spec.** | 1,07 | 0,53 | 0,49 | 0,25 | 0,35 | 0,75 | 0,75 | 0,28 | 1,5 | 0,25 | 0,37 | 1,8 |

## 3.2 SEVIRI Level 1.5 Data

For the derivation of cloud products SEVIRI level 1.5 data from the operational 0-degree MSG satellite are used. That is MSG3 until 2018-02-20 and MSG4 afterwards. Exceptions are maintenance periods of in which measurements of the backup MSG satellite are used. Level 1.5 data are image data that have already undergone the following preprocessing steps in the EUMETSAT ground segment:

- Removal of unwanted radiometric and geometric effects
- Re-projection and Geolocation. The image centre is now at (lat, lon)=(0,0) degrees independent of the actual subsatellite point
- Calibration and Radiance-Linearization

Although the original image dimensions are 3712x3712 rows/columns, we use a slightly smaller 3636x3636 domain with less space pixels.

**Calibration:**

SEVIRI does not carry an on-board calibration device for the solar channels. Therefore, EUMETSAT operates a vicarious calibration system using Earth targets (desert and ocean) as reference. Analyses by Doelling et al. (2004) and Ham and Sohn (2010) revealed that the resulting visible channel nominal calibration, provided in the SEVIRI Level-1.5 data files, has a considerable offset with respect to MODIS, which is thought to be a well-calibrated reference instrument. Meirink et al. (2013) extended these previous analyses to the NIR channels and to longer time periods. They used collocated, ray-matched, atmosphere-corrected, near-nadir SEVIRI and Aqua-MODIS reflectances to derive inter-calibration slopes, i.e. multiplicative factors to be applied to SEVIRI nominal reflectance in order to match the MODIS measurements. Recently, this calibration work was extended to cover the full CLAAS-2 time window of 2004 to 2015, including all three SEVIRI instruments that have been active in that period. The same method was applied as described in Meirink et al. (2013) but using MODIS Collection 6 instead of Collection 5 Level-1b data as a reference. Results are shown in Figure 3–2 of [RD 5].The operational MSG-SEVIRI calibration is offset relative to Aqua-MODIS by about -8%, -6% (but -4% for MSG-3), and +3%, for channels 1, 2, and 3, respectively. Furthermore, even if the SEVIRI calibration turns out to be quite stable over time, there are significant trends. For CLAAS-2 processing the calibration slopes shown by the solid lines in Figure 3–2 of [RD 5] were used.

As this intercalibration task is not feasible in a real-time environment, the additional calibration correction applied on top of the operational calibration is fixed:

- MSG3: Slope and offset are fixed to their (inter-calibrated) value at the end of the CLAAS-2 TCDR (2015-12-31) in order to prevent linear extrapolation errors.
- MSG4: Since the parallel dissemination time window for MSG4 is only 2 weeks long, a sound intercalibration is not possible. But as explained above, the offset of the operational calibration has been similar for all MSG instruments in the past which suggests the following heuristic approach. We use the relative calibration slope & offset from MSG3 when it was declared operational (2013-01-21= $t_0$) to correct the operational MSG4 slope & offset in channel $c$ at time $t$:

$$s_{ic}^{MSG4}(c,t) = s_{op}^{MSG4}(c,t) \cdot \frac{s_{ic}^{MSG3}(c,t_0)}{s_{op}^{MSG3}(c,t_0)}$$
$$o_{ic}^{MSG4}(c,t) = o_{op}^{MSG4}(c,t) \cdot \frac{o_{ic}^{MSG3}(c,t_0)}{o_{op}^{MSG3}(c,t_0)}$$

Here, $s$ is the slope and $o$ is the offset. Subscripts $op$ and $ic$ denote the operational and intercalibrated values, respectively. Apparently, the inter-calibrated slope and offset only change if the operational calibration does. The values of the RHS fractions at 2013-01-21 are approximately 109%, 103% and 97% for channels 1, 2, and 3, respectively.

# 4 NWP Data

Additional to SEVIRI level 1.5 data, MSGv2012 requires the following parameters from an NWP model for accurate computations:

- Surface: Geopotential (129), Surface Pressure (134), Total Column Water Vapour (137), Soil Temperature (139), 2m Temperature (167), 2m Dewpoint Temperature (168), Land Sea Mask (172), Skin Temperature (235)
- Pressure levels (1000, 950, 925, 900, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 10) hPa: Geopotential (129), Temperature (130), U wind component (131), V wind component (132), Relative Humidity (157)

The numbers in brackets are the corresponding GRIB codes. For CLAAS-2 we use the ERA-Interim reanalysis, for the ICDR we had to switch to ECMWF's operational IFS model, because ERA-Interim is not available in near-real-time. In both cases the temporal resolution is 3 hours and the spatial resolution is 0.5x0.5 degrees.

# 5 Retrieval of pixel-based cloud properties

This section provides information on the processing of MSG v2012 to retrieve cloud parameters from inter-calibrated SEVIRI measurements. Each parameter is briefly introduced in the following with the respective detailed ATBD being referred to.

## 5.1 Cloud detection

This product is derived directly from results of a cloud screening or cloud masking method. The cloud mask comprises 4 categories: Cloud filled, cloud-free, cloud contaminated and snow/ice contaminated. The cloud screening and cloud masking is performed using a custom modified version of the NWC SAF MSG v2012 algorithm. The basic algorithm is described in more detail in [RD 2], the custom modifications are explained below.

In the default SAFNWC-MSGv2012 cloud masking algorithm, computation time is reduced by computing one threshold for segments of 4x4 SEVIRI pixels. In order to exploit the full potential of the SEVIRI sensor, we reduce the segment size to one, so that individual thresholds are computed for each pixel. The increase in computation time is compensated by a higher degree of parallelization.

Some coastal cloud mask artefacts were discovered which are corrected as described in Section 4.1.2 of [RD 5].

## 5.2 Cloud Top level

Three versions of the CM SAF Cloud Top product exist: 1. Cloud Top Temperature (CTT), expressed in Kelvin; 2. Cloud Top Height (CTH), expressed as altitude above sea level (m); 3. Cloud Top Pressure (CTP), expressed in pressure co-ordinates (hPa). Cloud top products are retrieved with the following method.

In a first step, cloudy pixels are separated into three classes depending on cloud type or its opacity respectively: 1. very low, low or medium thick as well as middle level clouds; 2. high opaque clouds; 3. high semi-transparent clouds.

Using RTTOV (http://research.metoffice.gov.uk/research/interproj/nwpsaf/rtm/) the corresponding radiances and brightness temperatures for overcast and clear sky are simulated for each pixel, with vertical profiles of temperature and humidity analysis from ERA-Interim (Dee et al., 2012) as ancillary input. The SEVIRI channels used are: 6.2, 7.3, 13.4, 10.8, 12.0 µm.

For very low, low or medium thick clouds as well as opaque clouds the cloud top pressure is retrieved as the best fit between the simulated and the measured 10.8µm brightness temperatures. Also the possibility of a low level thermal inversion is taken into account with the help of the temperature profile from ECMWF's operational IFS model at the respective pixel. In that case the very low, low or medium clouds are assumed to form at the inversion level, while they can also rise above that level if their brightness temperatures are colder than the air temperature below the thermal inversion minus an offset, that depends on the type of the inversion (dry air above the inversion level or not). This dependence results from the question if the inversion follows a dry or wet adiabatic curve.

In case of semitransparent clouds the H2O/IRW intercept method is used, in which the radiances in each sounding channels is used together with the radiance in the window channel and each radiance pair is compared to simulated radiances of opaque clouds. When cloud top pressure cannot be obtained from at least two sounding channels, the radiance rationing method is used, in which the ratio of radiances from 2 channels is compared to simulated radiances at clear sky conditions for a fixed temperature profile.. For the latter a linear relationship of radiance between 2 spectral bands is assumed, but a curve for a window and a sounding channel. For opaque clouds this technique is always applied as preceding test, in order to remove any pixels that are semitransparent but where in fact falsely labeled as opaque by the cloud type test.

The retrieval algorithms are part of the NWC SAF MSG v2012 package, details can be found in [RD 2]. These algorithms were applied with a patch as described below.

**Patch for Extremely High Cloud Top Temperature:**

Extremely high cloud top temperatures > 340K were noticed in the level 2 data. Further investigation revealed that these were actually very low retrieved temperatures that fell below the lower scaling limit in the output files, and were then rendered as high temperatures. After contacting SAFNWC, a patch was provided to fix this problem. It was caused by a software bug in a spatial smoothing module.

# 6 Generation of daily/monthly means, and monthly mean diurnal cycles (Level 3)

ICDR SEVIRI Clouds contains Level 3 products. They are inferred from intermediate, pixel-level retrieval results (Level 2, not part of ICDR SEVIRI clouds) retrieved by employing the MSG v2012 package. The Level 3 outputs produced are fields of daily and monthly averages, and monthly mean diurnal cycles of CFC and CTO with specification defined in [AD 1]. These specifications are summarized in section 6.1. The covered geographic area is shown in Figure 6-1. The Level 2 data pixels are projected onto a regular latitude/longitude grid with a resolution of $(0.05°)^2$ and averaged to daily means. The daily means are then further processed to monthly means with each daily data being weighted equally. For monthly mean diurnal cycles the re-projected Level 2 data are averaged for each hour of the day and then averaged within a month separately for each hour.

## 6.1 Definition of product specifications

The ICDR SEVIRI Clouds provides CFC and CTO for the area indicated in Figure 6-1. Instantaneous retrievals with a temporal resolution of 15 minutes at original spatial resolution are used to derive the spatio-temporally collected data sets. The products are available as daily mean as well as monthly means on a regular latitude/longitude grid with a spatial resolution of 0.05° × 0.05° degrees. Also, monthly mean diurnal cycles are generated consisting of 24 time-steps with a spatial resolution of 0.25° × 0.25° degrees. The data of each of the 24 time steps is calculated by averaging all 4 time slots of a particular hour (‘00,’15,’30,’45) over all days of a month.

Acknowledging the different observation capabilities during night and during day and also taking into account existing diurnal variations in cloudiness, a further separation of results in daytime and night-time portions has also been done (for fractional cloud cover only). Here, all observations made under twilight conditions (solar zenith angle between 75° and 95°) have been excluded in order to avoid being affected by specific cloud detection problems occurring in the twilight zone.

## 6.2 Calculation of Level 3 products

For the daily averages all data fields with original SEVIRI pixel size and in 15 minutes resolution are temporally averaged and collected. Here, all values are considered equally valid, thus no weighting is applied. Monthly means are generated by averaging daily mean data.

### 6.2.1 Fractional Cloud Cover [CFC]

The cloud fractional cover is defined as the fraction of cloudy pixels per grid cell compared to the total number of analyzed pixels in the grid cell. Pixels are counted as cloudy if they belong to the classes cloud filled or cloud contaminated. Fractional cloud cover is expressed in percent. It is calculated as follows:

$$CFC(i,j) = \frac{N(i,j)_{Cloudy}}{N(i,j)_{Cloudy} + N(i,j)_{Clear}} \quad (1)$$

with $i$ and $j$ being the indices of the original field projection, $N(i,j)_{Cloudy}$ the number of cloudy cases and $N(i,j)_{Clear}$ the number of clear cases. Acknowledging the different cloud detection capability during day and night time, an additional separation is done leading to $CFC(i,j)_{Night}$ and $CFC(i,j)_{Day}$, separate day time and night time averages. Here, the solar zenith angle of ≤75° and ≥95° are used to define day and night, respectively. Cases with solar zenith angles between 75° and 95°are included the nominal daily mean but excluded when collecting data for day-only and night-only averages. The monthly mean cloud fractional cover is calculated as mean over the daily means with each day being weighted equally.

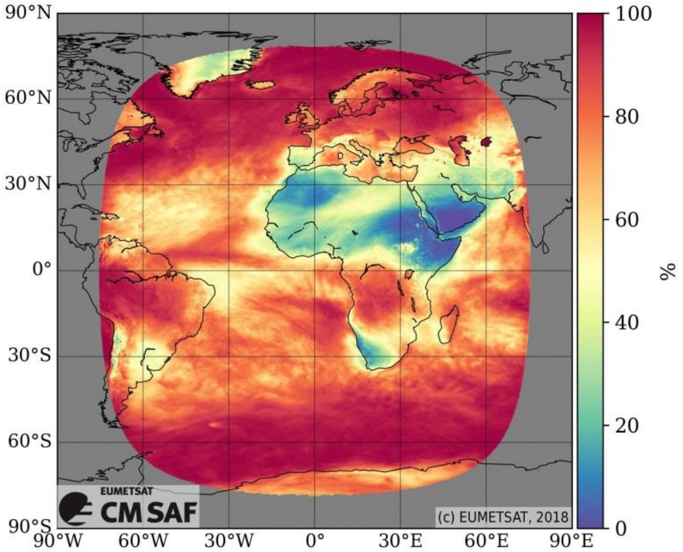


**Figure 6-1** Example is for monthly mean cloud fractional cover in December 2017.

### 6.2.2 Cloud Top Level [CTO]

The CTO product contains daily means for CTH, CTP, and CTT. For these parameters all valid entries of the original fields are aggregated and then weighted by the number of used entries.

$$< x(i,j) > = \frac{1}{N(i,j)_{Cloudy}} \sum_{k=1}^{N(i,j)_{Cloudy}} x_k(i,j) \quad (4)$$

with $x(i,j)$ being a general expression for CTH, CTP and CTT at a specific original grid cell.

After temporal averaging, the fields are remapped to the final resolution as described in section 6.1.

For CTP, an alternative way of averaging is followed and additionally calculated and provided as geometrical mean where the variables are averaged in logarithm space:

$$< ctp(i,j) >_{\ln} = \exp\left(\frac{1}{N(i,j)_{Cloudy}} \sum_{k=1}^{N(i,j)_{Cloudy}} \ln(ctp_k(i,j))\right) \quad (5)$$

Geometrical mean is added to keep consistency between CTH and CTP. CTP depends logarithmically on CTH, so if CTH is averaged linearly, CTP has to be averaged logarithmically to preserve the relation.

The monthly mean cloud top level parameters are calculated as mean over the daily means with each day being weighted equally.

**Bugfix affecting Monthly Mean Cloud Top Parameters**

Due to a software bug in CLAAS-2, cloud top parameters from grid cells with daily mean CTH > 10km were not taken into account for the monthly mean computation (see service message #107 at www.cmsaf.eu). Although introducing an inhomogeneity in the cloud top monthly means, that critical bug has been fixed in both the CLAAS-2 extension and the ICDR. Monthly mean diurnal cycles are not affected.

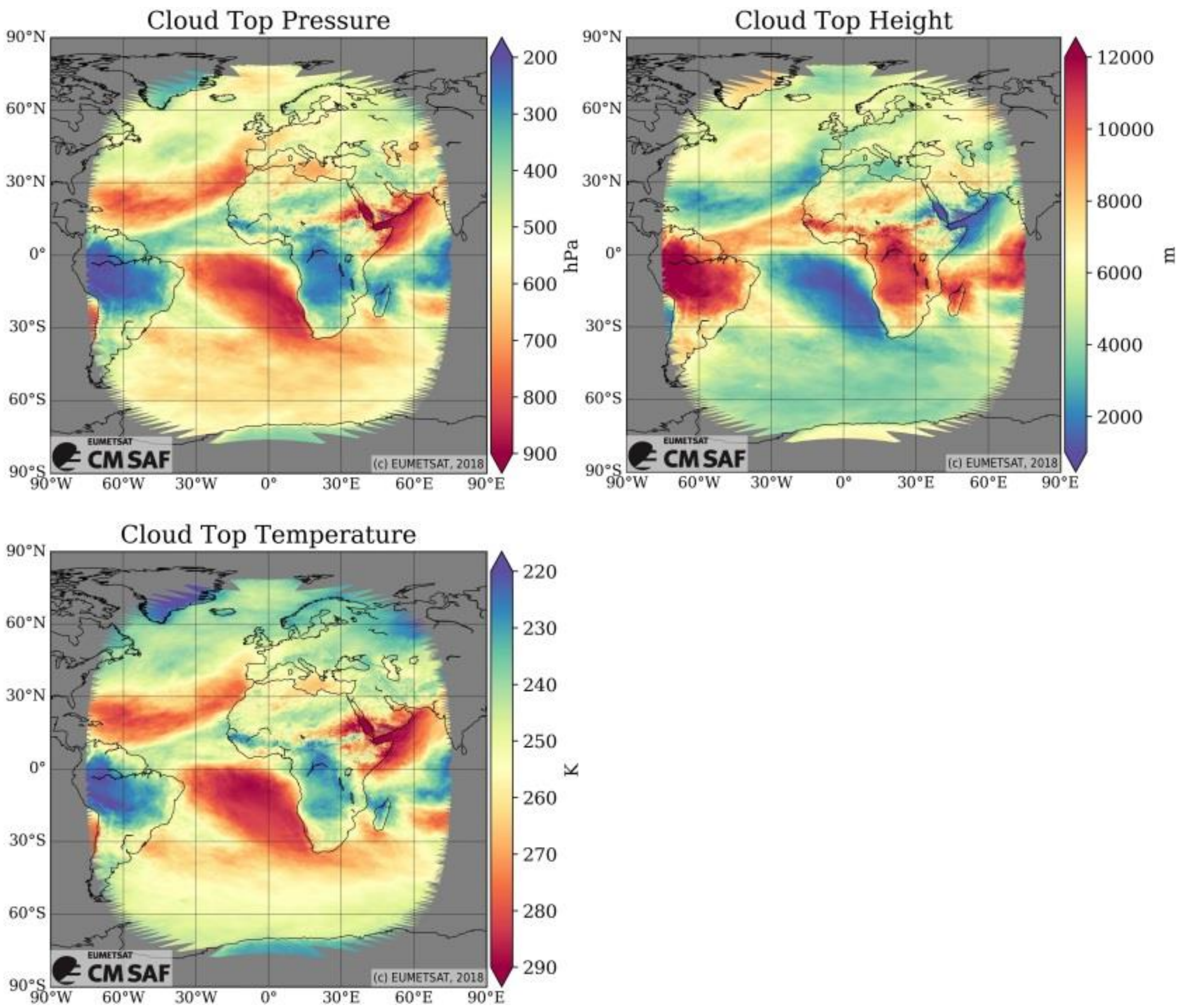


**Figure 6-2** Example of monthly mean cloud top pressure (top-left), height (top-right) and temperature (bottom-left) in December 2017.

### 6.2.3 Additional statistical parameters

In addition to the daily and monthly mean values, the standard deviations $s$ over all valid and used values is calculated for CFC and CTO for each grid box with

$$s(x(i,j)) = (< x^2(i,j) > - < x(i,j) >^2)^{0.5}$$

.

### 6.2.4 Monthly mean diurnal cycles

To facilitate the assessment of monthly mean diurnal cycle for the user not only daily and monthly means are created but also monthly mean diurnal cycles from the quantities CFC, and CTO. For a monthly mean diurnal cycle, all fields of a specific slot are considered and averaged hour wise, the result is a file with 24 fields. Each field contains the monthly average of all input fields of a specific hour (including 4 time slots per hours: ’00, ’15, ’30, ‘45). Please note that the time axis refers to UTC; for a depiction in local time the pixel will have to be sorted with respect to the time zones.

# 7 References

Benas, N., Finkensieper, S., Stengel, M., van Zadelhoff, G.-J., Hanschmann, T., Hollmann, R., and Meirink, J. F.: The MSG-SEVIRI-based cloud property data record CLAAS-2, Earth Syst. Sci. Data, 9, 415-434, https://doi.org/10.5194/essd-9-415-2017, 2017.

Dee, D. P., Uppala, S. M., Simmons, A. J., Berrisford, P., Poli, P., Kobayashi, S., Andrae, U., Balmaseda, M. A., Balsamo, G., Bauer, P., Bechtold, P., Beljaars, A. C. M., van de Berg, L., Bidlot, J., Bormann, N., Delsol, C., Dragani, R., Fuentes, M., Geer, A. J., Haimberger, L., Healy, S. B., Hersbach, H., Hólm, E. V., Isaksen, L., Kållberg, P., Köhler, M., Matricardi, M., McNally, A. P., Monge-Sanz, B. M., Morcrette, J.-J., Park, B.-K., Peubey, C., de Rosnay, P., Tavolato, C., Thépaut, J.-N. and Vitart, F. (2011), The ERA-Interim reanalysis: configuration and performance of the data assimilation system. Q.J.R. Meteorol. Soc., 137: 553–597. doi: 10.1002/qj.828

Derrien, M. and H. Le Gléau, 2005, MSG/SEVIRI cloud mask and type from SAFNWC, International Journal of Remote Sensing, **26**, No. 21, 10 November 2005, 4707–4732.

Doelling, D. R., L. Nguyen, and P. Minnis, 2004: Calibration comparisons between SEVIRI, MODIS, and GOES data. In Proceedings of the 2004 EUMETSAT Meteorological Satellite Conference, Prague, Czech Republic. EUMETSAT.

EUMETSAT, 2010: MSG Level 1.5 Image Data Format Description, EUM/MSG/ICD/105 v6.

EUMETSAT, 2007: A Planned Change to the MSG Level 1.5 Image Product Radiance Definition, EUM/OPS-MSG/TEN/06/0519.

Ham, S.-H. and B. J. Sohn, 2010: Assessment of the calibration performance of satellite visible channels using cloud targets: application to Meteosat-8/9 and MTSAT-1R. Atmospheric Chemistry and Physics, 10(22), 11131–11149.

Meirink, J.F., R.A. Roebeling and P. Stammes, 2013: Inter-calibration of polar imager solar channels using SEVIRI, Atm. Meas. Tech., 6, 2495-2508, doi:10.5194/amt-6-2495-2013.

Schmid, J., 2000: "The SEVIRI instrument." Proceedings of the 2000 EUMETSAT Meteorological Satellite Data User's Conference, Bologna, Italy, 29 May–2 June 2000.

# 8 Glossary

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|---|---|
| ATBD | Algorithm Theoretical Basis Document |
| AVHRR | Advanced Very High Resolution Radiometer |
| CDO | Climate Data Operators |
| CDOP | Continuous Development and Operations Phase |
| CFC | Fractional Cloud Cover |
| CLARA-A1 | CM SAF cLoud, Albedo and Radiation products, AVHRR-based, |
| CLAAS | CM SAF CLoud property dAtaset Using SEVIRI |
| CM SAF | Satellite Application Facility on Climate Monitoring |
| CPH | Cloud Phase |
| COT | Cloud Optical Thickness |
| CTH | Cloud Top Height |
| CTO | Cloud Top product |
| CTP | Cloud Top Pressure |
| CTT | Cloud Top Temperature |
| CPP | Cloud Physical Properties |
| DRI | Delivery Readiness Inspection |
| DWD | Deutscher Wetterdienst (German MetService) |
| ECMWF | European Centre for Medium-Range Forecasts |
| ECV | Essential Climate Variable |
| ERA-Interim | Second ECMWF Re-Analysis dataset |
| EUMETSAT | European Organisation for the Exploitation of Meteorological Satellites |
| FCDR | Fundamental Climate Data Record |
| GCOS | Global Climate Observing System |
| IRW | Infrared window |
| ISCCP | International Satellite Cloud Climatology Project |
| IWP | Ice Water Path |
| JCH | Joint Cloud properties Histogram |
| KNMI | Koninklijk Nederlands Meteorologisch Instituut (Dutch MetService) |
| LWP | Liquid Water Path |
| MODIS | Moderate Resolution Imaging Spectroradiometer |
| MSG | Meteosat Second Generation |
| NOAA | National Oceanic & Atmospheric Administration |

| | |
|---|---|
| NWC SAF | SAF on Nowcasting and Very Short Range Forecasting |
| NWP | Numerical Weather Prediction |
| PRD | Product Requirement Document |
| PUM | Product User Manual |
| SEVIRI | Spinning Enhanced Visible and InfraRed Imager |
| SAF | Satellite Application Facility |
| SMHI | Swedish Meteorological and Hydrological Institute |