EUMETSAT Satellite Application Facility on Climate Monitoring

The EUMETSAT Network of Satellite Application Facilities

CM SAF Climate Monitoring

Product User Manual

CLOUDS

Cloud Fractional Coverage:	**CM-02, CM-03, CM-04**
Cloud type:	**CM-08, CM-09, CM-10**
Cloud top products	**CM-14, CM-15, CM-16**
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Liquid water path	**CM-36, CM-37**
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1.5	26.05.2011	SAF/CM/DWD/PUM/CLOUDS	Changes according to retrieval system updates; mapping table for ATBD's introduced.

Version history since operational introduction in IOP phase

The following two tables list product versions according to the current officially available product dataset in the CM-SAF product database and split by satellite. It also means that some versions are not mentioned since they have been replaced by new products produced by reprocessing activities. Notice also that more details on the actual implications on specific products due to version upgrading is described later in the document in connection to individual product descriptions.

AVHRR version	Time range	Major changes
130	Jan 2005 – Mar 2005	Initial version based on PPS version 1.0 Cloud Physical Processing Scheme (CPP) version 1.0
140	Apr 2005 – Jul 2005	Averaging limits for cloud products (except for COT/CWP products) have been changed. CPP version 1.2 implemented
150	Aug 2005 – Dec 2006	Change from 32 x 32 pixel per tile to 45 x 45 pixel per tile in the clouds processing to fix error of artefacts in the end products (straight lines across sub-areas)
160	Jan 2007 – Jun 2007	Upgrading to PPS version 1.1
300	Jul 2007 – Dec 2008	Correction of GME remapping bug
310	Jan 2009 – Jun 2009	Implementation of PPS version 2.0, change to swath based processing include the use of METOP data. Introduction of products over the Arctic Area.
320	Jul 2009 – Dec 2012	SW update to PPSv2009, Sun-Earth distance correction, update to CPP version 2.4
330	Jan 2011 – today	SW update to PPS v2010

SEVIRI version	Time range	Major changes
210	Sep 2005 – Apr 2007†	Initial MSG version operated on Baseline area. NWC-SAF MSG software v2.1; Cloud Physical Processing Scheme (CPP) version 2.0
300	May 2007 – April 2008	Area extension of SEVIRI processing to full disk; Change to CPP version V2.2.2
310	May 2008- Dec 2008	Implementation of new radiance definition at EUMETSAT; Upgrade to NWC-SAF SW package MSG2008
320	Jan 2009 – Dec. 2009	Migration to new processing environment
330	Jan 2010 – today	Bug fix for Cloud type

†Version 210 data are available up to 9 May 2007.

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1 The EUMETSAT SAF on Climate Monitoring

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

The Satellite Application Facility on Climate Monitoring (CM SAF) targeted its development in the period 1999-2003 on generation and archiving high quality data sets on a continuous basis for the analysis and monitoring of the climate system, its changes and the validation of numerical models (climate and NWP models). The CM SAF started an Initial Operations Phase (IOP) covering the period January 2004 to February 2007. The objectives of the CM SAF IOP were mainly the operational production, control and distribution of products developed in the previous phase, and to carry out research and development for an extension of the product line with new sensors and platforms. The Continuous Development and Operations Phase (CDOP) started in 2007 covering the period March 2007 – February 2012. This CDOP covers – among others – the continuation and further development of the products from the IOP, addition of further GCOS ECV's, but also the provision of long-term data sets with known error characteristics and temporal stability.

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) and the Meteorological Service of Switzerland (MeteoSwiss).

CM SAF data products are distinguished in operational monitoring products and retrospectively produced data sets (Schulz et al. (2009)). Operational monitoring products are disseminated with high timeliness (within 8 weeks after observation) to support operational climate monitoring application of National Meteorological and Hydrological Services. The timeliness requirement most likely makes this type of product not suitable for monitoring of inter-annual variability and trends with high confidence. Bias errors due to shift of equator overpass times and orbit height decay as well as instrument caused inter-satellite biases are not corrected for in the operational monitoring product. However, the characterisation of relatively strong anomalies on monthly scale should be possible.

Within the retrospectively produced data sets the above described errors are minimised to a level that the data sets can safely be used to analyse variability at longer scales than inter-annual. CM SAF aims at the delivery of such data sets for a number of ECVs, as defined by GCOS.

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

2 Introduction

This CM-SAF Product User Manual provides information on the CM-SAF cloud products. These products are currently derived from two different passive imaging sensors:

- The Advanced Very High Resolution Radiometer (AVHRR) operated onboard the polar National Oceanic and Atmospheric Administration (NOAA) satellites NOAA-15, -16, -17 and -18 and onboard current and upcoming polar Meteorological Operational satellites (MetOp-A, -B, and -C).

- The Spinning Enhanced Visible and InfraRed Imager (SEVIRI) operated onboard the geostationary METEOSAT satellites (Meteosat-8, -9).

Observe that not all products are defined for all satellite datasets listed above. For example, some products depend on the specific spectral channel at 1.6 µm which is not operated on all NOAA-satellites.

The manual describes available products with example images, gives basic algorithm descriptions and a brief overview on validation versus various reference observations. 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.

This Product User Manual describes exclusively the CM-SAF operational monitoring cloud products which are generated and disseminated within two months after reception of satellite data.

The basic motivation for retrieving cloud climate products from satellite data is that clouds play an important role in the global energy and water cycle. In particular, the presence of clouds dominates the planetary albedo which is a crucial quantity that controls the fraction of the incoming solar radiation that is directly reflected back to space. Consequently, a very important task for climate monitoring missions is to document any changes in the planetary albedo associated with changes in global cloudiness. Important is also to study associated potential feedback links to changes in atmospheric temperatures and water vapour contents. Furthermore, the fact that different types of clouds have different reflection and absorption characteristics motivates the definition of an additional set of cloud physical properties products as a complement to the traditional cloud amount, cloud type and cloud top products. For example, a situation could occur when the planetary albedo is kept constant but the amount of semi-transparent high ice clouds would increase. Since this category of clouds reflects only small amounts of solar radiation but absorbs significant amounts of terrestrial radiation an increase in the occurrence of this cloud category might enhance the total atmospheric greenhouse effect.

Both types of CM-SAF cloud products, i.e., operational monitoring products and retrospectively produced datasets, should be useful for evaluating cloud simulations from current atmospheric forecasting models as well as from climate models as demonstrated by Karlsson et al., (2008), Roebeling et al., (2009) and Willén (2008). In a longer perspective the retrospectively produced datasets should be the most useful datasets permitting more complete and accurate studies, e.g., of the type published by Zhang et al. (2005).

2.1 Applicable Documents

Reference	Title	Code
AD.1.	CM-SAF Service Specification Document	SAF/CM/DWD/SeSp/1
AD.2.	Annual Validation Report 2007	SAF/CM/VAL/OR-3/1
AD.3.	Annual Validation Report 2008	SAF/CM/VAL/OR-4/1
AD.4.	Scientific validation of basic polar cloud products for the Operational Readiness Review ORR-V1 2004.	SAF/CM/SMHI/CFC-CTH/1
AD.5.	Scientific validation of CM-SAF cloud products using MSG/SEVIRI data for the Operational Readiness Review ORR-V3 2006.	SAF/CM/DWD/SMHI/KNMI/SR/CLOUDS/3
AD.6.	Validation of CM-SAF cloud products derived from AVHRR data in the Arctic region for Operational Readiness Review ORR-B 2009.	SAF/CM/SMHI/VAL/CFC_CTY_CTO_AVHRR_ARCTIC
AD.7	Annual Product Quality and Assessment Report 2009	SAF/CM/VAL/OR-5/1.1
AD.8	Annual Product Quality and Assessment Report 2010	SAF/CM/VAL/OR-6/1.1

2.2 Reference Document

Reference	Title	Code
RD.1.	CM-SAF Product Requirements Document	SAF/CM/DWD/PRD/1.8

2.3 Mapping of ATBDs to product version

Table 2-1: *Mapping of product version vs ATBD for AVHRR based products.*

AVHRR version	Time range	ATBD
130	Jan 2005 – Mar 2005	ATBD SAF-NWC software PPS 1.0 ATBD COT/CWP software version V1.2
140	Apr 2005 – Jul 2005	
150	Aug 2005 – Dec 2006	
160	Jan 2007 – Jun 2007	ATBD SAF-NWC software PPS 1.1 ATBD COT/CWP software version V2.2.1
300	Jul 2007 – Dec 2008	
310	Jan 2009 – Jun 2009	ATBD NWC-SAF SW package PPS 2008 ATBD COT/CWP software version V2.2.2
320	Jul 2009 – 31.12.2010	SAF/CM/SMHI/ATBD/CFC_AVHRR v1.0 SAF/CM/SMHI/ATBD/CTY_AVHRR v1.0 SAF/CM/SMHI/ATBD/CTO_AVHRR v1.0 SAF/CM/KNMI/ATBD/CPP v1.1
330	01.01.2011 – today	SAF/CM/SMHI/ATBD/CFC_AVHRR v2.0 SAF/CM/SMHI/ATBD/CTY_AVHRR v2.0 SAF/CM/SMHI/ATBD/CTO_AVHRR v2.0 SAF/CM/KNMI/ATBD/CPP_v1.1

Table 2-2 *Mapping of product version vs ATBD for SEVIRI based products.*

SEVIRI version	Time range	ATBD
210	Sep 2005 – Apr 2007†	ATBD SAF-NWC software MSG 1.1 ATBD COT/CWP software V2.2.2
300	May 2007 – April 2008	ATBD SAF-NWC software MSG 1.2 ATBD COT/CWP software V2.3
310	May 2008- Dec 2008	SAF/CM/DWD/ATBD/CFC_CTH_CTO_ SEVIRI_1.0 SAF/CM/KNMI/ATBD/CPP_v1.1
320	Jan 2009 – Dec. 2009	
330	Jan 2010 – today	

†Version 210 data are available up to 9 May 2007.

3 Description of cloud products

Six different cloud products are defined in a grid with a spatial resolution of 15 km x 15 km. All cloud products are introduced in Table 3-1 with associated acronyms and units. Notice that each product exists in two different versions; one for polar orbiting data (NOAA/METOP AVHRR) and one for geostationary data (METEOSAT/SEVIRI). All products exist also as both daily and monthly averages. To notice here is that a specific mean monthly diurnal cycle product is added for the geostationary dataset.

Table 3-1 *Overview of CM-SAF cloud products.*

Acronym	Product title	Unit
CFC	Cloud Fractional Cover (or Cloud Amount).	%
CTY	Cloud Type category contribution.	%
CTO	Cloud Top information, expressed either as Cloud Top Pressure, geometrical Cloud Top Height or Cloud Top Temperature.	hPa, m or K
CPH	Cloud particle Phase category contribution.	%
COT	Cloud optical thickness.	dimensionless
CWP	Cloud liquid Water Path.	%

Figure 3-1 gives an overview of the current processing areas.

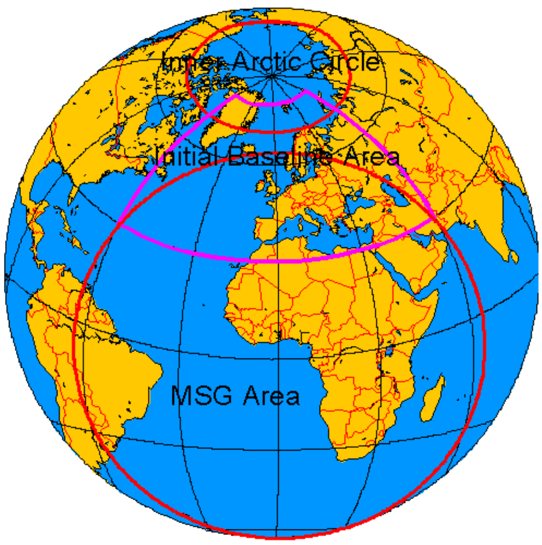

Figure 3-1: *Area coverage for CM-SAF cloud products. The PUM describes products over the Initial Baseline Area (enclosed by magenta line), the MSG Area (left, enclosed by red line) and the Arctic Area.*

3.1 Basic processing for AVHRR data

Currently, products based on AVHRR data from the polar orbiting satellites are defined exclusively over the Initial Baseline Area and the Arctic Area. The initial Baseline area is defined within latitudes 30 and 80 degrees and within +/- 60 degrees longitude in a sinusoidal equal area projection and with a spatial resolution of 15 km x 15 km.

The Arctic Area encompasses the region enclosed by the latitude of approximately 65 degrees north. It is defined as a square with a size of 5010 km × 5010 km centred to the pole with grid cells oriented parallel to the 0◦ and 90◦ meridians) at a spatial resolution of 15 km × 15 km (Lambert Azimuthal Equal Area projection).

AVHRR data sets are collected in three different ways. The different ways of collection are also visible through the version numbering.

1. NOAA AVHRR data direct reception with a single HRPT station in Offenbach **(only for versions prior to 310!)**

2. NOAA AVHRR data is provided by the EARS-AVHRR service. (Starting with Version 310)

3. METOP AVHRR data is provided from global 1-km PDUs archived at UMARF. (Starting with version 310)

This means that we have full METOP coverage over the respective processing areas but that the coverage of NOAA satellites depends on the available HRPT stations in the EARS-AVHRR distribution service. Figure 3-2 shows the EARS-AVHRR coverage as realised through the network of the following HRPT stations: Maspalomas (Spain), Lannion (France), Svalbard (Norway), Kangerlussuaq (Denmark, Greenland) and Athens (Greece). It is notable that this constellation of HRPT stations will give good coverage of the Initial Baseline area but that the coverage of the Arctic region is still somewhat restricted (for example, poor coverage of remote part near Alaska).

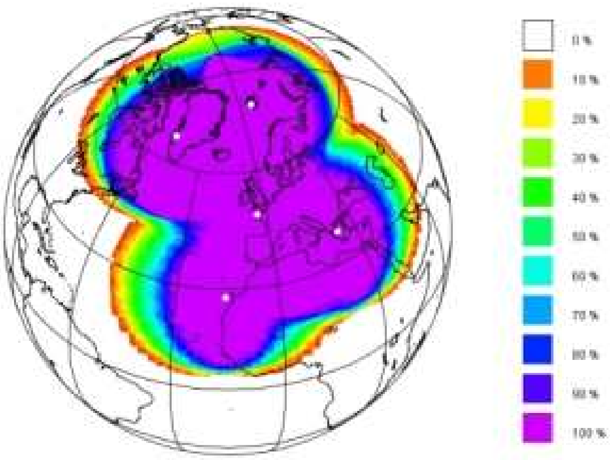

Figure 3-2 *EARS-AVHRR coverage in 2009. Different colours describe the combined HRPT reception capability for the combined network of stations (each station indicated by a white dot).*

However, please observe that for AVHRR product versions prior to version 310 only the Initial Baseline area was covered exclusively using data received at the HRPT station in Offenbach. This means that the data coverage within the Baseline area is limited and with best coverage in the central portion (visualised in Figure 3-3).

In order to define products with a fixed horizontal resolution products are transferred to map projections with equal area property. Figure 3-4 and Figure 3-5 show the resulting rectangular areas over which the CM-SAF grid is defined. The special character of the sinusoidal map projection leads to strong map distortions in the most northern part of the region in Figure 3-4. Even some parts (i.e., close to the upper left and upper right corners) of the area will become undefined. Thus, the user should discard these parts of the extracted grid fields and concentrate on regions coinciding with the original extent of the area (according to Figure 3-1).

Notice that the grid field for cloud parameters over the Arctic Area will be rectangular according to the area displayed in Figure 3-5. Thus, some parts of the area will contain information also south of the above mentioned latitude of 65 degrees (for example, full coverage of Greenland is realised).

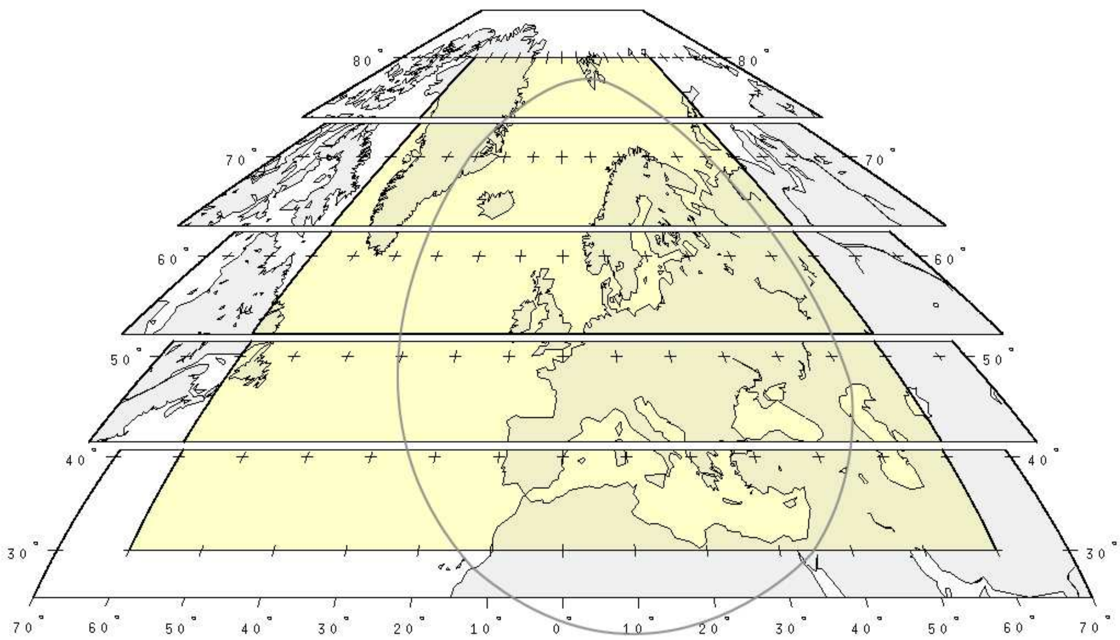

Figure 3-3 *CM-SAF baseline area in sinusoidal projection (yellow area). The circle marks the area within the CM-SAF baseline area which can be seen with the local HRPT receiving station in Offenbach, Germany. Latitude limitations of AVHRR processing tiles are indicated. For practical reasons, also a further subdivision in the longitudinal direction is applied. Please note, that this information is valid for all AVHRR versions prior to 310.*

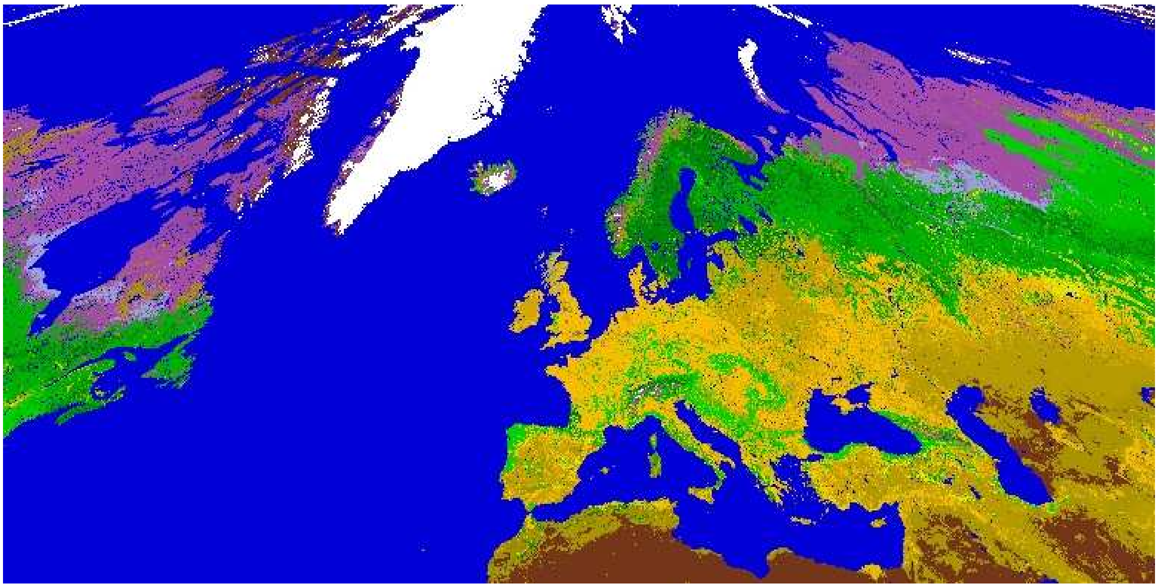

Figure 3-4 *The Initial Baseline Area defined in sinusoidal equal area map projection. The figure shows USGS land use categories in different colours.*

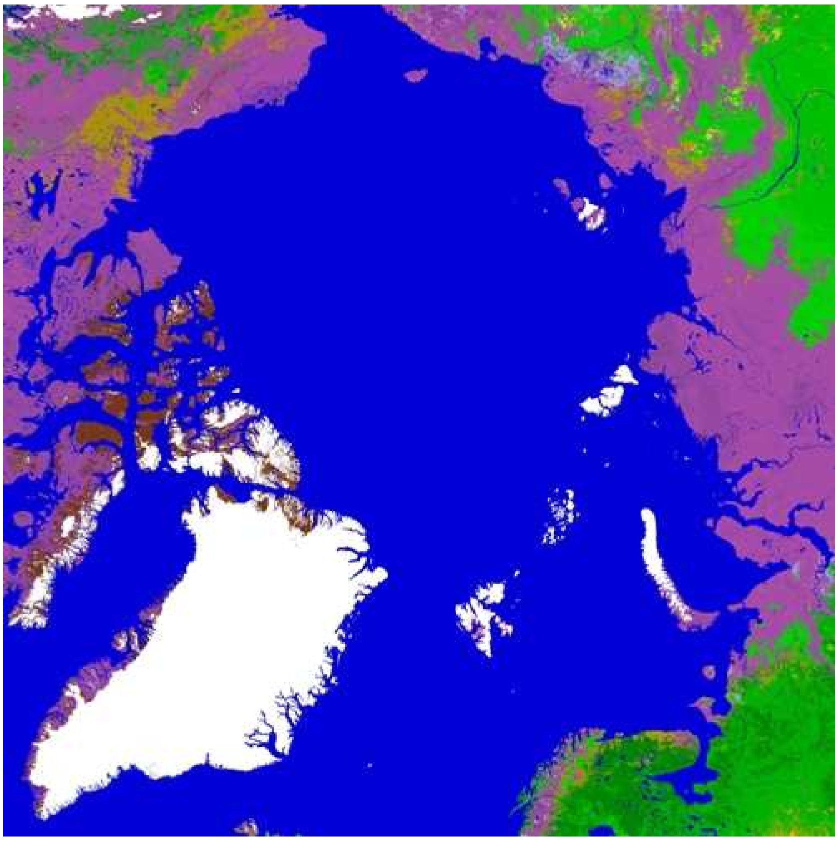

Figure 3-5 *The Arctic Area defined in Lambert Azimuthal Equal Area projection. The figure shows USGS land use categories in different colours.*

3.1.1 Details on processing for AVHRR products up to version 300

AVHRR CFC products are produced using pre-processed radiances (Level 1b) provided by the ATOVS and AVHRR Pre-processing Package (AAPP) package for NOAA satellites. For all products versions prior to AVHRR version 310 the processing of AVHRR swaths covering the area is sub-divided into 36 fixed sub-regions (tiles, see Figure 3-3). Then only those tile are being processed which have a significant amount of observed data (threshold set to 5 % of pixel numbers per tile). After the calculation of all products on these tile, all tiles per day or month are combined to the final product covering the baseline area.

Note, that the unequal coverage of locally received data lead to an unequal distribution of observations for the baseline. In addition, the tile-based processing approach leads for some products to horizontal and vertical incorrect lines along tile boundaries (e.g. Figure 3-6) as no interpolation or merging is done between neighbouring tiles). Please note, that only for CFC two examples (e.g. Figure 3-6 and Figure 3-7) are given to demonstrate the difference in spatial coverage between all AVHRR versions before and after version 310.

3.1.2 Details on processing for AVHRR products from version 310

AVHRR products are produced using pre-processed radiances (Level 1b) provided by the ATOVS and AVHRR Pre-processing Package (AAPP) package for NOAA satellites. AVHRR for MetOp is directly received as level 1b data.

AVHRR products are first produced in satellite projection mode (swaths) where the swath length is determined so that all lines can be confined to the same GME analysis time. Furthermore, some practical adaptations are made to optimise the processing in the two processing areas. In conclusion, the full swath covering both the Initial Baseline Area and the Arctic Region may be sub-divided into two or three segments. In the final averaging step, products are remapped from swath mode to the respective regions defined in equal area projection. The Artic region processing is described in more detail in Kaspar et al. (2009). Please note, that only for CFC two examples (e.g. Figure 3-6 and Figure 3-7) are given to demonstrate the difference in spatial coverage between all AVHRR versions before and after version 310.

3.2 Basic processing for geostationary data

For SEVIRI data, processing is first made in satellite projection and results are then transferred to the sinusoidal projection representation. Differences between the polar and geostationary algorithms exists for all cloud products. However, the products retrieved from SEVIRI are on the same sinusoidal 15 km x 15 km grid as the AVHRR retrieved products.

Furthermore after the extension of the SEVIRI processing to the full SEVIRI disk in 2007 (version 300 onwards) it was assured that the Baseline Area is a well defined sub set of the SEVIRI full disc product.

3.2.1 Details on processing

SEVIRI CFC products are produced from its original HRIT format and using the new SEVIRI radiance definition (for all SEVIRI products since May 2008, version is 310 or higher).

The initial processing of MSG products (i.e., before averaging takes place) is done on pixel level for the full disk in one step. Then a re-projection to an intermediate grid of 3x3 km^2 is followed by spatial and temporal averaging to achieve the 15 km x 15 km spatial sinusoidal resolution.

AVHRR products for version 310 or higher are first produced in satellite projection mode (swaths) where the swath length is determined so that all lines can be confined to the same GME analysis time. Furthermore, some practical adaptations are made to optimise the processing in the two processing areas. In conclusion, the full swath covering both the Initial Baseline Area and the Arctic Region may be sub-divided into two or three segments. In the final averaging step, products are remapped from swath mode to the respective regions defined in equal area projection.

In the following sub-sections a brief description of each individual cloud product will be given with associated information on averaging methods, validation procedures and limitations.

3.3 Cloud Fractional Cover

3.3.1 Product definition

This product is derived directly from results of a cloud screening or cloud masking method. The cloud fractional cover is defined as the fraction of cloudy pixels per sub-region compared to the total number of analysed pixels in the sub-region. In this case it means that the cloud fractional cover is computed as the cloudy fraction of all pixels within a 15x15 km grid square. Fractional cloud cover is expressed in percent.

3.3.2 Basic approach

This product is calculated using the NWC-SAF cloud mask algorithms (see http://nwcsaf.inm.es/ for details on the NWC-SAF project). The algorithm applied to NOAA AVHRR data is introduced by Dybbroe et al. (2005a and 2005b) and the corresponding algorithm applied to MSG SEVIRI data is introduced by Derrien and LeGleau (2005). A detailed description are given in the ATBD's of the corresponding product versions (Table 2-1, Table 2-2). Both algorithms are based on a multi-spectral threshold technique applied to each pixel of the satellite scene. Several threshold tests may be applied (and must be passed) before a pixel is assigned to be cloudy or cloud-free. For every satellite overpass a unique set of feature thresholds is extracted in full image resolution and is applicable only for that particular satellite scene. Thresholds are determined from present viewing and illumination conditions and from the current atmospheric state (prescribed by data assimilation products from numerical weather prediction models). For this version of the AVHRR algorithm some adjustments have been made to cope with Arctic conditions. These adjustments are described in the ATBD of the corresponding product version (Table 2-1) and by Eliasson et al. (2007).

In principle, the basic MSG/SEVIRI methodology is very similar but there are also significant differences. The most important ones are the use of additional spectral channels and some different approaches for generation of thresholds (e.g. the use of climatological surface reflectance and sea surface temperature maps instead of using NWP data assimilation products). For more details on these differences, see reference ATBD's of the corresponding product version (Table 2-2).

3.3.3 Details on processing, gridding and averaging

In the final computation of the CFC product, cloud fractional cover is computed as the fraction of all pixels within a remapped 15 km x 15 km square that has been labelled by the cloud mask product either as fully cloudy or cloud contaminated.

The monthly mean is calculated from the corresponding daily averages of cloud fractional cover for each individual month. This constraint was introduced to emphasise the importance of giving equal weight to each day of a month, in order to be able to construct a representative monthly mean.

For geostationary data the monthly mean is calculated in the same way using all available hourly scenes for the construction of the daily averages.

For CFC a minimum set of 6 overpasses (or MSG time slots) is defined which is needed to compute a daily mean. To build a monthly mean 20 daily means are required. Currently these threshold are applied per area/tile and not per pixel.

To obtain a monthly mean diurnal cycle for a given MSG time slot all days of this time slot are used to compute the product. This is then repeated for all time slots per day, thus giving the monthly mean diurnal cycle. For each time slot 20 individual days of the month are needed to compute a product.

Due to the different Level 0 data streams, only METOP overpasses are fully covering the Arctic area which is not the case for the NOAA-satellite AVHHR based products. For METOP the full data stream is available, whereas for AVHRR only the data from the EARS data stream can be used. I.e., METOP provides full coverage of the Arctic whereas the EARS data stream provides only coverage of the Atlantic sector. Thus for the averages of all satellite data a spatial inhomogeneity can not be avoided.

To make this difference visible to the user for the Arctic area the averaging process is done separately for all polar satellites and in an additional step for METOP data only. Thus, all Arctic products (Table 4-3) include two datasets. The major difference between both is purely sampling and quality differences depend on the variability of cloud properties. Therefore, the data over the Atlantic sector have the best quality w.r.t. sampling.

For users interested in those areas it is recommended to use the full product including all satellites. Users who need to analyse the whole Arctic and have strong spatial homogeneity requirements should use METOP-only products as those have homogeneous sampling characteristics in the whole area (Table 4-3).

3.3.4 Product examples

Figure 3-6 to Figure 3-9 illustrate the AVHRR and SEVIRI CFC products over their respective processing areas.). Please note, that only for CFC two examples (e.g. Figure 3-6 and Figure 3-7) are given to demonstrate the difference in spatial coverage between all AVHRR versions before and after version 310.

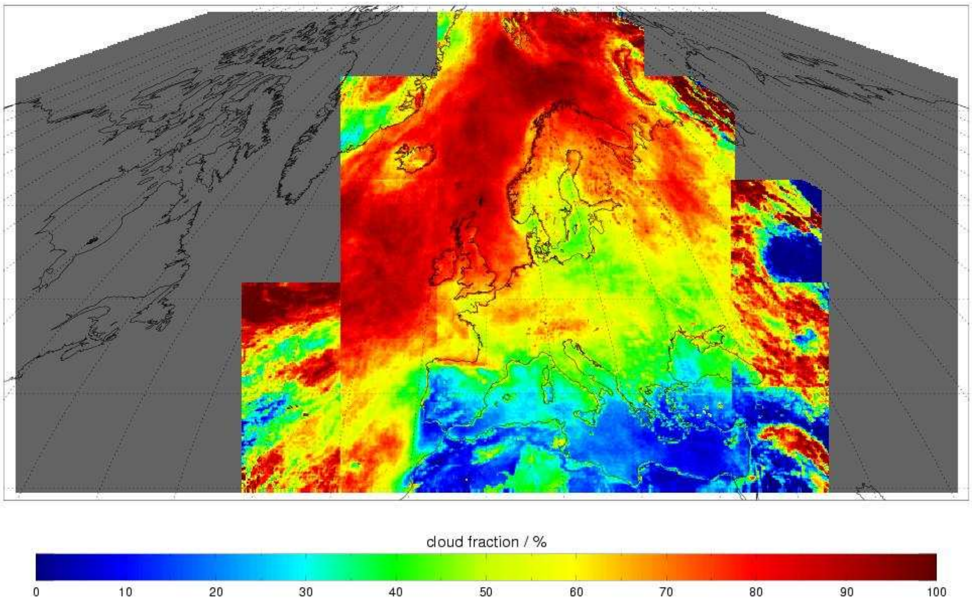

Figure 3-6 *Example of CFC monthly mean product (in %) for June 2008 from AVHRR over the Initial Baseline Area. Notice that this example is valid for product prior to version 300.*

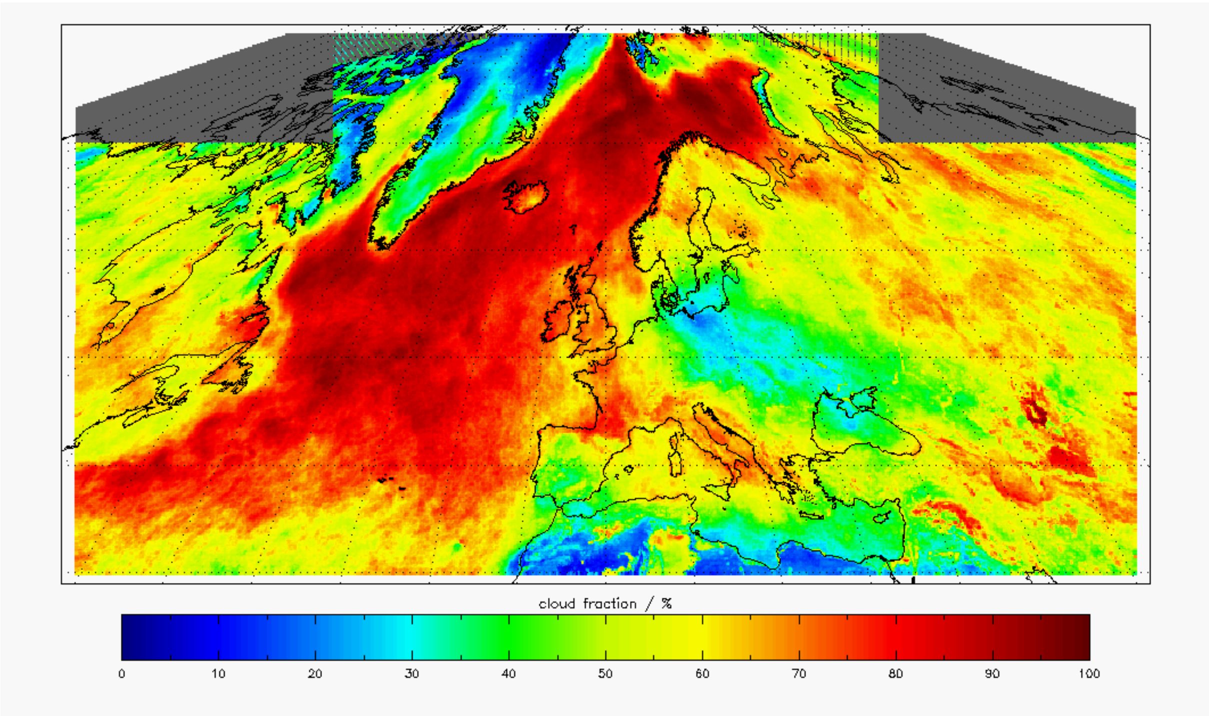

Figure 3-7: *Example of CFC monthly mean product (in %) for April 2009 from AVHRR over the Initial Baseline Area. Notice that this example is valid for product since version 310.*

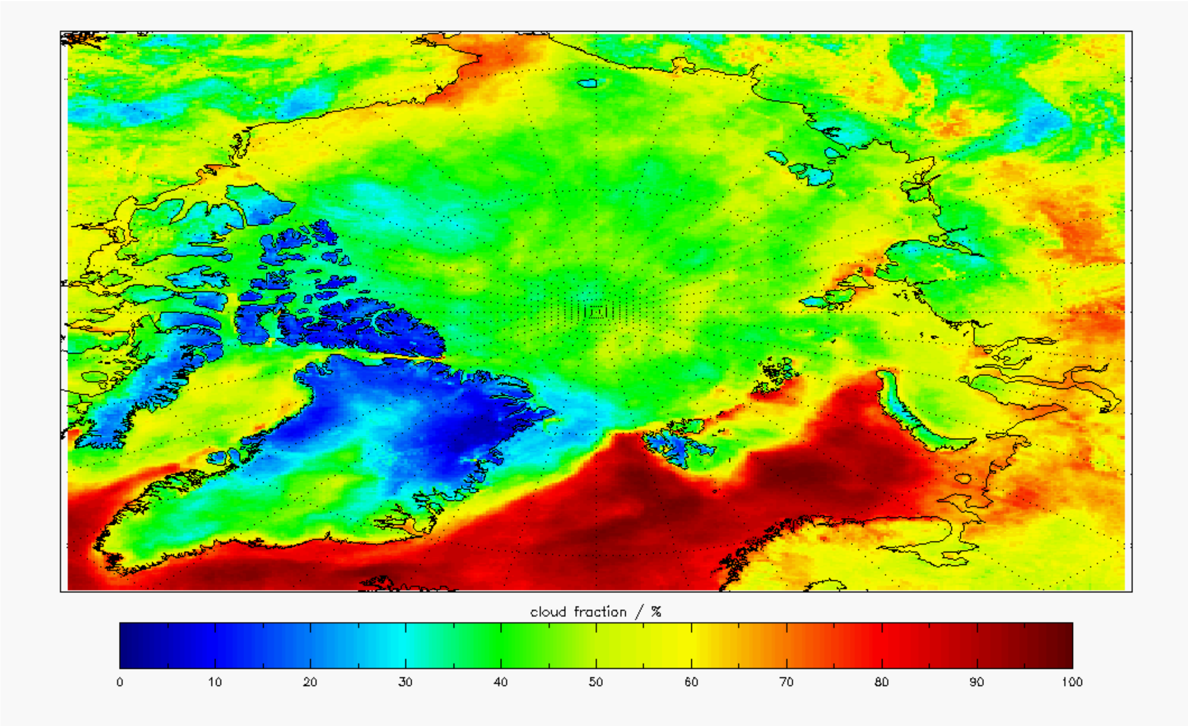

Figure 3-8 *Example of CFC monthly mean product (in %) over the Arctic Area from April 2009.*

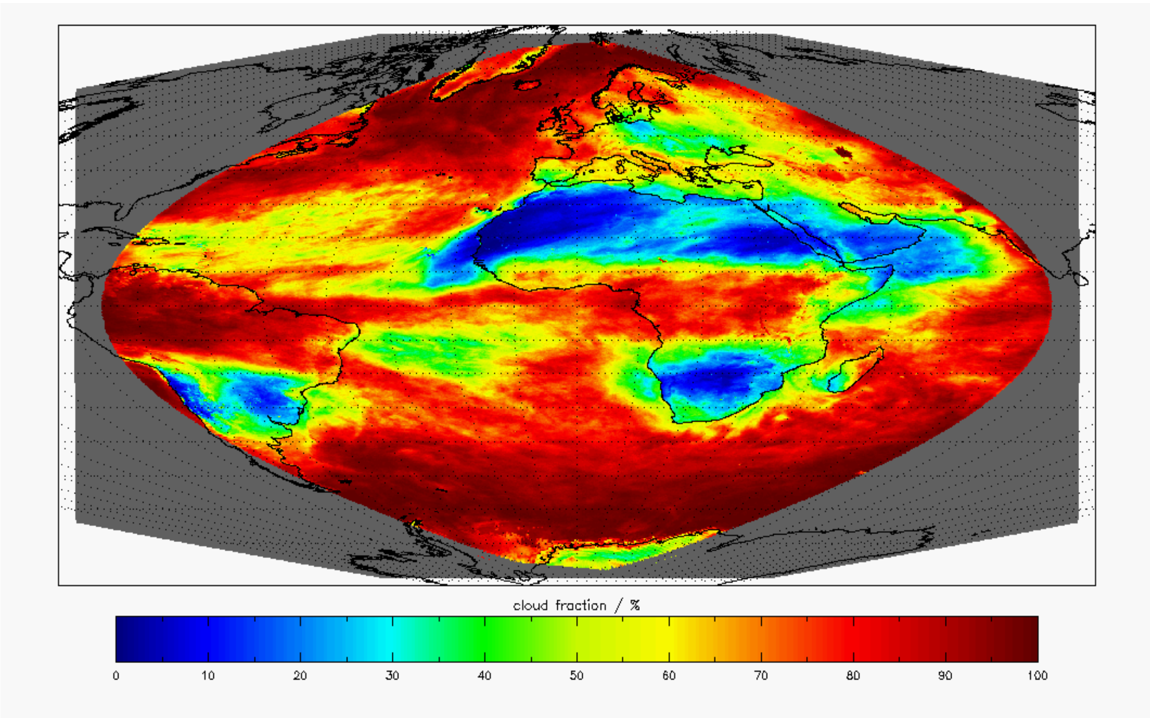

Figure 3-9 *Example of the MSG/SEVIRI monthly mean CFC product (in %) for April 2009 over the MSG Area. Notice that this is version 320.*

3.3.5 Validation

The Service Specification Document (SeSp) [AD.1] lists specific product requirements which have to be fulfilled by the products. The requirements for the CFC product are shown in Table 3-2.

Table 3-2 *Product requirements according to the Service Specification Document.*

Product	Requirements on mean error (absolute)
CFC for AVHRR (Initial Baseline Area) CFC for AVHRR (Arctic Region)	+/- 10 % *Higher deviations may occur over ocean surfaces (+ 10-15 %)* +/- 30 % *Higher deviations might occur in very cold Polar winter months, especially over the highest portions of Greenland*
CFC for SEVIRI	+/- 10 % *Higher deviations may occur over ocean surfaces (up to + 15 %), over the tropical region (down to -15 %) and for MSG viewing angles above 70 degrees (leading to substantial overestimation of CFC).*

The uncertainty of the disseminated products is assessed each year against this requirement and the results are summarised in the CM-SAF Annual Validation Reports [AD.2, AD.3, AD.7, AD.8].

3.3.6 Limitations

Below is listed some of the known deficiencies and limitations of the CFC product:

- Differences caused by varying viewing angles

Generally, cloud amounts are higher for SEVIRI in the northern part of the commonly viewed area compared to AVHRR. Validation results (AD.2) have shown that this difference is varying over the Baseline area from being negligible in the southern part to increase to about 20 % in the most northern part. This can mainly be understood as an effect of the increasing viewing angles as a function of latitude which causes vertically extended cloud elements to become mis-projected (elongated) northward. The possibility to correct future CM-SAF products for viewing angle effects is under consideration and different methods are currently evaluated.

- Effect of sub-pixel cloudiness

In the present calculation of the CFC product no attempt is made to take into account for the fact that pixels labelled as being only cloud-contaminated are not totally covered by clouds. This means that the CFC values will generally slightly overestimate cloud amounts. The overestimation is largest over ocean surfaces and may be as high as 10 % in absolute CFC units. Current validation results indicate that this difference is larger for SEVIRI products than for AVHRR products.

- Land-ocean differences

Related to the previous point is the fact that it is obvious from theoretical considerations that cloud detection is generally easier to accomplish over oceanic surfaces than over land surfaces. This is due to generally lower and less variable surface albedo values and temperatures found over ocean surfaces. It means that we have normally better contrasts between cloudy and cloud-free areas in satellite imagery over ocean areas except in cases of sunglints.

- Spurious artificial clouds along coastlines

Since image navigation is not perfect, especially for NOAA AVHRR scenes (errors are generally larger than 1 km), some problems may also occur close to coasts. This is explained by an improper use of land thresholds over ocean surfaces and vice versa when image navigation is not perfect. In SEVIRI products also the coastline might appear as a line.

- Missing low clouds in twilight conditions

Problems in low-level cloud detection during twilight conditions (with solar zenith angles ranging from 85-90 degrees) have been shown to result in a general underestimation of cloud amounts of the order of 10 %. The situation is slightly better for SEVIRI products thanks to the availability of more channels that are not subject to the same type of changes when conditions change from darkness to daylight.

- Day and night differences

Since the amount of useful satellite information is reduced during night (i.e., no visible information is available), also the quality of the CFC product will be different day and night. Most problematic is the combination of darkness and cold surface temperatures since this leads to smaller contrasts between clouds and cloud-free surfaces in infrared imagery. Thus, cloud amounts are generally underestimated in the winter season, especially at high latitudes and over the inner parts of continents.

An accurate quantification of the day-night difference in connection to validation activities has still not been possible since also reference observations (i.e., synoptical observations) have obvious limitations during night.

- Impact of extremely cold surfaces in polar winter

Conditions prevailing during the polar winter mean that several of the above mentioned problems may be added to result in large total errors of the CFC product. If conditions are very cold (e.g. as anticipated over the highest portions of Greenland) CFC may be underestimated by more than 30 % in absolute amounts. It is mainly explained by an inability to detect thin clouds over extremely cold surfaces regardless of cloud top height but also optically thick clouds can be missed in cases when these clouds occur in strong low-level temperature inversions. Over high topography (e.g. Greenland) a significant underestimation of CFC values may occur also in the polar summer due to the low surface temperatures here. However, the underestimation will not be as high as in the polar winter mainly because optically thick clouds are better detected.

- Horizontal and vertical lines for AVHRR products prior to version 310

AVHRR based products sometimes show vertical and horizontal lines at the boundary from one tile to its neighbouring tiles. An example of this behaviour is given in Figure 3-6. This comes from the unequal data reception statistics from the local receiving station and the averaging method which is applied to full tiles and not per pixel. This becomes especially critical for the tiles that are most distant to the HRPT receiving station in Offenbach.

- Overestimation of land sea contrasts

Most prominent here are the gradients seen along the western part of Greenland. Since surface conditions are very different it is expected that this lead to large differences in CFC even if large-scale dynamical effects might smear out such details. If the polar jet flow is not particularly strong across Greenland (which shouldn't normally be the case in a polar summer month) the cold snow-covered surface on Greenland would have a stabilising effect on temperature profiles leading to suppression of cloud formation. As a contrast, relatively warm surfaces over open sea waters will be able to produce a substantial amount of convective cumulus and stratocumulus clouds. This is the most likely cause of the sharp land-sea gradients. The situation becomes much more problematic in the polar winter. The gradient in cloud cover across a boundary of ice-free and ice-covered ocean is then likely to increase due to existence of very cold surface temperatures (much colder than in polar summer) over the ice-covered surface and the lack of visible AVHRR information and especially the reflected information in 1.6 and 3.7 micron channels. The consequence is that clouds are still well detected over open ocean while a substantial fraction of clouds over ice-covered surfaces will remain undetected. Thus, in the polar winter such gradients along ice edges and coasts might be overestimated.

3.3.7 Version traceability

Two tables stating current product version numbers and a brief modification history since the start of operational activities were given in the beginning of this document.

In Table 3-3 and Table 3-4 below follow some more specific details on how version updates have affected the CFC products derived from AVHRR and SEVIRI data, respectively.

Table 3-3 *List of AVHRR product versions and descriptions of the impact of changes on the CFC product.*

Version AVHRR	Description of version update and the impact on the new product version	Valid time
130	Initial version based on NWC-SAF PPS cloud processing software version 1.0.	Jan 2005 – Mar 2005
140	Averaging limits for cloud have been changed.	Apr 2005 – Jul 2005
150	Change from 32 x 32 pixel per segment to 45 x 45 pixel per segment in the cloud top processing to fix error of artefacts in the end cloud top products (straight lines across sub-areas) *The CFC product was not affected by this change.*	Aug 2005 – Dec 2006
160	Introduction of NWC-SAF PPS cloud processing software version 1.1. *The main change is a more cautious treatment of cloud detection over dry and vegetation-free areas (deserts). This results in reduced cloud amounts in particular over the northern parts of Africa.*	Jan 2007 – Jun 2007
300	Correction of GME remapping bug. *This change removes a previous feature in version 160 of giving too high CFC values over land and too low values over ocean surfaces. This was caused by the use of incorrect surface temperatures in the threshold calculation. The change is also clearly visible in the most northern part of the Baseline area where CFC values generally increase more than 10 % in cloud amount units.*	Jul 2007 – Dec 2008
310	Introduction of products over the Arctic Area and the change to processing of full AVHRR swaths over the Initial Baseline Area (also improving the data coverage over the area).	Jan 2009 – Jun 2009
320	SW update to PPSv2009, Sun-Earth distance correction; *Small impacts for CFC*	Jul 2009 – 31.12.2010
330	SW update to PPSv2010 *Small impacts for CFC*	01.01.2011 – today

Table 3-4 *List of SEVIRI product versions and descriptions of the impact of changes on the CFC product.*

Version SEVIRI	Description of version update	Valid time
210	Initial version based on NWC-SAF MSG cloud processing software 2.1	Sep 2005– Apr 2007†
300	Changing from Meteosat-8 to Meteosat-9 *Introduction of MSG/SEVIRI cloud processing software version 2.1 adapted to Meteosat-9. Changes in CFC products are generally small or negligible.*	May 2007 – Apr 2008 (*Products for both satellites are available for March and April 2007)*
310	Introduction of the new SEVIRI radiance definition. *Introduction of MSG/SEVIRI cloud processing software version 2008 adapted to new radiance definition. Changes in CFC products are generally small or negligible*	May 2008 – Dec. 2008
320	Migration to new processing environment, No effect on CFC product	Jan 2009 – today

† Version 210 data are available until 9 May 2007.

3.4 Cloud Type

3.4.1 Product definition

The CM-SAF produced CTY product is based on a condensed description of cloud types. Presently the following five cloud classes are defined: **Low clouds**; **Middle level clouds**; **High opaque clouds**; **High semitransparent clouds** and **Fractional clouds**. Thus, the CTY results are given as five individual components. The resulting average value denotes the percentage of pixels of the appropriate class relative to all cloudy pixels in each remapped 15 km * 15 km grid square.

3.4.2 Basic approach

Just as for the CFC product, the CTY product is based on results from the NWC-SAF Cloud Type algorithms (described by the same references given previously) for both polar and geostationary satellite data. Also here a threshold approach is used. The main principle is to make use of measured cloud temperatures in the infrared for thick clouds for the vertical separation of clouds. Furthermore, ice clouds are identified using reflection characteristics at short-wave infrared channels (e.g., at 1.6 µm, 3.7 µm and 3.9 µm) and thin clouds are identified using transmission differences revealed by measurements in infrared channels (3.7 µm or 3.9 µm, 8.7 µm, 11 µm and 12 µm). The category Fractional clouds describe cloud-contaminated (thus, partly cloudy) pixels where it has not been possible to uniquely define the cloud altitude.

The CTY algorithms are described in detail in the ATBD's of the corresponding product version for AVHRR (Table 2-1), and in Table 2-2 for SEVIRI products, respectively.

3.4.3 Details on processing, gridding and averaging

In the final computation of the CTY product, a merging is made of the original 20 different cloud types of the NWC-SAF cloud type algorithms into the five CM-SAF categories (Table 3-5). The final product is computed as the fraction of all cloudy pixels within a 15 km x 15 km square that has been labelled into each respective cloud type category. Consequently, the CTY product consists of five separate components that sum up to 100 % if being added. The absolute contribution from each cloud type category can be calculated by multiplying by the corresponding CFC value.

The monthly mean is calculated from the corresponding daily averages of fractional cloud type for each class and individual month. This constraint was introduced to emphasise the importance of giving equal weight to each day of a month, in order to be able to construct a representative monthly mean.

For geostationary data the monthly mean is calculated in the same way using all available hourly scenes for the construction of the daily averages. For CTY, a minimum set of 6 overpasses (or MSG time slots) is defined which is needed to compute a daily mean. To build a monthly mean 20 daily means are required.

To obtain a monthly mean diurnal cycle for a given MSG time slot all days of this time slot are used to compute the product. This is then repeated for all time slots per day, thus giving the monthly mean diurnal cycle. For each time slot 20 individual days of the month are needed to compute a product.

Due to the different Level 0 data streams only with METOP the Arctic area is fully covered which is not the case for the NOAA-satellite AVHHR based products. For METOP the full data stream is available, whereas for AVHRR only the data from the EARS data stream can be used. I.e., METOP provides full coverage of the Arctic whereas the EARS data stream provides only coverage of the Atlantic sector. Thus for the averages of all satellite data a spatial inhomogeneity can not be avoided.

Table 3-5: *Table of reclassification into the 5 CM-SAF cloud types from 20 instantaneous cloud type classes for both products.*

Instantaneous /description		Averaged data set	
Class	**Description**	**MSG**	**AVHRR**
0	non-processed containing no data or corrupted data	Not used	Not used
1 **2** **3** **4**	cloud free land no contamination by snow/ice covered surface, no contamination by clouds cloud free sea no contamination by snow/ice covered surface, no contamination by clouds land contaminated by snow sea contaminated by snow/ice	Cloud free	Cloud free
5 **6** **7** **8**	very low and cumuliform clouds very low and stratiform clouds low and cumuliform clouds low and stratiform clouds	Low clouds	Low clouds
9 **10**	medium and cumuliform clouds medium and stratiform clouds	Middle level clouds	Middle level clouds
11 **12** **13** **14**	high opaque and cumuliform clouds high opaque and stratiform clouds very high opaque and cumuliform clouds very high opaque and stratiform clouds	High clouds	High clouds
15 **16** **17**	high semitransparent thin clouds high semitransparent meanly thick clouds high semitransparent thick clouds	highsemi-transpa-rent clouds	high semi-transpa-rent clouds
18	high semitransparent above low or medium clouds		
19	fractional clouds (sub-pixel water clouds)	Fractional clouds	Fractional clouds
20	fined by cloud mask)	Not used	Not used

To make this difference visible to the user for the Arctic area the averaging process is done separately for all polar satellites and in an additional step for METOP data only. Thus, all Arctic products (Table 4-3) include two datasets per category. The major difference between them is purely sampling and quality differences depend on the variability of cloud properties. Therefore, the data over the Atlantic sector have the best quality w.r.t. sampling.

For users interested in those areas it is recommended to use the full product including all satellites. Users who need to analyse the whole Arctic should use METOP-only products as those have homogeneous sampling characteristics in the whole area (Table 4-3).

3.4.4 Product examples

Figure 3-10 to 2-10 illustrate the AVHRR and SEVIRI CTY products over their respective processing areas. Figure 3-10 illustrates all five components of the CTY product while Figure 3-11 shows exclusively the High-level clouds over the Arctic Area and Figure 3-12 shows exclusively the component of Low-level clouds over the MSG area.

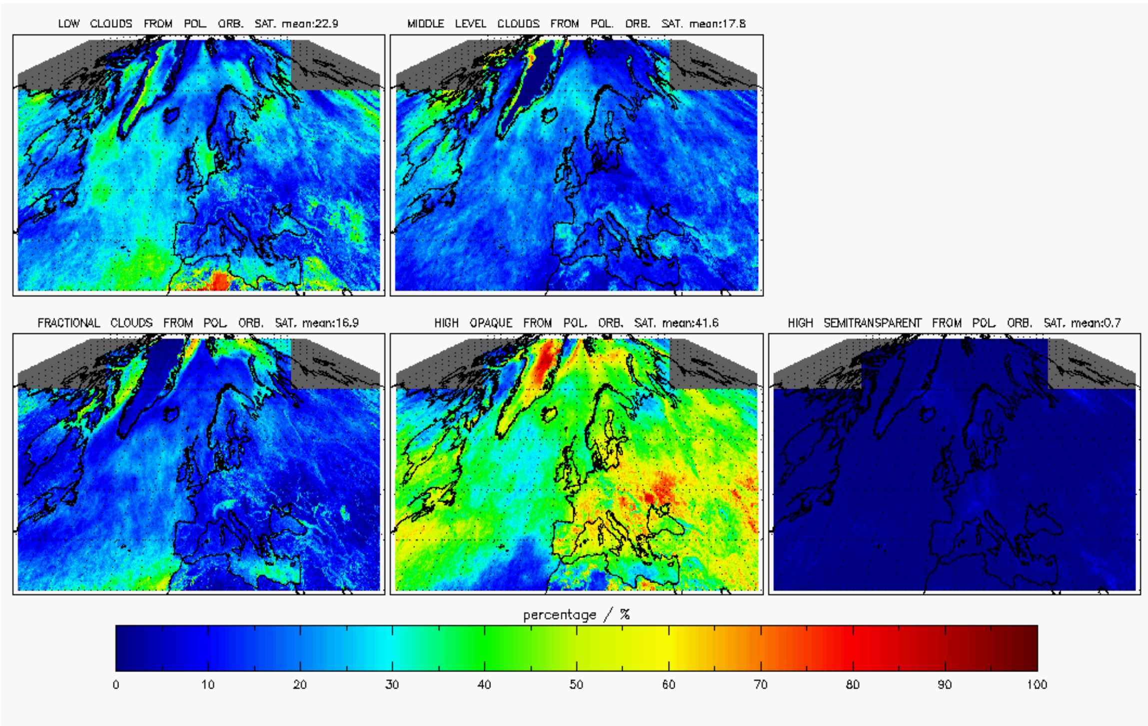

Figure 3-10. *Example of the AVHRR-derived CTY monthly mean product for April 2009 showing the contribution (in %) of each cloud type category. The product version is 310.*

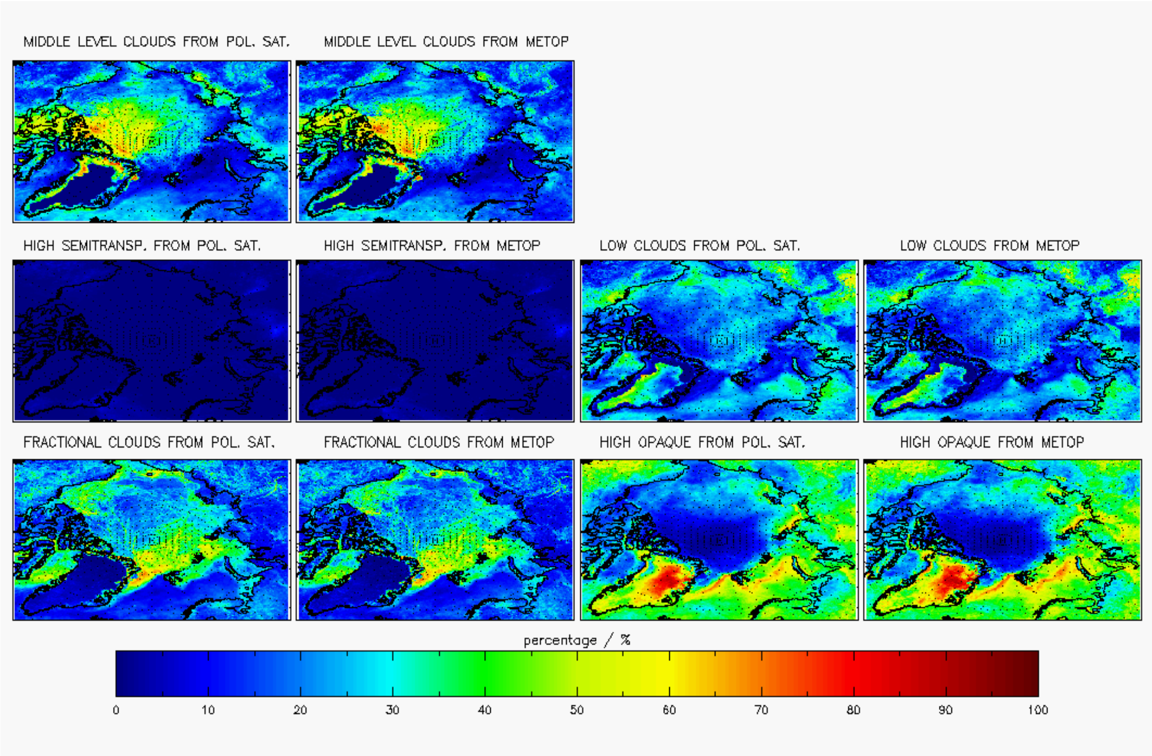

Figure 3-11 *Example of the monthly mean CTY fraction (in %) for all 5 classes over the Arctic Region for April 2009. Notice that for each class, both datasets are displayed, one for all polar satellites (left image of each class), and that for METOP products only (right image of each class)s.*

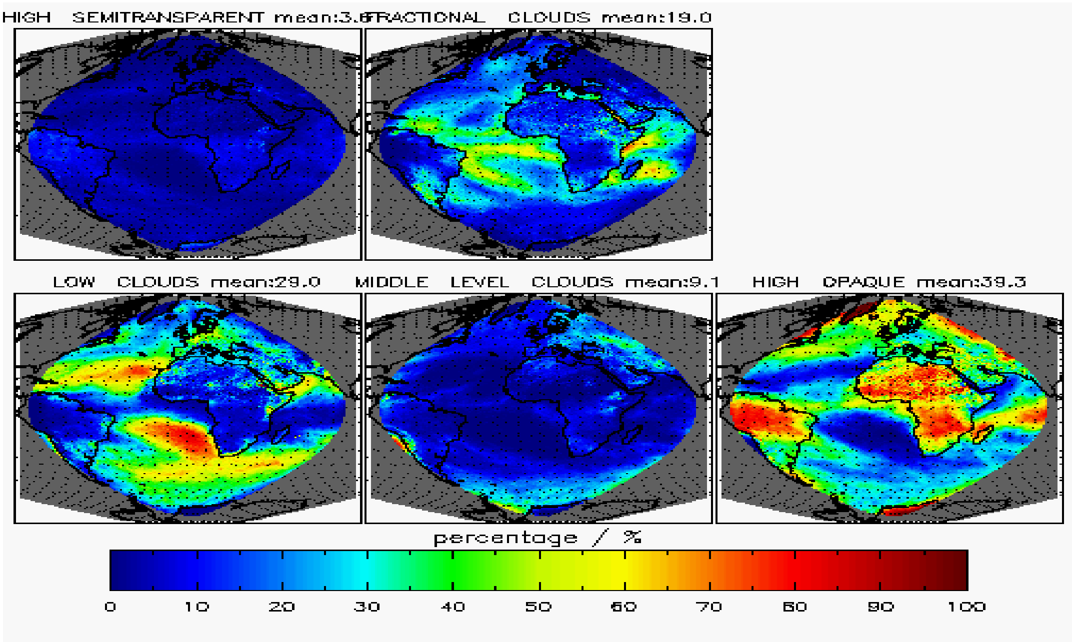

Figure 3-12 *SEVIRI-derived CTY monthly mean product for June 2008 showing the relative contribution to the total cloud cover for the five clouds types. Notice that this example is valid for products since version 320.*

3.4.5 Validation

The Service Specification Document (SeSp) [AD.1] lists specific product requirements which have to be fulfilled by the products. The requirements for the CTY product are shown in Table 3-6.

Table 3-6 *Product requirements according to the Service Specification Document.*

Product	Requirements on mean error (absolute)
CTY for AVHRR (Initial Baseline Area)	+/- 30 %
CTY for AVHRR (Arctic Area)	+/- 30 %
CTY for SEVIRI	+/- 30 %

The uncertainty of the disseminated products is assessed each year against this requirement and the results are summarised in the CM-SAF Annual Validation Reports [AD.2, AD.3, AD.7, AD.8].

3.4.6 Limitations

From validation activities it is well known that the ability to separate different cloud types and surface types varies with seasons, illumination conditions and the satellite viewing geometry. The main limitation here is naturally the lack of visible measurements during the dark part of the day. For example, the ability to detect snow cover on the ground using AVHRR and SEVIRI imagery is impossible due to this limitation. Also the existence of very low ground temperatures might cause problems. In this sense, the error characteristics are closely linked to those of the CFC product (i.e., depending very much on the success of cloud detection).This generally means that the CTY results are more reliable during the warmer seasons and during daylight conditions.

Some more specific deficiencies of the CTY product are the following:

- Twilight misclassifications and effects of high solar zenith angles

Particularly difficult is the twilight period under which radiances in visible and near-infrared spectral channels change rapidly and very sensitively with the sun elevation (see also corresponding section for the CFC product). Also cloud shadows will influence cloud type assignments negatively during twilight. This means that for some cloud types (low water clouds and thin cirrus clouds) cloud detection will fail at night and in twilight giving a surface type as output. The same effect will also be seen during dark and very cold winter situations where cloud detection might fail because of low level clouds being trapped in strong surface temperature inversions, thus becoming substantially warmer than the surface.

- Mixing sunglints over ocean with low-level clouds

A correct separation of sun glint and low level cloudiness over ocean and lake surfaces is not always achieved. The current methodology is still not capable of making this distinction in all cases, especially for cases in early spring when ocean/lake surface temperatures at high latitudes are low and comparable with low level cloud top temperatures.

- Misinterpretation of thin cirrus clouds over snow cover

When thin semi-transparent cirrus clouds are superimposed over snow-covered ground the mixed signal can sometimes give rise to an erroneous output such as Mid-level clouds. Otherwise, snow- or ice–covered surfaces are generally efficiently separated from clouds by use of the very low reflectivity of snow in the 1.6 and 3.7 micron channels for NOAA AVHRR and the 1.6 and 3.9 micron channels for METEOSAT SEVIRI.

- The impact of large viewing angles

The quality of the AVHRR CTY product (and also most other AVHRR cloud products) for versions prior to 310 along the extreme western, eastern and northern parts of the CM-SAF baseline area (e.g. Greenland) is currently limited due to the use of AVHRR data from only one HRPT reception station (Offenbach). It means that products are here often based on near-swath edge parts of AVHRR scenes having very large viewing angles. This could e.g. lead to that semi-transparent clouds are being falsely interpreted as opaque clouds. Furthermore, the number of used samples for the creation of monthly averages is currently much smaller in this part of the area than in the central parts of the area. The next product version under development will be based on an enhanced AVHRR dataset. This deficiency is not present in products from version 310 and onwards.

- Product inconsistency with other cloud products

Currently, the cloud type product does not make full use of all the other cloud products (especially the cloud top product and the cloud physical products CPH, COT and CWP). A more consistent definition of the cloud type product is under construction.

- Cloud type inconsistencies in AVHRR products over high terrain

If a medium-level opaque cloud is found in an area with topography exceeding 2000 meters above mean sea level there is currently a redefinition of medium-level opaque clouds into low-level clouds in the AVHRR product. This comes from the desire in nowcasting applications to always indicate or warn for conditions when there is a risk for presence of near-surface clouds (especially important for aviation forecasts). Since this is not really appropriate for climate monitoring purposes a change here will also be considered in the foreseen revision of the Cloud Type product (see previous point).

- Product inconsistency between MSG and AVHRR

The products for high clouds and high-semitransparent clouds derived from AVHRR and MSG are not consistent (see Table 3-5) for SEVIRI product versions prior to version 320. The recommendation is to use the sum of both classes, when using both satellite products together.

- Horizontal and vertical lines for AVHRR products prior to version 310

AVHRR based products sometimes show vertical and horizontal lines at the boundary from one tile to its neighbouring tiles. An example of this behaviour is given in Figure 3-6 for cloud fractional cover. This comes from the unequal data reception statistics from the local receiving station and the averaging method which is applied to full tiles and not per pixel. This becomes especially critical for the tiles that are most distant to the HRPT receiving station in Offenbach.

3.4.7 Version traceability

Two tables stating current product version numbers and a brief modification history since the start of operational activities were given in the beginning of this document.

In Table 3-7 and Table 3-8 below follow some more specific details on how version updates have affected the CTY products derived from AVHRR and SEVIRI data, respectively.

Table 3-7 *List of AVHRR product versions and descriptions of the impact of changes on the CTY product.*

Version AVHRR	Description of version update and the impact on the new product version	Valid time
130	Initial version based on NWC-SAF PPS cloud processing software version 1.0.	Jan 2005 – Mar 2005
140	Averaging limits for cloud products have been changed.	Apr 2005 – Jul 2005
150	Change from 32 x 32 pixel per segment to 45 x 45 pixel per segment in the cloud top processing to fix error of artefacts in the end cloud top products (straight lines across sub-areas). This change does not affect the CTY product at all.	Aug 2005 – Dec 2006
160	Introduction of NWC-SAF PPS cloud processing software version 1.1. Changes will remove misclassified clouds over dry and sparsely vegetated areas (see Table 3-3). Thus, also CTY products (e.g., previously giving false low-level clouds over desert areas) will be improved here.	Jan 2007 – Jun 2007
300	Correction of GME remapping bug. This change removes a previous feature of giving too high CFC values over land and too low values over ocean surfaces. This was caused by the use of incorrect surface temperatures in the threshold calculation. This bug also resulted in corresponding anomalous deviations of the CTY contributions which are now removed.	Jul 2007 – Dec. 2008

Version AVHRR	Description of version update and the impact on the new product version	Valid time
310	Introduction of products over the Arctic Area and the change to processing of full AVHRR swaths over the Initial Baseline Area (also improving the coverage over the area).	Jan. 2009 – Jun 2009
320	SW update to PPSv2009, Sun-Earth distance correction; Small impacts on CTY	Jul 2009 – Dec 2010
330	SW update to PPSv2010 Small impacts on CTY	Jan 2011 – today

Table 3-8: *List of SEVIRI product versions and descriptions of the impact of changes on the CTY product.*

Version SEVIRI	Description of version update	Valid time
210	Initial version based on NWC-SAF MSG cloud processing software 2.1.	Jan 2007 – Apr 2007†
300	Changing from Meteosat-8 to Meteosat-9 Introduction of MSG/SEVIRI cloud processing software version 2.1 adapted to Meteosat-9. Changes in CTY products are generally small but changes of a few % in contributions of categories Low Clouds and Fractional Clouds have been noticed in the tropical region.	May 2007 – Apr 2008 (Products for both satellites are available for March and April 2007)
310	Introduction of the new SEVIRI radiance definition. *Introduction of MSG/SEVIRI cloud processing software version 2008 adapted to new radiance definition.*	May 2008 – Dec 2008
320	Change of remapping table (Table 3-5) to be consistent with AVHRR processing; Migration to new processing environment.	Jan 2009 – Dec. 2009
330	Bug fix in cloud type averaging routine.	Jan 2010 – today

† Version 210 data are available until 9 May 2007.

3.5 Cloud Top Products

3.5.1 Product definition

Three versions of the CM SAF Cloud Top product (commonly denoted the CTO product) exist:

1. The Cloud Top Temperature (CTT), expressed in Kelvin
2. The Cloud Top Height (CTH), expressed as altitude (m).
3. The Cloud Top Height (CTP), expressed in pressure co-ordinates (hPa).

Notice that the CTH product for AVHRR data is given relative to the topography and not relative to the mean sea level. This is a heritage from the NWCSAF where applications (e.g. for aviation) often desire results relative to local topography. Unfortunately, the SEVIRI product differs here and report results relative to mean sea level. A harmonisation of CM-SAF products will be considered in the future. However, a way to avoid this problem is to always use the CTP product.

3.5.2 Basic approach

For the determination of cloud top information the CM SAF is also here using the NWC-SAF algorithms. However, as a contrast to the situation for the cloud masking and cloud typing algorithms, there are now considerable differences between the algorithms applied either to NOAA AVHRR data or MSG SEVIRI data. The reason is the availability of spectral channels in non-window regions for the SEVIRI instrument which are not present on the AVHRR instrument.

The CTO product is derived using two algorithms (or, in the SEVIRI case, algorithm groups), one for opaque and one for fractional and semitransparent clouds, and it is applied to all cloudy pixels as given by the CTY product. The algorithms are briefly summarised below and further details are given in ATBD of the corresponding product version for AVHRR (Table 2-1) and MSG-SEVIRI (Table 2-2), respectively.

The opaque algorithms for AVHRR and SEVIRI use both simulated cloud free and cloudy TOA 11 µm radiances which are compared to measured radiances. Cloudy radiances are simulated assuming “black-body”-clouds at various levels. The radiance simulations are made on a coarse horizontal resolution (on segments of high-resolution pixels). The segment size in number of high-resolution pixels is configurable for the user, but should be chosen so as to be comparable to the grid resolution of the NWP model used. The lower the resolution the faster the algorithm is. For the CM SAF implementation, a segment size of 45 km has been chosen.

For all pixels classified into one of the opaque cloud types, the cloud top pressure is derived from the best fit between the simulated and the measured brightness temperatures. The corresponding simulated cloud layer temperature from the segment closest in space to the given pixel is chosen as the associated cloud top temperature.

Semi-transparent algorithm for AVHRR:

The semi-transparent algorithm is applied to all pixels classified as semi-transparent cirrus or fractional water cloud. A histogram technique is applied based on the construction of two-dimensional histograms using AVHRR channel 4 and 5 brightness temperatures composed over the larger segments (see Figure 3-13). By an iterative procedure a polynomial curve (simulating the arc shape) is fitted to the histogram-plotted values from which the cloud top temperature and pressure (taken from NWP profiles) is retrieved. In this procedure, first guess values of surface temperatures are taken from NWP analyses as an external constraint.

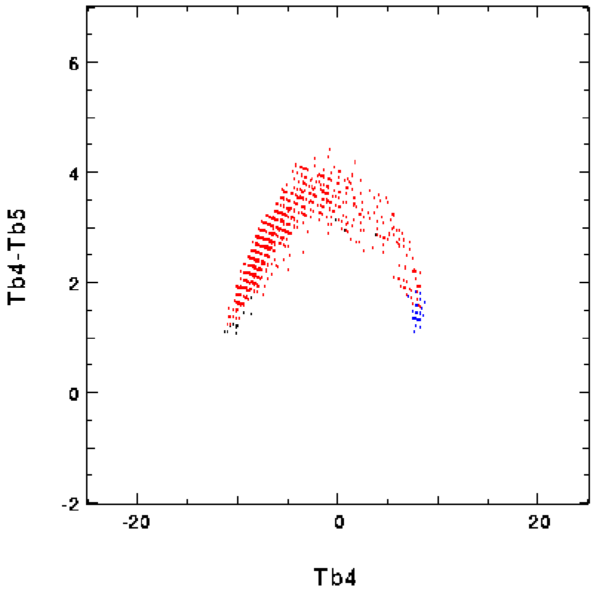

Figure 3-13 *Example distribution of pixels from a 32x32 size image segment. Brightness temperature difference in AVHRR channels 4 (11 µm) and 5 (12 µm) is shown as a function of brightness temperature at channel 4. The pixels classified as clear are shown in blue, and the cloudy pixels are shown in red (semitransparent) and black (opaque).*

Semi-transparent algorithm for SEVIRI:

For MSG SEVIRI data, the so called H2O/IRW intercept method (Schmetz et al, 1993) and the radiance rationing method (outlined by Menzel et al.,1983) have been used. Both methods utilise linear relationships between radiances in one window channel and in one sounding channel to estimate the cloud top radiance and cloud top pressure. The final conversion to temperatures and height is done by comparing to NWP profiles.

As a final comment it should be mentioned that the derived cloud top temperature/pressure/height results for the opaque cloud pixels are merged with the cloud top temperature/pressure/height results for the semi-transparent cirrus and fractional water cloud pixels into one final product.

3.5.3 Details on processing, gridding and averaging

The final daily and monthly average products are calculated by averaging the original algorithm output in full pixel resolution over 15x15 km grid sub-areas. Cloud-top temperature and height are averaged linearly while cloud-top pressure is averaged logarithmically. The logarithmic averaging is motivated by the desire to keep consistency between the three different cloud top product realisations. For example, linearly averaged geometrical cloud top heights in meters will not correspond to the same geometrical height as the corresponding linearly averaged cloud top pressure. Since pressure decreases exponentially as a function of the geometrical height (more specifically, as a function of geometrical height normalised with the scale height) a logarithmic averaging will reduce these differences and makes it possible to correct it further using the scale height parameter.

Generally, for all products such pixels where the retrieval failed for any reason are excluded from averaging.

Monthly mean CTO values are calculated from daily mean values based on data from all available daily overpasses (AVHRR) or scenes (SEVIRI). There is no further weighting of daytime/night-time data.

For CTO a minimum set of 6 overpasses (or MSG time slots) is defined which is needed to compute a daily mean. To build a monthly mean 20 daily means are required. Currently these threshold are applied per area and not per pixel.

To obtain a monthly mean diurnal cycle for a given MSG time slot all days of this time slot are used to compute the product. This is then repeated for all time slots per day, thus giving the monthly mean diurnal cycle. For each time slot 20 individual days of the month are needed to compute a product.

It is emphasised that grid averages are based exclusively on values of the cloudy part of the grid square.

3.5.4 Product examples

Figure 3-14 to 2-16 give examples of the CTO product for all processing areas.

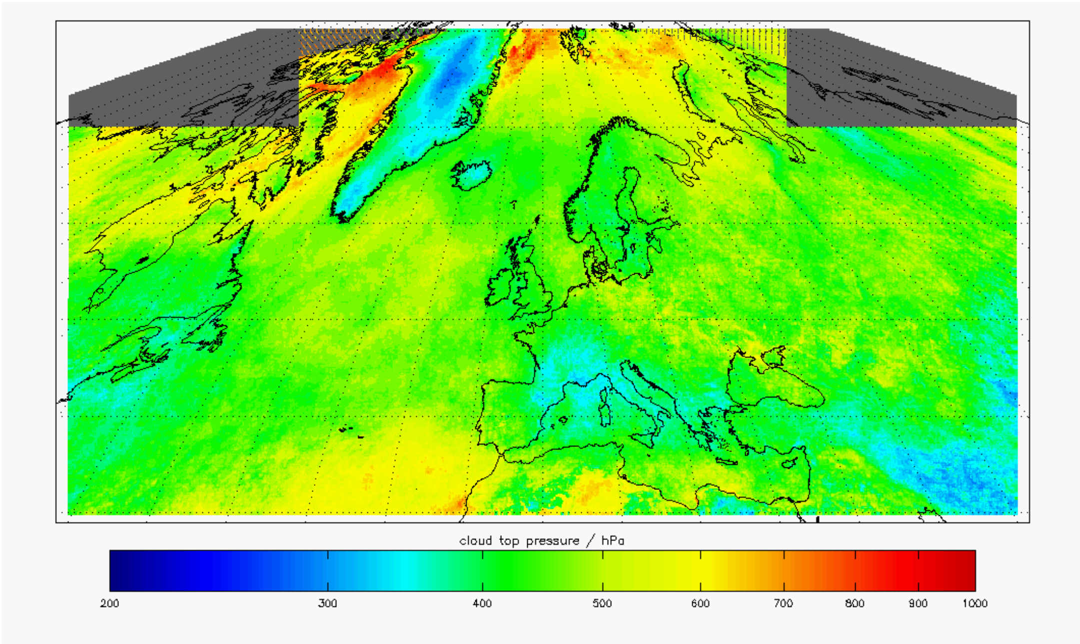

Figure 3-14 *Example of the AVHRR derived CTP monthly mean product (in hPa) for the Baseline Area for April 2009. Notice that this example is valid for product version 310.*

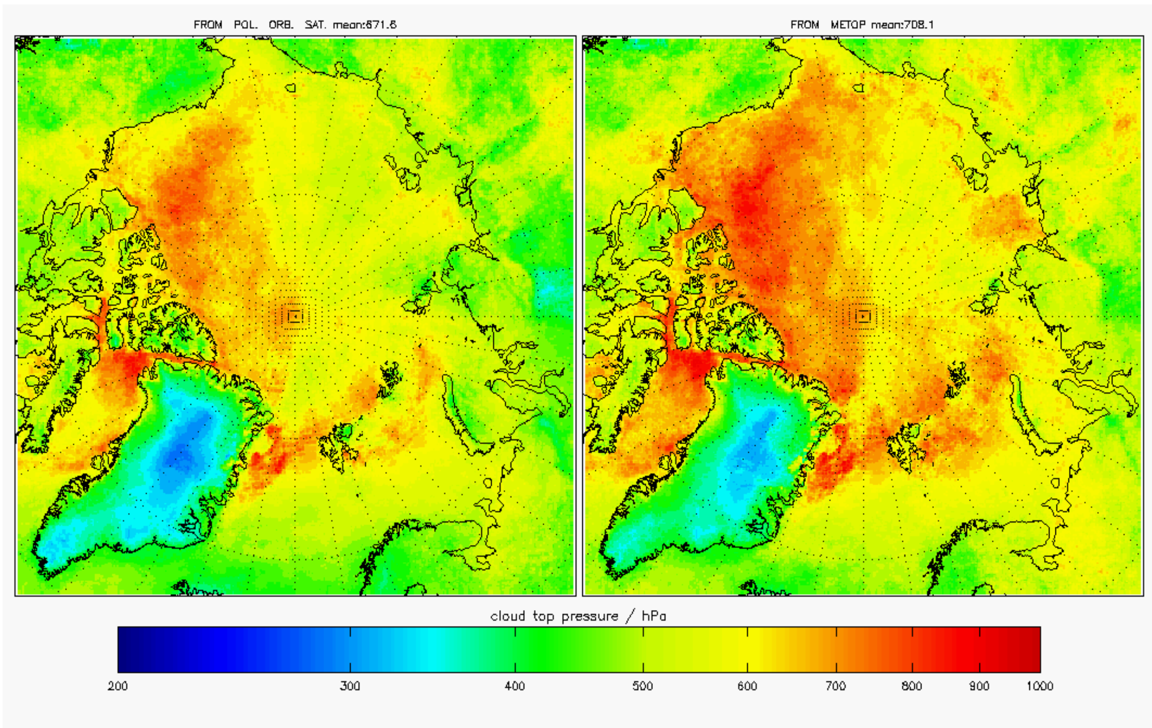

Figure 3-15 *Example of CTP monthly mean product (in hPa) over Arctic Area for Apil 2009. Left hand gives the monthly derived from all polar satellites, the right side the METOP only product.*

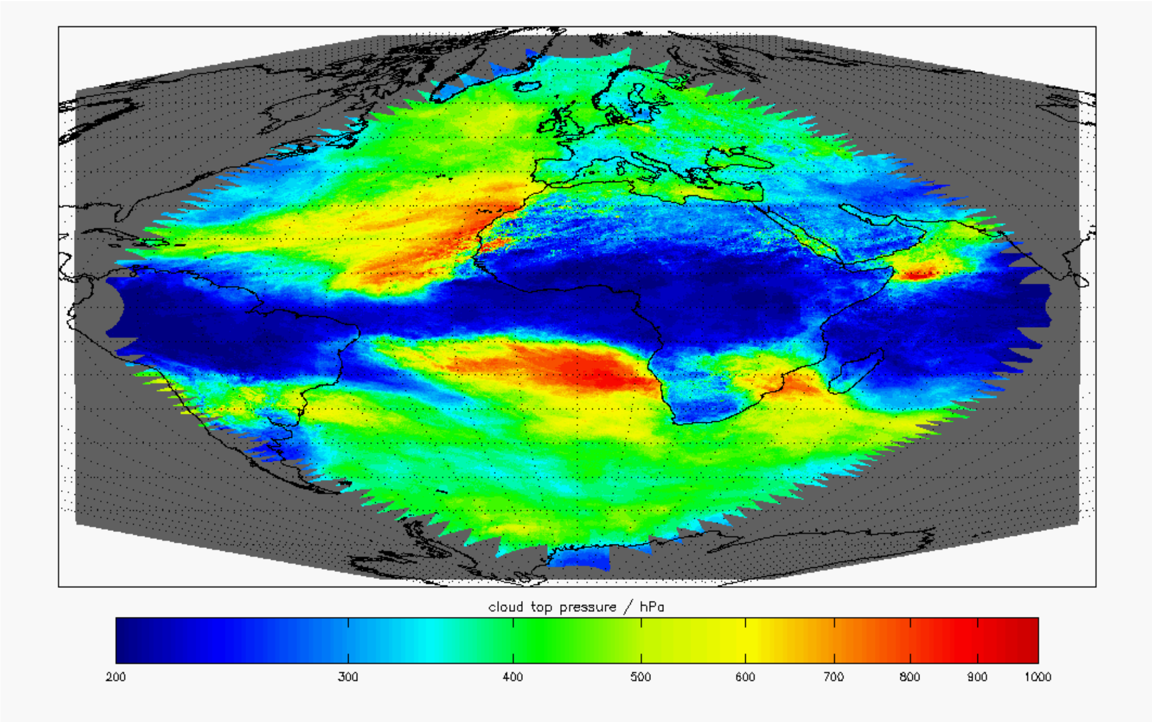

Figure 3-16 *Example of the CTP monthly mean product (in hPa) over the MSG full disk for April 2009. Notice that this example is valid for product version 320.*

3.5.5 Validation

The Service Specification Document (SeSp) [AD.1] lists specific product requirements which have to be fulfilled by the products. The requirements for the CTO product are shown in Table 3-6.

Table 3-9 *Product requirements according to the Service Specification Document. Notice that no values are specified for the CTT product mainly since it is judged as enough to evaluate the other two versions of the same basic product in Operations Reviews.*

Product	Requirements on mean error
AVHRR (Baseline):	
CTH	+/- 1200 m
CTP	+/- 160 hPa
AVHRR (Arctic):	
CTH	+/- 1200 m
CTP	+/- 75 hPa
SEVIRI:	
CTH	+/- 1200 m
CTP	+/- 140 hPa

The uncertainty of the disseminated products is assessed each year against these requirements and the results are summarised in the CM-SAF Annual Validation Report [AD.2, AD.3, AD.7, AD.8].

3.5.6 Limitations

- Higher cloud top pressure for AVHRR estimates

Cloud top pressure is generally higher in PPS estimations which are mainly explained by the higher sensitivity in the detection of thin high clouds by MSG due to higher viewing angles. The accuracy of this product is still under investigation, mainly because of a lack of ground-based validation measurements. Generally, the method applied to opaque clouds have been shown to give reasonable estimations (although generally underestimating cloud top heights) while the method applied for achieving a semi-transparent correction of cloud heights has been noticed to give results with very variable quality (for the MSG/SEVIRI case indicating some overestimation of cloud top heights). When applied to AVHRR data, the semi-transparency correction algorithm often fails in producing valid results. This is explained by the fact that the method is based on assumptions of a single cloud layer and if multiple cloud layers are present the method will not converge to realistic values. The consequence of these missing values is a positive bias in CTP and a negative bias in CTH.

- Dependence on NWP analyses

The quality of the CTO product depends to some extent on the quality of the reference vertical profiles of temperature and moisture taken from NWP model analyses. Especially troublesome is the treatment of situations with temperature inversions since this implies that there are several solutions to the problem of matching measured cloud top temperatures to vertical reference profiles. Details of the impact of varying NWP information on CTO products are included in the visiting scientist study from Trolez et al. (2008). Also, the NWP model analysis often fails in reproducing the strength of temperature inversions on the local scale due to the coarse NWP model resolution. The latter circumstance has been shown to produce a systematic overestimation of the cloud top height of fog and low stratus clouds in the Arctic region (AD. 6).

- Horizontal and vertical lines for AVHRR products version prior to 310

AVHRR based products sometimes show vertical and horizontal lines at the boundary from one tile to its neighbouring tiles. An example of this behaviour is given in Figure 3-6 for cloud fractional cover. This comes from the unequal data reception statistics from the local receiving station and the averaging method which is applied to full tiles and not per pixel. This becomes especially critical for the tiles that are most distant to the HRPT receiving station in Offenbach.

3.5.7 Version traceability

Two tables stating current product version numbers and a brief modification history since the start of operational activities were given in the beginning of this document.

In Table 3-10 and Table 3-11 below follow some more specific details on how version updates have affected the CTO products derived from AVHRR and SEVIRI data, respectively.

Table 3-10 *List of AVHRR product versions and descriptions of the impact of changes on the CTO product.*

Version AVHRR	Description of version update and the impact on the new product version	Valid time
130	Initial version based on NWC-SAF PPS cloud processing software version 1.0.	Jan 2005 – Mar 2005
140	Averaging limits for cloud products have been changed.	Apr 2005 – Jul 2005
150	Change from 32 x 32 pixel per segment to 45 x 45 pixel per segment in the cloud top processing to fix error or artefacts in the end cloud top products (straight lines across sub-areas). *The previous configuration caused artificial straight lines in the cloud top products showing the boundaries between individual sub-tiles that were used for processing the products.*	Aug 2005 – Dec 2006
160	Introduction of NWC-SAF PPS cloud processing software version 1.1. *Method-wise no change to cloud top algorithms. However, removal of artificial low-level clouds over African desert regions (CFC and CTY algorithms) improves also resulting CTO values there.*	Jan 2007 – Jun 2007
300	Correction of GME remapping bug. *The remapping bug meant that GME-analysed model profiles valid over south Africa and the South Atlantic Ocean was erroneously used over Europe and matched to interpreted cloud top temperatures. This lead to too high overall cloud top pressures in the summer season and too low overall cloud top pressures in the winter season.*	Jul 2007 – Dec 2008

Version AVHRR	Description of version update and the impact on the new product version	Valid time
	As an example, after correction the overall mean of CTP over the Baseline area changed from 720 hPa to 660 hPa.	
310	Introduction of products over the Arctic Area and the change to processing of full AVHRR swaths over the Initial Baseline Area (also improving the coverage over the area). Processing of MetOP-A data.	Jan 2009 – June 2009
320	SW update to PPSv2009, Sun-Earth distance correction; *Small impacts on CTO*	Jul 2009 – Dec 2010
330	SW update to PPSv2010 *Small impacts for CTO*	Jan 2011 – today

Table 3-11 *List of SEVIRI product versions and descriptions of the impact of changes on the CTO product.*

Version SEVIRI	Description of version update	Valid time
210	Initial version based on NWC-SAF MSG cloud processing software 2.1	Sep 2005 – Apr 2007†
300	Changing from Meteosat-8 to Meteosat-9 *Introduction of MSG/SEVIRI cloud processing software version 2.1 adapted to Meteosat-9. Changes in CTO products are generally small.*	May 2007 – Apr 2008 *(Products for both satellites are available for March and April 2007)*
310	Introduction of the new SEVIRI radiance definition. *Introduction of MSG/SEVIRI cloud processing software version 2.2 adapted to new radiance definition.*	May 2008 – Dec. 2008
320	Migration to new processing environment. No effect on CTO products	Jan.2009 – today

† Version 210 data are available until 9 May 2007.

3.6 Cloud Phase

3.6.1 Product definition

The Cloud Phase product gives the thermodynamic cloud phase at the cloud top level and it provides the following possible output categories: *Water, Ice* or *Mixed***.** However, notice that the *Mixed* category is currently only provided by the AVHRR algorithm.

Thus, the product has two or three individual components and for each component the corresponding contribution is given in percent (%). Currently, the product exists in two versions, one all-day algorithm for AVHRR data and one day-time only algorithm for SEVIRI.

3.6.2 Basic approach

AVHRR method:

The present CPH product is based on a simple algorithm using only brightness temperatures measured at the infrared channel at 11 µm (T_{11}), i.e., a pure temperature interpretation approach is applied. This method is identical to the method previously used by the International Satellite Cloud Climatology Project (ISCCP, see Rossow and Schiffer, 1991).

The cloud top is interpreted as consisting of pure ice particles if T_{11} is lower than 233 K and by water particles if T_{11} is higher than 260 K. In between, both cloud phases may co-exist (the *mixed* phase). The CPH product is given for each component in percentage of all clouds present in each grid square.

SEVIRI method:

For SEVIRI, the cloud phase is interpreted primarily using reflected solar radiation in the 0.6 and 1.6 micron channels. The method is based on the fact that liquid and solid cloud particles behave differently in terms of 1.6-µm reflectance. At 0.6 µm, both liquid water and ice have very small values of the imaginary index of refraction, which determines the amount of absorbed solar radiation. At 1.6 µm, the imaginary index of refraction is higher for ice particles than for liquid particles, thus a smaller reflectance will be measured from ice clouds. As a result, the 1.6 µm channel is useful to distinguish water from ice clouds (see e.g. Baum et al., 2000).

Water and *ice* are assigned to those cloud flagged pixels for which the measured 0.6-µm and 1.6-µm reflectances correspond to the respective simulated LUT reflectance. Since visual image inspection revealed that ice is erroneously assigned to optically thin water clouds (e.g. at the edges of cloud fields), an empirical cloud-top temperature check, based on measured 10.8-µm brightness temperature, was included. The cloud-top temperature is obtained by correcting for cloud emissivity less than unity, using the ratio of visible to infrared cloud optical thickness and neglecting thermal infrared scattering (Minnis et al., 1993). When the *ice* phase has been retrieved initially, but the cloud top temperature is higher than 265 K, the phase is set to *water*.

Currently, the output values of the CPH product are *ice* and *water*, i.e.: the *mixed* phase is not retrieved by this method. Addition of a *mixed* phase classification is intended for the next major upgrade.

3.6.3 Details on processing, gridding and averaging

The calculation of the average product is principally similar to the calculation of the average cloud-type product, as explained in Section 3.4.3. To be noticed, however, is that for SEVIRI no CPH retrievals are made for solar zenith angles exceeding 72 degrees.

Monthly mean values of the cloud phase are calculated under the following conditions:

- Monthly mean values are derived from daily averages (no further weighting of daytime/night-time overpasses).
- The sum of all different cloud phases is always 100%. Thus, a 50% amount of water clouds at a CFC of 50% translates into a monthly average coverage of water clouds of about 25%.

The temporal and spatial averaging is done within one single step, i.e. searching for all available time slots and pixels for a given spatial area and time range (e.g. 15 x 15 km², daily).

To obtain a monthly mean diurnal cycle for a given MSG time slot all days of this time slot are used to compute the product. This is then repeated for all time slots per day, thus giving the monthly mean diurnal cycle. For each time slot 20 individual days of the month are needed to compute a product.

3.6.4 Product examples

Figure 3-17 and Figure 3-18 give an example of the MSG and AVHRR-based CPH products from April 2009.

3.6.5 Validation

The Service Specification Document (SeSp) [AD.1] lists specific product requirements which have to be fulfilled by the products. The requirements for the CPH product are shown in Table 3-12.

Table 3-12 *Product requirements according to the Service Specification Document.*

Product	Requirements on mean error (absolute)
AVHRR: CPH	+/- 25 %
SEVIRI: CPH	+/- 20 %

The uncertainty of the disseminated products is assessed each year against these requirements and the results are summarised in the CM-SAF Annual Validation Report [AD.2, AD.3, AD.7, AD.8].

3.6.6 Limitations

The CPH product has the following limitations:

- Limited skill of Limited skill of the AVHRR method

In general, a limited skill of the AVHRR method can be expected since it is well known from observations that, for example, pure water clouds may still exist for temperatures as low as –35°C or –40 °C (see e.g. Hogan et al., 2003). The SEVIRI method is a more direct physical retrieval and could be expected to give more realistic estimations.

- Erroneous water phase cloud detection of thin ice clouds over water clouds

In case of thin ice clouds over water clouds the visible and near-infrared reflectances are dominated by the water cloud layer, which results in an erroneous *water* labelling. The most recent validation results indicate that the water cloud occurrence might be overestimated by almost 100 % at the expense of the corresponding ice cloud occurrence. The largest overestimations occur in case of very thin ice clouds over thick water clouds. Wolters et al. (2008) have shown that these overestimations rapidly decrease with increasing ice cloud optical thickness, and are less than 10% in case of ice clouds with COT > ~1.

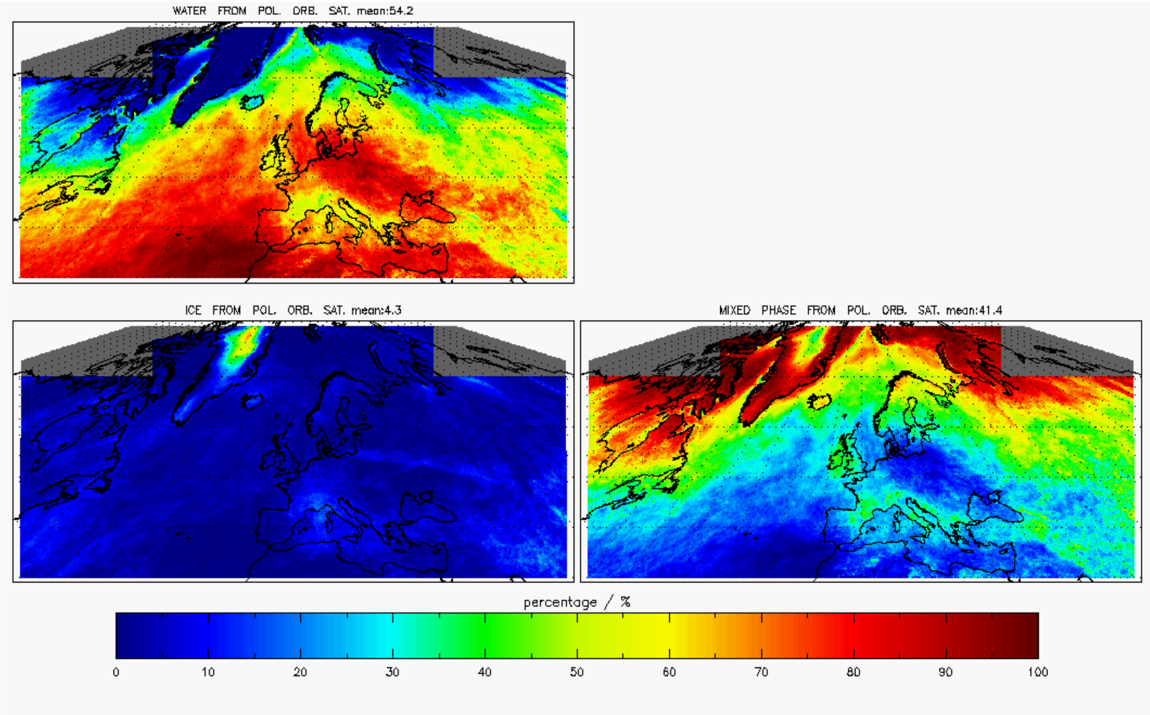

Figure 3-17 *Example of the AVHRR-derived CPH monthly mean product (in %) for the Baseline Area for April 2009 showing the contribution from water, ice and mixed phase clouds. Notice that this example is valid for product version since 310.*

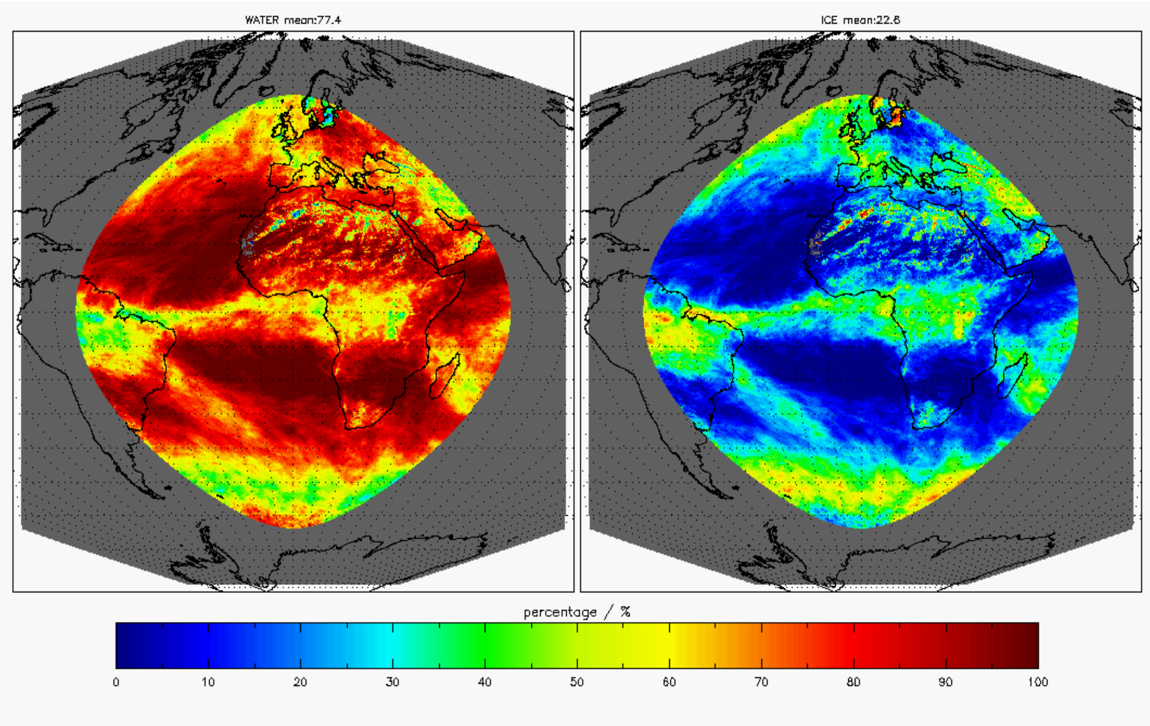

Figure 3-18: *Example of the MSG-derived CPH monthly mean product (in %) for the full MSG disc April 2009 showing the contribution from water and ice phase clouds. Notice that this example is valid for product version 320*

- Horizontal and vertical lines for AVHRR products prior to version 310

AVHRR based products sometimes show vertical and horizontal lines at the boundary from one tile to its neighbouring tiles. An example of this behaviour is given in Figure 3-6 for cloud fractional cover. This comes from the unequal data reception statistics from the local receiving station and the averaging method which is applied to full tiles and not per pixel. This becomes especially critical for the tiles that are most distant to the HRPT receiving station in Offenbach.

Future upgrades of this product are foreseen. The SEVIRI method will be implemented for AVHRR and more advanced methods based on the use of both visible and infrared radiances will be considered for realising an all-day algorithm also for SEVIRI. Especially the MODIS cloud phase determination algorithm (which uses among others 8.5-11µm brightness temperature difference threshold, see Strabala et al.1994) will be subject of research for adaptation to SEVIRI. Furthermore, efforts will be made to alleviate the problematic cloud phase retrievals in multi-layer cloud systems.

3.6.7 Version traceability

Two tables stating current product version numbers and a brief modification history since the start of operational activities were given in the beginning of this document.

In Table 3-13 and Table 3-14 below follow some more specific details on how version updates have affected the CPH products derived from AVHRR and SEVIRI data, respectively.

Table 3-13 *List of AVHRR product versions and descriptions of the impact of changes on the CPH product. CPH for AVHRR is based on PPS and not on CPP..*

Version AVHRR	Description of version update and the impact on the new product version	Valid time
130	Initial version based on PPS ISCCP-type method.	Jan 2005 – Mar 2005
140	Averaging limits for cloud products have been changed. *No effect on CPH.*	Apr 2005 – Jul 2005
150	Change from 32 x 32 pixel per tile to 45 x 45 pixel per tile in the clouds processing to fix error of artefacts in the end products (straight lines across sub-areas) *No effect on CPH*	Aug 2005 – Dec 2006
160	Introduction of NWC-SAF PPS cloud processing software version 1.1. *No effect on CPH.*	Jan 2007 – Aug 2007
300	Correction of GME remapping bug. *This bug did not affect the CPH product, although some indirect changes should be seen due to changes in cloud detection*	Sep 2007 – Dec 2008
310	Changed to swath-based processing. Otherwise, no change to the CPH algorithms. *Observe, that the CPH product is not produced over the Arctic region!*	Jan 2009 – Jun 2009
320	SW update to PPSv2009, Sun-Earth distance correction; *Small effects on CPH*	Jul 2009 – Dec 2010
321	SW update to PPSv2010 *Small impacts for CPH (input Cloud mask changed)*	Jan 2011 – today

Table 3-14 *List of SEVIRI product versions and descriptions of the impact of changes on the CPH product.*

Version SEVIRI	Description of version update	Valid time
210	Initial version based on NWC-SAF MSG cloud processing software 2.1 and CPP version 2.0	Sep 2005 – Apr 2007†
300	Changing from Meteosat-8 to Meteosat-9. New CPP version 2.2.2 *Introduction of MSG/SEVIRI cloud processing software version 2.1 adapted to Meteosat-9. Changes in CPH products are generally small.*	May 2007 – Apr 2008 (*Products for both satellites are available for March and April 2007)*
310	Introduction of the new SEVIRI radiance definition. *Introduction of MSG/SEVIRI cloud processing software version 2008 and CPP version 2.3 adapted to new radiance definition.* *Changes in CPH products are small.*	May 2008 – Dec 2008
320	Migration to new processing environment. No effect on CPH product.	Jan. 2009 - today

† Version 210 data are available until 9 May 2007.

3.7 Cloud Optical Thickness

3.7.1 Product definition

This product provides information on the Cloud Optical Thickness (COT) for pixels that are flagged cloudy by the cloud detection test. The retrieval algorithm is based on 0.6 and 1.6-µm channel radiances of NOAA-AVHRR and METEOSAT-SEVIRI. As an intermediate product the algorithm provides cloud droplet effective radius, r_e, as well. However, since the droplet effective radius is not validated it is not provided as an output product in the CMSAF.

3.7.2 Basic approach

The principle of methods to retrieve cloud physical properties is that the reflectance of clouds at a non-absorbing wavelength in the visible region (0.6 or 0.8 µm) is strongly related to the optical thickness and has very little dependence on particle size, whereas the reflectance of clouds at an absorbing wavelength in the near-infrared region (1.6 or 3.8 µm) is primarily related to particle size.

In the CPP algorithm, the Doubling-Adding KNMI (DAK) radiative transfer model (De Haan et al. 1987 and Stammes 2001) is used to simulate 0.6- and 1.6-µm top-of-atmosphere reflectances as a function of viewing geometry, cloud optical thickness , effective radius, and cloud phase: $R(\theta, \theta_0, \phi$, COT, r_e, and CPH), where θ is the satellite zenith angle, θ_0 the solar zenith angle and ϕ the relative azimuth angle. These simulated reflectances are stored in a look-up table (LUT). Figure 2-11 shows a cross section through the LUT.

COT and r_e are retrieved for cloudy pixels in an iterative manner by simultaneously comparing satellite-observed reflectances at 0.6 and 1.6 µm to the LUT of RTM-simulated reflectances (further described by Rosenfeld et al. (2004), Watts et al., (1998); Jolivet and Feijt, 2005). The iteration process continues until the retrieved cloud physical properties converge to stable values. For optically thin clouds (COT < 8) climatological mean effective radii of 8 µm and 26 µm are used for water and ice clouds, respectively, which are slightly lower than the values used in ISCCP (Rossow and Schiffer, 1991). A weighting function is applied to obtain a smooth transition toward climatological values for clouds with COT<8. SCIAMACHY spectra are used to calculate the conversion coefficients between simulated line reflectances of DAK and observed channel reflectances of SEVIRI.

Further details on the CPP algorithm can be found in Roebeling et al. (2006).

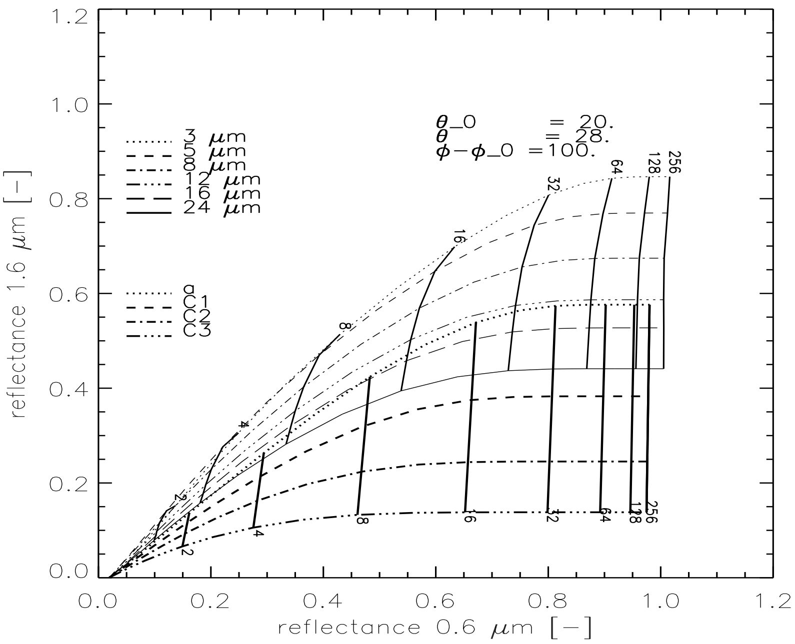

Figure 3-19 *Modelled 0.6 and 1.6 μm reflectances for □□=20o, □=28o, and □-□̦□□ı00o. Optical thickness is denoted by the various vertically oriented lines, effective radius by horizontally oriented lines. Water particles are represented in the upper part of the graph, ice particles in the lower part.*

3.7.3 Details on processing, gridding and averaging

The daily mean COT product is calculated from all available daily overpasses (AVHRR) or scenes (SEVIRI) by *logarithmic* averaging of the original algorithm output over 15 × 15 km^2 grid cells. Pixels for which the retrieval failed for any reason are excluded from averaging. *Cloud-free pixels are also excluded.* Notice that this product is only derived during daytime conditions (more precisely: the solar zenith angle must be smaller than 72 degrees) because visible and near infrared channels are used. At least two overpasses/scenes per day are needed to compute a product.

Monthly mean values of COT are calculated from daily mean values by logarithmic averaging.

The temporal and spatial averaging is done within one single step, i.e. searching for all available time slots and pixels for a given spatial area and time range (e.g. 15 x 15 km², daily).

To obtain a monthly mean diurnal cycle for a given MSG time slot all days of this time slot are used to compute the product. This is then repeated for all time slots per day, thus giving the monthly mean diurnal cycle. For each time slot 20 individual days of the month are needed to compute a product.

3.7.4 Product examples

An example of the COT monthly mean product for April 2009 derived from AVHRR is given in Figure 3-20 and in Figure 3-21 for SEVIRI, respectively.

The COT values in these figures seem to be rather low. This is first of all related to the logarithmic averaging, yielding lower values than a linear averaging procedure would. Secondly, the optical properties are calculated for pixels labelled *cloud certain* and *cloud contaminated*. The latter category contains a considerable number of pixels with broken clouds, for which a low COT is retrieved. If this category were discarded, the average COT would be much higher.

Another striking feature in the figures is the high COT over snow-covered surfaces, because currently no filtering for snow cover is applied (see also Section 2.7.6).

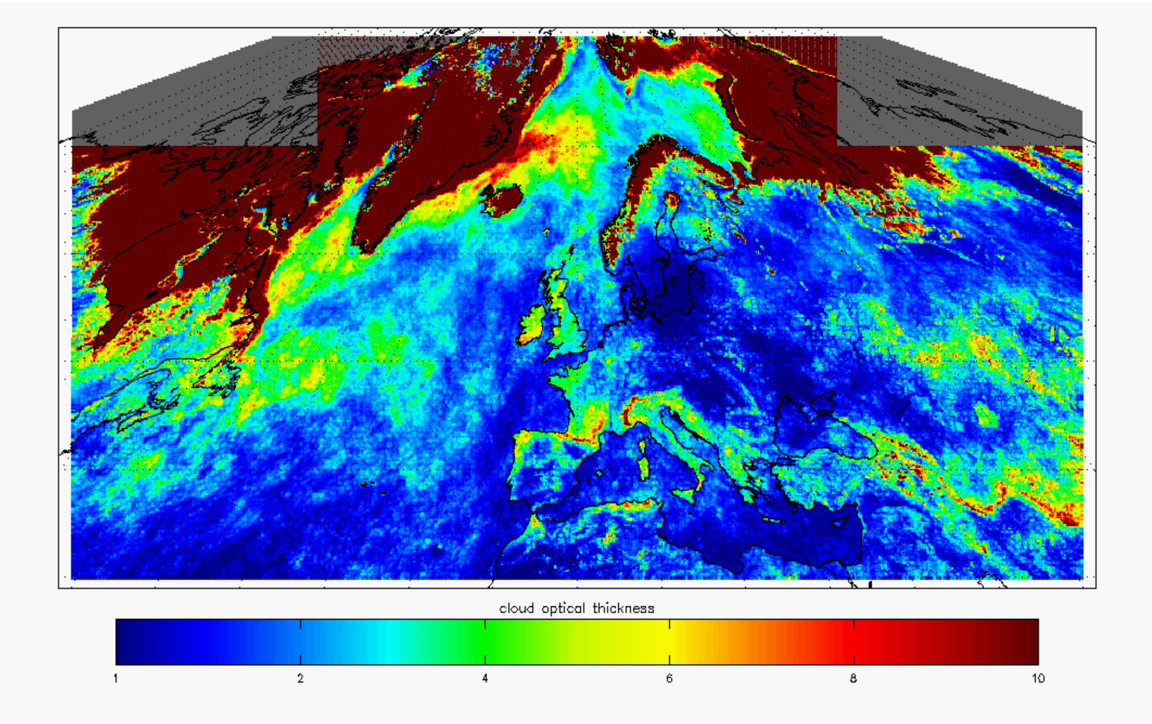

Figure 3-20 *Example of COT monthly mean product for April 2009 from AVHRR Notice that AVHRR product version is 310.*

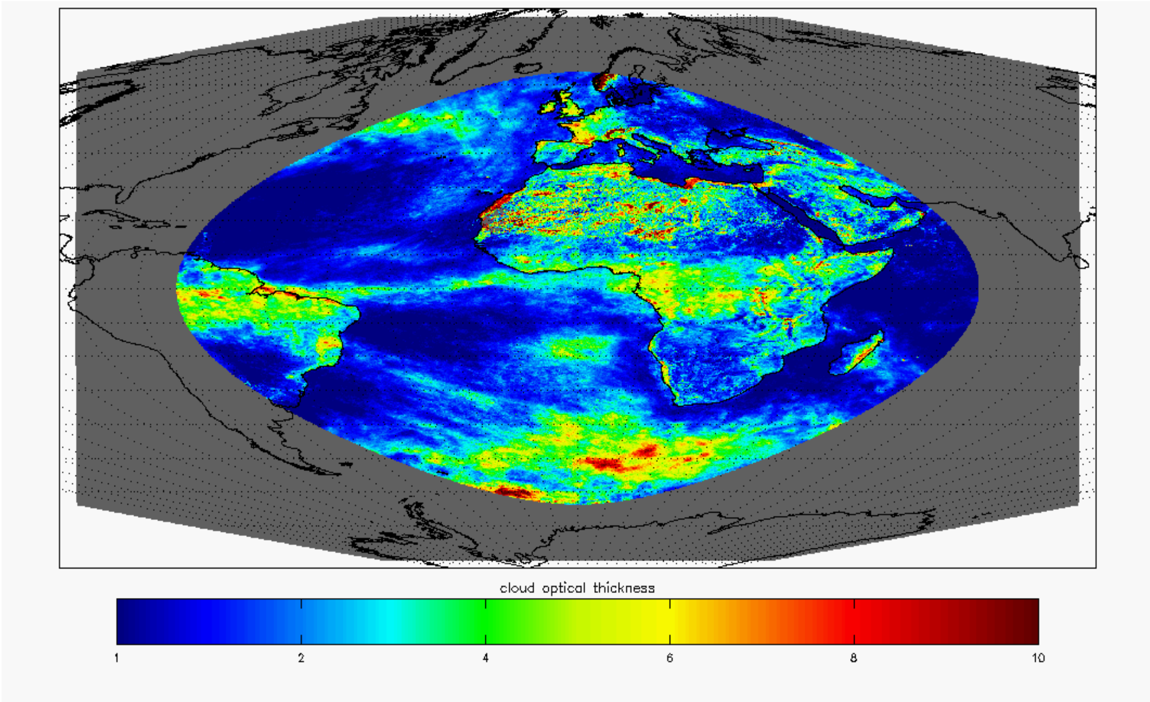

Figure 3-21 *Example of the COT monthly mean product over the MSG full disk for April 2009. The valid product version here is 320*

3.7.5 Validation

The Service Specification Document (SeSp) [AD.1] lists specific product requirements which have to be fulfilled by the products. The requirements for the COT product are shown in Table 3-15.

Table 3-15 *Product requirements according to the Service Specification Document.*

Product	Requirements on mean error (relative)
AVHRR: COT	+/- 20 %
SEVIRI: COT	+/- 20 %

The uncertainty of the disseminated products is assessed each year against these requirements and the results are summarised in the CM-SAF Annual Validation Reports [AD.2, AD.3, AD.7, AD.8].

3.7.6 Limitations

It should be reminded that the COT product requires the availability of satellite measurements in the visible region. Thus, no information from night-time scenes is included.

Currently there is no dependency between the AVHRR CPH and COT products, i.e., the CPH product is not used when deriving COT. Instead, an internal interpretation of cloud phase is used for COT extraction (as explained above for the SEVIRI CPH product). In the next upgrade, the AVHRR cloud phase product will be retrieved in the same way as for SEVIRI, so that the CPH and COT products will be consistent with each other.

Other specific limitations are:

- Broken clouds

The CPP retrieval algorithm assumes plane parallel clouds. For pixels with broken clouds (i.e. clouds that do not cover the whole satellite pixel), normally a lower COT is retrieved than applicable to the cloudy fraction of the pixel. Since the cloud mask used is not very strict (i.e. a relatively large fraction of all pixels is assigned cloudy), relatively many broken-cloud cases will be included, yielding a relatively low average COT.

- 3D effects

During winter the solar zenith angles (SZA) are large (θ_0> 60°) and scattering is often in backward directions. Although similar large SZA occur for SEVIRI during summer in the morning or late afternoon, these observations do not coincide with scattering angles close to the backward scattering peak. Loeb et al. (1998) found that the relative difference between three-dimensional and one-dimensional cloud reflectance can be large due to sub-pixel variations in cloud-top height (i.e., cloud bumps), especially in backward scattering directions. Such 3D effects are largest at SZA > 60°, where they may lead to a significant overestimation of COT. Radiative transfer simulations with DAK show that 3D effects of 10% may lead to very large errors in COT retrievals at large solar zenith angles for thick clouds (COT > 30). Because of the non-linear relationship between the simulated reflectances and COT an increase of the reflectance of 5% at azimuth difference angle (ϕ) =160^o and SZA (θ_0)= 70° results in a COT increase from about 50 to 250 (about 500%). The DAK simulations show that this sensitivity is much lower at low SZA. In addition, the 3D effects are smaller at low SZA

- COT lower for AVHRR than for SEVIRI before product versions 300 (SEVIRI) and 160 (AVHRR)

This feature was due to higher 1.6-µm reflectances for the SEVIRI sensor compared to the corresponding reflectances measured by AVHRR. Investigations of the reason for this difference based on comparisons to MODIS data revealed a problem with especially the AVHRR calibration of the 1.6-µm channel radiances. Consequently, a correction of 1.6-µm reflectances was introduced in product version 300 for SEVIRI and product version 160 for AVHRR.

- Unrealistic COT over certain surfaces before product versions 300 (SEVIRI) and 160 (AVHRR)

The assumption of a fixed surface albedo caused unrealistic COT, for example very high values over the northern part of Africa, in the mentioned product versions. More recent versions make use of MODIS-retrieved surface reflectances, which has improved the COT retrieval. However, there is still the limitation that seasonal variations in surface reflectance are not covered.

- Sea ice and snow

Pixels contaminated with sea ice are snow cover are currently not excluded from the CPP retrieval. At the same time, the retrieval for these pixels is notoriously difficult: in most cases the surface will be interpreted as a thick cloud, yielding very large COT. A filtering scheme for sea-ice and snow covered surfaces will be implemented in the near future. Until then, the user should take care of this by discarding retrieval products possibly affected by sea ice or snow cover.

- Horizontal and vertical lines for AVHRR products prior to version 310

AVHRR based products sometimes show vertical and horizontal lines at the boundary from one tile to its neighbouring tiles. An example of this behaviour is given in Figure 3-6 for cloud fractional cover. This comes from the unequal data reception statistics from the local receiving station and the averaging method which is applied to full tiles and not per pixel. This becomes especially critical for the tiles that are most distant to the HRPT receiving station in Offenbach.

- Azimuth angle difference misinterpretation for AVHRR products versions 160 to 310

Due to an implementation bug, the sun-satellite azimuth difference angle was not used correctly when deriving COT. Specifically, instead of the correct azimuth difference angle, 180 degrees minus this angle was used.

The associated error can be large (more than 10%) for individual overpasses. The error is smaller for daily means and yet smaller for monthly means, because the error in individual overpasses partly cancels out by averaging.

3.7.7 Version traceability

Two tables stating current product version numbers and a brief modification history since the start of operational activities were given in the beginning of this document.

In Table 3-16 and Table 3-17 below follow some more specific details on how version updates have affected the COT products derived from AVHRR and SEVIRI data, respectively.

Table 3-16 *List of AVHRR product versions and descriptions of the impact of changes on the COT product.*

Version AVHRR	Description of version update and the impact on the new product version	Valid time
130	Initial version based NWCSAF PPS version 1.0 and on CPP version 1.0	Jan 2005 – Mar 2005
140	Averaging limits for cloud products (except for COT/CWP products) have been changed. CPP version 1.2 was implemented.	Apr 2005 – Jul 2005
150	Change from 32 x 32 pixel per segment to 45 x 45 pixel per segment in the cloud top processing to fix error or artefacts in the end cloud top products (straight lines across sub-areas) *No effect for COT*	Aug 2005 – Dec 2006
160	Introduction of NWC-SAF PPS cloud processing software version 1.1. CPP version 2.2.2.0 was introduced. *Enhanced look-up tables w.r.t. optical properties of especially ice clouds; Inclusion of surface albedo maps based on MODIS white-sky albedo maps; Optional recalibration of AVHRR radiances of channels 1 -3 relative to corresponding MODIS radiances (switched on)*	Jan 2007 – Aug 2007
300	Correction of GME remapping bug. New CPP version 2.2.2.1 *This bug did not affect the COT product, although some indirect changes should be seen due to changes in cloud detection*	Sep 2007 – Dec. 2008
310	Change to Swath-based processing mode; Added an additional dataset for averages including the cloud free data as well to be consistent with SEVIRI derived products. New CPP version 2.3 **Observe, that this product is not produced over the Arctic region!**	Jan 2009 – June 2009
320	SW update to PPSv2009, Sun-Earth distance correction; *Effects on COT are about 1-3% for Sun-Earth distance correction* CPP version 2.4 introduced (bug fix of the azimuth difference angle). *Errors are higher for daily means than for monthly mean (~ 5%).*	Jul 2009 – Dec 2010
321	SW update to PPSv2009, input cloud mask changed *Changes in COT products are small.*	Jan 2011 – today

Table 3-17 *List of SEVIRI product versions and descriptions of the impact of changes on the COT product.*

Version SEVIRI	Description of version update	Valid time
210	Initial version based on NWC-SAF MSG cloud processing software 2.1 and CPP version 2.0	Sep 2005 – Apr 2007†
300	Changing from Meteosat-8 to Meteosat-9. New CPP version 2.2.2 *Introduction of MSG/SEVIRI cloud processing software version 2.1 adapted to Meteosat-9. Changes in COT products are generally small.*	May 2007 – Apr 2008 (*Products for both satellites are available for March and April 2007)*
310	Introduction of the new SEVIRI radiance definition. New CPP version 2.3 *Introduction of MSG/SEVIRI cloud processing software version 2008 and new CPP version 2.3 adapted to new radiance definition.* *Changes in COT products are small.*	May 2008 – Dec. 2008
320	Migration to new processing environment. *No effect on COT product.*	Jan. 2009 – today

† Version 210 data are available until 9 May 2007.

3.8 Cloud Liquid Water Path

3.8.1 Product definition

This product provides information on the Cloud Water Path (CWP) given in kg/m^2.

3.8.2 Basic approach

Cloud optical thickness (COT) and droplet effective radius (r_e) are retrieved simultaneously using the algorithm outlined in Section 3.7.2. From these two properties, the cloud water path (CWP) of water clouds (or liquid water path, LWP) can be computed using the following relation (Stephens, 1978):

$$CWP = \frac{2}{3}\rho_l COT r_e \tag{3-1}$$

where ρ_l is the density of liquid water. For water clouds effective radii between 1 and 24 µm are retrieved.

The CWP for ice clouds (or ice water path, IWP) is approximated using the same relation as above but with COT and r_e retrievals based on RTM simulations for imperfect hexagonal ice crystals. Homogeneous distributions of C0, C1, C2, and C3 type ice crystals from the COP library (Hess et al., 1998) are assumed, with effective radii of 6, 12, 26, and 51 µm, respectively (see Figure 3-19). Knap et al. (2005) demonstrated that these crystals can be used to give adequate simulations of total and polarized reflectance of ice clouds.

Currently, IWP is not validated. Work is foreseen to compare the CPP IWP with Cloudsat-Calipso observations, and to subsequently improve the IWP retrieval algorithm.

3.8.3 Details on processing, gridding and averaging

The daily mean CWP product is calculated from all available daily overpasses (AVHRR) or scenes (SEVIRI) by *linear* averaging of the algorithm output over 15 $\times$ 15 km^2 grid cells. Pixels for which the retrieval failed for any reason are excluded from averaging. Notice also that this product is only derived during daytime conditions (more precisely: solar zenith angle must be lower than 72 degrees) because visible and near-infrared channels are used.

Monthly mean values of CWP are calculated from daily mean values by *linear* averaging.

An inconsistency between AVHRR and SEVIRI products with versions prior to 310 exists meaning that cloud-free pixels are included in the averaging for SEVIRI products but not for AVHRR products. With the implementation of version 310 for AVHRR for the baseline area, two different datasets of daily (and monthly) means are produced. For the first one, the averaging procedure takes into account all pixels including the clear sky data within the spatial grid box. The second dataset is using only the cloudy pixels within the spatial grid box. For direct comparisons of AVHRR and METEOSAT based products, it is recommended to use the dataset including the clear sky data. It is foreseen to modify the METEOSAT processing to separate the cloudy and all-sky averages of CWP.

The temporal and spatial averaging is done within one single step, i.e. searching for all available time slots and pixels for a given spatial area and time range (e.g. 15 x 15 km², daily). To obtain a monthly mean diurnal cycle for a given MSG time slot all days of this time slot are used to compute the product. This is then repeated for all time slots per day, thus giving the monthly mean diurnal cycle. For each time slot 20 individual days of the month are needed to compute a product.

3.8.4 Product examples

Figure 3-22 and Figure 3-23 give examples of the AVHRR and SEVIRI-derived monthly mean CWP products for April 2009. Notice that the results displayed here are given in the unit kg/m^2.

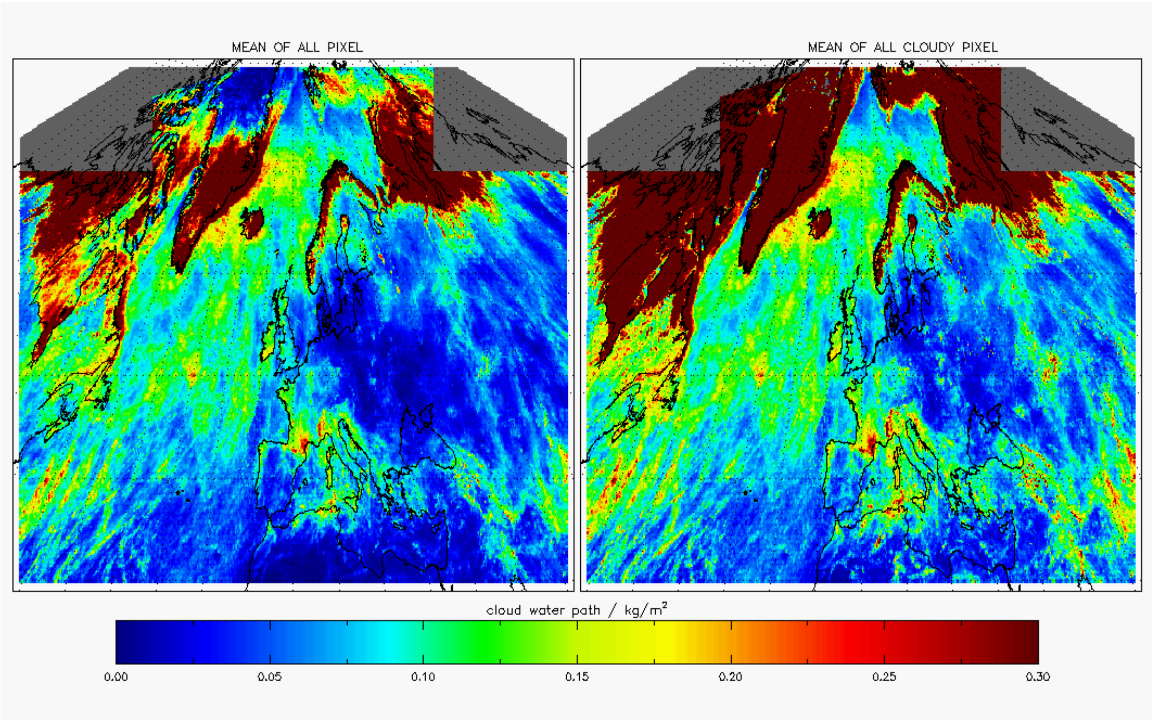

Figure 3-22 *AVHRR-derived CWP monthly mean product for April 2009. (product version 310). Both datasets of the product are displayed, the left side shows the average over all pixels within the spatial resolution of 15 x 15 km². The right side takes only the cloudy pixel into account.*

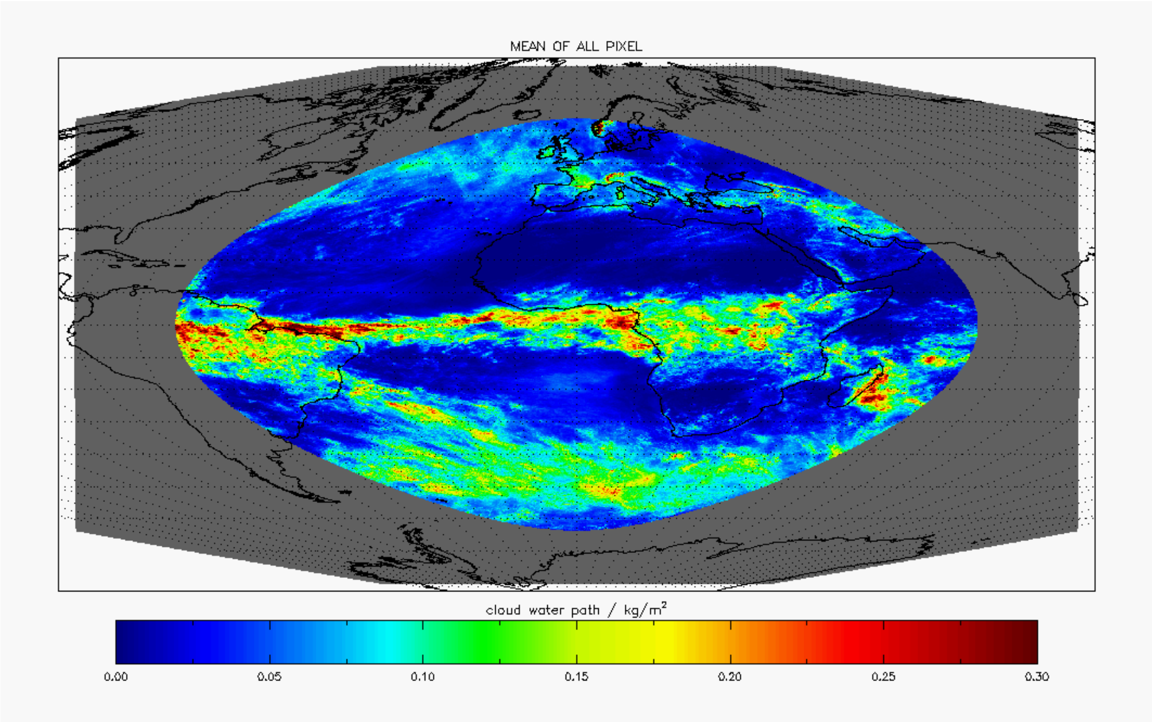

Figure 3-23 *MSG/SEVIRI-derived CWP monthly mean product for April 2009 (product version 320).*

3.8.5 Validation

The Service Specification Document (SeSp) [AD.1] lists specific product requirements which have to be fulfilled by the products. The requirements for the CWP product are shown in Table 3-18.

Table 3-18 *Product requirements according to the Service Specification Document.*

Product	**Requirements on mean error (relative)**
AVHRR: CWP	+/- 20 %
SEVIRI: CWP	+/- 20 %

The uncertainty of the disseminated products is assessed each year against these requirements and the results are summarised in the CM-SAF Annual Validation Reports [AD.2, AD.3, AD.7, AD.8].

3.8.6 Limitations

The current version the CWP product is retrieved using an algorithm that is in principle valid for water clouds (retrieving the liquid water path – LWP), although it is widely used for ice clouds as well. Improved estimates of the ice water path (IWP) will be considered later. It should be reminded that this product requires the availability of satellite measurements in the visible spectral region. Thus, no information from night-time scenes is included.

Currently there is no dependency between the AVHRR CPH and CWP products, i.e., the CPH product is not used when deriving CWP. Instead, an internal interpretation of cloud phase is used for CWP extraction. In the next upgrade, the AVHRR cloud phase product will be retrieved in the same way as for SEVIRI, so that the CPH and CWP products will be consistent with each other.

More specific limitations are:

- Errors in retrieved COT and effective radius (r_e) will affect the CWP retrieval.

The CWP is calculated from COT and droplet effective radius (r_e) information.

This implies that **all limitations for COT mentioned in Section 3.7.6 are also limitations for CWP**. Amongst others it means that for clouds with COT > 50 the CWP retrievals will become less reliable. Since the retrieval of effective radius is not reliable for thin clouds a climatological effective radius is assumed for clouds with a COT < 8. Using the latter assumption the quality of the CWP retrieval for thin clouds will only decrease slightly.

- 3D cloud effects

Due to 3D cloud effects the droplet effective radius may be largely overestimated. The retrievals have shown that – in combination with overestimated COT – this may lead to largely overestimated CWP due to 3D effects.

- Horizontal and vertical lines for AVHRR products prior to version 310

AVHRR based products sometimes show vertical and horizontal lines at the boundary from one tile to its neighbouring tiles. An example of this behaviour is given in Figure 3-6 for cloud fractional cover. This comes from the unequal data reception statistics from the local receiving station and the averaging method which is applied to full tiles and not per pixel. This becomes especially critical for the tiles that are most distant to the HRPT receiving station in Offenbach.

- Inconsistency between AVHRR version prior to 310 and SEVIRI

For all AVHRR data with version prior to 310 an inconsistency between AVHRR and SEVIRI products exists meaning that cloud-free pixels are included in the averaging for the SEVIRI CWP product but not for the AVHRR CWP product.

- Azimuth angle difference misinterpretation for AVHRR products versions 160 to 310

Due to an implementation bug, the sun-satellite azimuth difference angle was not used correctly when deriving COT. Specifically, instead of the correct azimuth difference angle, 180 degrees minus this angle was used.

The associated error can be large (more than 10%) for individual overpasses. The error is smaller for daily means and yet smaller for monthly means, because the error in individual overpasses partly cancels out by averaging.

3.8.7 Version traceability

Two tables stating current product version numbers and a brief modification history since the start of operational activities were given in the beginning of this document.

In Table 3-19 and Table 3-20 below follow some more specific details on how version updates have affected the CWP products derived from AVHRR and SEVIRI data, respectively.

Table 3-19 *List of AVHRR product versions and descriptions of the impact of changes on the CWP product.*

Version AVHRR	Description of version update and the impact on the new product version	Valid time
130	Initial version based NWCSAF PPS version 1.0 and on CPP version 1.0	Jan 2005 – Mar 2005
140	CPP version 1.2 was implemented	Apr 2005 – Jul 2005
150	Change from 32 x 32 pixel per segment to 45 x 45 pixel per segment in the cloud top processing to fix error or artefacts in the end cloud top products (straight lines across sub-areas) *Not affecting CWP*	Aug 2005 – Dec 2006
160	Introduction of NWC-SAF PPS cloud processing software version 1.1. New CPP version 2.2.2.0 *Enhanced look-up tables w.r.t. optical properties of especially ice clouds; Inclusion of surface albedo maps based on MODIS white-sky albedo maps; Optional recalibration of AVHRR radiances of channels 1 -3 relative to corresponding MODIS radiances (switched on)*	Jan 2007 – Aug 2007
300	Correction of GME remapping bug. New CPP version 2.2.2.1 *This bug did not affect the CWP product, although some indirect changes should be seen due to changes in cloud detection*	Sep 2007 – Dec 2008
310	Changed to swath-based processing mode. New CPP version 2.3. now two datasets are produced, on averaged over all pixel, the other averaged only over cloudy pixels within the spatial grid. **Observe, that this product is not produced over the Arctic region!**	Jan 2009 – Jun 2009

Version AVHRR	Description of version update and the impact on the new product version	Valid time
320	SW update to PPSv2009, Sun-Earth distance correction; *Effects on CWP are about 1-3% for Sun-Earth distance correction* CPP version 2.4 introduced (bug fix of the azimuth difference angle). *Errors are higher for daily means than for monthly mean (~5 %).*	Jul 2009 – Dec 2010
321	SW update to PPSv2010, input cloud mask changed *Changes in CWP products are small.*	Jan 2011 – today

Table 3-20 *List of SEVIRI product versions and descriptions of the impact of changes on the CWP product.*

Version SEVIRI	Description of version update	Valid time
210	Initial version based on NWC-SAF MSG cloud processing software 2.1 and COT/CWP version 2.0	Sep 2005 – Apr 2007†
300	Changing from Meteosat-8 to Meteosat-9. New COT/CWP version 2.2.2 *Introduction of MSG/SEVIRI cloud processing software version 2.1 adapted to Meteosat-9. Changes in CWP products are generally small.*	May 2007 – Apr 2008 (*Products for both satellites are available for March and April 2007)*
310	Introduction of the new SEVIRI radiance definition. New COT/CWP version 2.3 *Introduction of MSG/SEVIRI cloud processing software version 2008 and new COT/CWP version 2.3 adapted to new radiance definition.* *Changes in CWP products are small.*	May 2008 – Dec. 2008
320	Migration to new processing environment. No effect on CWP product.	Jan. 2009 – today

† Version 210 data are available until 9 May 2007.

4 Data description

This section describes the output formats for the six cloud parameters. Each cloud parameter is averaged over an area with an anticipated size of 15 x 15 km^2. The time resolution ranges from daily mean values, monthly mean values to monthly mean diurnal cycle. The final products are either mean values (CFC, CTH, CTT, COT, CWP) or frequency distributions (CTY, CPH) over the specified time period, depending on the cloud parameter.

4.1 Product Names

Product types are:

- fractional cloud cover (CFC)
- cloud type (CTY)
- cloud top height (CTH)
- cloud top pressure (CTP)
- cloud top temperature (CTT)
- cloud phase (CPH)
- cloud optical thickness (COT)
- cloud water path (CWP)

Notice that product names CTH, CTP and CTT are just different representations of one cloud top product (denoted CTO).

Time resolution:

- Daily mean value
- Monthly mean value
- Monthly mean diurnal cycle

All cloud products are coded in HDF5 format which is described at http://hdf.ncsa.uiuc.edu/products/hdf5/index.html. Details for the cloud products are described in Appendix A.

4.1.1 AVHRR product description prior to version 310

Table 4-1 *Cloud products identifier in HDF5 files prior to version 310.*

Product	Daily average	Monthly average
CFC	CFC-DM	CFC-MM
CTH	CTH-DM	CTH-MM
CTP	CTP-DM	CTP-MM
CTT	CTT-DM	CTT-MM
COT	COT-DM	COT-MM
CWP	CWP-DM	CWP-MM
CTY	CTY-DM LOW CLOUDS CTY-DM MIDDLE LEVEL CLOUDS CTY-DM HIGH OPAQUE CTY-DM HIGH SEMITRANSPARENT CTY-DM FRACTIONAL CLOUDS	CTY-MM LOW CLOUDS CTY-MM MIDDLE LEVEL CLOUDS CTY-MM HIGH OPAQUE CTY-MM HIGH SEMITRANSPARENT CTY-MM FRACTIONAL CLOUDS
CPH	CPH-DM WATER CPH-DM ICE CPH-DM MIXED PHASE	CPH-MM WATER CPH-MM ICE CPH-MM MIXED PHASE

4.1.2 AVHRR product description since version 310

Starting with version 310 the general processing has changed (ref. section 3.1.2) In addition also the cloud product identifier are changed and also new entries have been added. The following Table 4-2 describes the new entries for AVHRR since version 310

Table 4-2: *Cloud products identifier in HDF5 files for AVHRR baseline products since version 310.*

Product	Daily average	Monthly average
CFC	CFC-DM FROM POL. ORB. SAT.	CFC-MM FROM POL. ORB. SAT.
CTH	CTH-DM FROM POL. ORB. SAT.	CTH-MM FROM POL. ORB. SAT.
CTP	CTP-DM FROM POL. ORB. SAT.	CTP-MM FROM POL. ORB. SAT.
CTT	CTT-DM FROM POL. ORB. SAT.	CTT-MM FROM POL. ORB. SAT.
COT	COT-DM FROM POL. ORB. SAT.	COT-MM FROM POL. ORB. SAT.
CWP	CWP-DM FROM POL. ORB. SAT.	CWP-MM FROM POL. ORB. SAT.
CTY	CTY-DM LOW CLOUDS FROM POL. ORB. SAT. CTY-DM MIDDLE LEVEL CLOUDS FROM POL. ORB. SAT. CTY-DM HIGH OPAQUE FROM POL. ORB. SAT. CTY-DM HIGH SEMITRANSPARENT FROM POL. ORB. SAT. CTY-DM FRACTIONAL CLOUDS FROM POL. ORB. SAT.	CTY-MM LOW CLOUDS FROM POL. ORB. SAT. CTY-MM MIDDLE LEVEL CLOUDS FROM POL. ORB. SAT. CTY-MM HIGH OPAQUE FROM POL. ORB. SAT. CTY-MM HIGH SEMITRANSPARENT FROM POL. ORB. SAT. CTY-MM FRACTIONAL CLOUDS FROM POL. ORB. SAT.
CPH	CPH-DM WATER FROM POL. ORB. SAT. CPH-DM ICE FROM POL. ORB. SAT. CPH-DM MIXED PHASE FROM POL. ORB. SAT.	CPH-MM WATER FROM POL. ORB. SAT. CPH-MM ICE FROM POL. ORB. SAT. CPH-MM MIXED PHASE FROM POL. ORB. SAT.

Table 4-3: *Cloud products identifier in HDF5 files for AVHRR Arctic products since version 310.*

Product	Daily average	Monthly average
CFC	CFC-DM FROM POL. ORB. SAT. CFC-DM FROM METOP	CFC-MM FROM POL. ORB. SAT. CFC-MM FROM METOP
CTH	CTH-DM FROM POL. ORB. SAT. CTH-DM FROM METOP	CTH-MM FROM POL. ORB. SAT. CTH-MM FROM METOP
CTP	CTP-DM FROM POL. ORB. SAT. CTP-DM FROM METOP	CTP-MM FROM POL. ORB. SAT. CTP-MM FROM METOP
CTT	CTT-DM FROM POL. ORB. SAT. CTT-DM FROM METOP	CTT-MM FROM POL. ORB. SAT. CTT-MM FROM METOP
CTY	CTY-DM LOW CLOUDS FROM POL. ORB. SAT. CTY-DM MIDDLE LEVEL CLOUDS FROM POL. ORB. SAT. CTY-DM HIGH OPAQUE FROM POL. ORB. SAT. CTY-DM HIGH SEMITRANSPARENT FROM POL. ORB. SAT. CTY-DM FRACTIONAL CLOUDS FROM POL. ORB. SAT. CTY-DM LOW CLOUDS FROM METOP CTY-DM MIDDLE LEVEL CLOUDS FROM METOP. CTY-DM HIGH OPAQUE FROM METOP. CTY-DM HIGH SEMITRANSPARENT FROM METOP. CTY-DM FRACTIONAL CLOUDS FROM METOP.	CTY-MM LOW CLOUDS FROM POL. ORB. SAT. CTY-MM MIDDLE LEVEL CLOUDS FROM POL. ORB. SAT. CTY-MM HIGH OPAQUE FROM POL. ORB. SAT. CTY-MM HIGH SEMITRANSPARENT FROM POL. ORB. SAT. CTY-MM FRACTIONAL CLOUDS FROM POL. ORB. SAT. CTY-MM LOW CLOUDS FROM METOP CTY-MM MIDDLE LEVEL CLOUDS FROM METOP CTY-MM HIGH OPAQUE FROM METOP CTY-MM HIGH SEMITRANSPARENT FROM METOP CTY-MM FRACTIONAL CLOUDS FROM METOP

4.1.3 MSG product description

Table 4-4: *Cloud products identifier in HDF5 files for MSG based products.*

Product	Daily average	Monthly average	Monthly mean diurnal cycle
CFC	CFC-DM	CFC-MM	CFC-MMDC
CTH	CTH-DM	CTH-MM	CTH-MMDC
CTP	CTP-DM	CTP-MM	CTP-MMDC
CTT	CTT-DM	CTT-MM	CTT-MMDC
COT	COT-DM	COT-MM	COT-MMDC
CWP	CWP-DM	CWP-MM	CWP-MMDC
CTY	CTY-DM LOW CLOUDS CTY-DM MIDDLE LEVEL CLOUDS CTY-DM HIGH OPAQUE CTY-DM HIGH SEMITRANSPARENT CTY-DM FRACTIONAL CLOUDS	CTY-MM LOW CLOUDS CTY-MM MIDDLE LEVEL CLOUDS CTY-MM HIGH OPAQUE CTY-MM HIGH SEMITRANSPARENT CTY-MM FRACTIONAL CLOUDS	CTY-MMDC LOW CLOUDS CTY-MMDC MIDDLE LEVEL CLOUDS CTY-MMDC HIGH OPAQUE CTY-MMDC HIGH SEMITRANSPARENT CTY-MMDC FRACTIONAL CLOUDS
CPH	CPH-DM WATER CPH-DM ICE	CPH-MM WATER CPH-MM ICE	CPH-MMDC WATER CPH-MMDC ICE CPH-MMDC MIXED PHASE

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. We refer the user 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.

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.

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. Users can either contact the User Help Desk (see chapter 5.2) 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.

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 Tools and Auxiliary data

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

All described tools and auxiliary data are free of charge. They come with no warranty and are based on best effort basis. When obtaining problems, please contact the User help desk (section 5.2).

6.1 Climate data operators (CDO)

In order to allow easy access to CMSAF datasets not only for the climate modelling community, 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 (http://www.mpimet.mpg.de/~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's, interpolation or the calculation of climate indices). Besides the pure conversion of CM-SAF-HDF5-files to NetCDF and GRIB, this offers additional possibilities for pre-processing the data for validation studies, especially interpolation to other grid types and selection of regions. The implementation considers special features, e.g. methods for interpolation of non-continuous datasets as e.g. cloud types.

Daily and monthly mean products of CMSAF are provided in equal-area projections that are described in the metadata entries of the HDF5-files. CDO employs this information for spatial operations on these final products. Processing of CM-SAF intermediate products on original pixel-resolution for polar-orbiting satellites as well as geostationary satellites is also facilitated when pixel-related geolocation is available. A link to this tools is available on the CM-SAF web site (www.cmsaf.eu).

Please refer to the CDO-manual for detailed instructions to read CM-SAF products.

6.2 Graphical user interface (GUI)

For the user's convenience an IDL-based tool (CM-SAF-gui) has been developed. This graphical user interface is accessible from www.cmsaf.eu and allows, after installation, to read, display and export CM-SAF cloud and radiation products.

Currently the software will not work with global and humidity products.

The tool is based on IDL and can be used to display products on different computer environments like LINUX, Windows and UNIX.

This tool is free of charge and comes as it is. CM-SAF can not take any warranty and responsibility for a running tool under all conditions. The IDL-code is distributed on request via the User help desk (section 5.2).

CM-SAF is interested in your experiences with the tool and encourage to report all observed problems to the user help desk (section 5.2).

6.3 Auxiliary Data

This section gives an overview of available auxiliary datasets which will be helpful for further processing and interpretation of CM-SAF products. All auxiliary datasets are accessible via the webpage www.cmsaf.eu in the folder 'data access' . Table 6-1 lists the available auxiliary datasets for all regions.

CM-SAF products are available covering different areas in different spatial resolution.

All hdf-files contain the information per pixel in the same projection as the corresponding CM-SAF product. Please note, that the information is given for the centre coordinate of the pixel!

The metadata field contained in the filename of the product is given in the table below for easier identification of the correct fields.

Please, note, that the files with Land-sea also contains datasets with fraction of land (FOL) and water (FOC) per grid box to allow the user to establish own thresholds for the land-sea mask. The included binary land sea mask is based on a threshold of

Table 6-1: *Table of available auxiliary datasets*

Region	Latitude & Longitude [°]	Elevation [m]	Land/Sea mask [-]
CMSAF full disc area ("MA") (SEVIRI only)	x	x	x
CMSAF Baseline area ("CA") (SEVIRI and AVHRR)	x	x	x
CMSAF baseline area plus MSG disk and arctic ("CD")	x	x	x
Global ("GL").	x	x	x
Arctic ("IA")	x	-	-

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Appendix A Definition of the HDF attributes

CM-SAF's climate monitoring products are provided as HDF5 (Hierarchical Data Format, release 5). Reasons for selecting HDF5 were its high compression efficiency and the features to include several data models and selfdescribing datasets.

The data in the HDF5 files is organised under four groups: *Metadata, Product Specific Metadata, Geolocation and Data*. The file structure is shown in Figure 7-1.

The contents of the *Metadata* group are common to all products. This group contains general information about the product, for example the algorithm and version used to generate the product.

The *Product Specific Metadata* group is used for additional information related to the product. For example methods and parameters which are specific to the algorithm used in the generation of the product are included in this group, such as applied calibrations coefficients or ingested NWP data. The *Geolocation* group contains information that describes the projection used and the region covered by the data. The *Data* group contains the products and related information as e.g. quality flags. The specific contents of the groups are described in the following subsections.

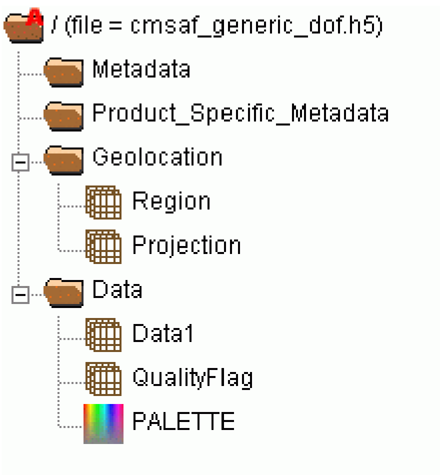

Figure 7-1 *Structure of the CM-SAF HDF5 files.*

The next sections give on overview about the hdf5 file content split for the three different processed regions and satellites. Appendix A.1 described the content of HDF5 files for all METEOSAT based products, Appendix A.2 gives the content of HDF5 files for the AVHRR baseline area products prior to version 310, appendix A.3 the content of HDF5 files for AVHRR baseline products since version 310 and finally appendix A.4 the content of HDF5 files for the AVHRR Arctic area products.

A.1 METEOSAT based products

A.1.1 Metadata group for METEOSAT

Table A.1.1: *Metadata group contents.*

Attribute name	Type	Size	Description	Mandatory
Title	string	128	As described in Table 4-4	yes
DateAndTime	string	16	Date and time coded as yyyymmdd or yyyymmdd_hhmm For the monthly mean and the monthly mean diurnal cycle, the date of the first day of the month is given	yes
TimeMean	string	32	Time integration „daily mean“, „monthly mean“, „monthly mean diurnal cycle“	yes
Producer	string	32	Processing center “CMSAF_DWD”	yes
Version	string	128	Product version according to configuration management	yes
ProductionMode	string	128	„nominal“, „reprocessed“, „experiment“	yes

A.1.2 Product Specific Metadata group for METEOSAT

Table A.1.2: *Product_Specific_Metadata group contents*

Attribute name	Type	Size	Description	Mandatory
Calibration coefficients information	String	128	“pre-launch”, “after-launch”, “Vxx.yy”	no
NWP information applied	String	128	Name and version of NWP model “ECMWF Vxx.yy”, “GME Vxx.yy”	No

A.1.3 Geolocation Group for METEOSAT

Table A.1.3: *Geolocation group contents*

Dataset name	Data type	Size	Description	Mandatory
Region	Compound	1	Parameter to describe region of dataset	yes
Projection	Compound	1	Parameter to describe the projection	yes

Table A.1.4: *Region dataset contents*

<table>
<tr><th>Dataset name</th><th>Data element</th><th>Type</th><th>Size</th><th colspan="2">Description</th><th>Mandatory</th></tr>
<tr><td rowspan="3">Region</td><td rowspan="3">Xmin</td><td rowspan="3">float</td><td rowspan="3">1</td><td colspan="2">“left” margin of region; units [m] of projections coordinate system</td><td rowspan="3">yes</td></tr>
<tr><td>baseline area</td><td>–5827500.0</td></tr>
<tr><td>Meteosat disk</td><td>-8887500.0</td></tr>
<tr><td rowspan="3">Region</td><td rowspan="3">Xmax</td><td rowspan="3">float</td><td rowspan="3">1</td><td colspan="2">“right” margin of region; units [m] of projections coordinate system</td><td rowspan="3">yes</td></tr>
<tr><td>baseline area</td><td>5827500.0</td></tr>
<tr><td>Meteosat disk</td><td>+8887500.0</td></tr>
<tr><td rowspan="3">Region</td><td rowspan="3">Ymin</td><td rowspan="3">float</td><td rowspan="3">1</td><td colspan="2">“lower” margin of region; units [m] of projections coordinate system</td><td rowspan="3">yes</td></tr>
<tr><td>Baseline area</td><td>3307500.0</td></tr>
<tr><td>Meteosat disk</td><td>-8887500.0</td></tr>
<tr><td rowspan="3">Region</td><td rowspan="3">Ymax</td><td rowspan="3">float</td><td rowspan="3">1</td><td colspan="2">“upper” margin of region; units [m] of projections coordinate system</td><td rowspan="3">yes</td></tr>
<tr><td>baseline area</td><td>+8887500.0</td></tr>
<tr><td>Meteosat disk</td><td>+8887500.0</td></tr>
<tr><td>Region</td><td>Dx</td><td>float</td><td>1</td><td colspan="2">“pixel” increment in x direction in units of projections coordinate system
15000.0</td><td>yes</td></tr>
<tr><td>Region</td><td>Dy</td><td>float</td><td>1</td><td colspan="2">“pixel” increment in y direction in units of projections coordinate system
15000.0</td><td>yes</td></tr>
</table>

Table A.1.5: *Projection dataset contents*

Dataset name	Data element	Type	Size	Description	Mandatory
Projection	Projection name	string	128	"sinusoidal "	Yes
Projection	Reference Ellipsoid	string	128	"WGS-84"	Yes
Projection	Projection parameter #1	array	depends on projection	X0=0.0, Y0=0.0, Lon0=0.0, Lat0=0.0	yes

A.1.4 Data Group for METEOSAT

Table A.1.6:*Data group contents.*

Dataset name	Data type	Size	Description	Mandatory
Data1	byte	1185 x 1185 pixel for MMDC: 1185 x 1185 x 24	Product: Fractional cloud cover cloud type cloud top temperature cloud top height cloud top pressure cloud phase cloud optical thickness cloud water path	**Yes**
QualityFlag	long	1185 x 1185 pixel	Bit fields	no
Palette	Byte	(256,3)	Predefined colour table	no

Table A.1.7 *Dataset attributes in Data group.*

Dataset name	Attribute name	Type	Size	Description	Mandatory
Data1	Title	string	128	Description of the dataset: According to, Table 4-4 e.g. "CFC-DM"	yes
Data1	Unit	string	16	CFC, CTY, CPH: percent CTT: K CTH: meter CTP: hPa COT:- CWP: kg/m^2	yes
Data1	Gain	float	1	CFC, CTY, CTT, CTP, CPH: gain=1 CTH: gain=200 COT: gain= 0.01 CWP: gain=0.0002	yes
Data1	Intercept	float	1	CTT: intercept=100 all other products: intercept=0	yes
Data1	Nodata_value	Same as the dataset	1	No data values. CWP, COT: -1.0, Other products: 255	yes
Data1	Time	string	128	Time (hhmm) in UTC for MMDC composed from all available time slots	yes for MMDC

The following equation transforms the HDF5 data to physical products:

Product_value = (data1 * gain) + intercept

where data1 (e.g. Table A.1.7) are the data from the HDF5 file, product_value the product values in the given unit. Gain and intercept are from Table A.1.7.

Please note that gain and intercept is not applied to the undef_value.

A.2 Metadata group for AVHRR baseline products prior to version 310

A.2.1 Metadata group for AVHRR baseline products

Table A.2.1 *Metadata group contents.*

Attribute name	Type	Size	Description	Mandatory
Title	string	128	Description of the dataset as described in Table 3.1	yes
DateAndTime	string	16	Date and time coded as yyyymmdd or yyyymmdd_hhmm For the monthly mean and the monthly mean diurnal cycle, the date of the first day of the month is given	yes
TimeMean	string	32	Time integration „daily mean“, „monthly mean“, „monthly mean diurnal cycle“	yes
Producer	string	32	Processing center “CMSAF_DWD”	yes
Version	string	128	Product version according to configuration management	yes
ProductionMode	string	128	„nominal“, „reprocessed“, „experiment“	yes

A.2.2 Product_Specific_Metadata Group

Table A.2.2 *Product_Specific_Metadata group contents*

Attribute name	Type	Size	Description	Mandatory
Calibration coefficients information	String	128	“pre-launch”, “after-launch”, “Vxx.yy”	no
NWP information applied	String	128	Name and version of NWP model “ECMWF Vxx.yy”, “GME Vxx.yy”	No

A.2.3 Geolocation Group

Table A.2.3 *Geolocation group contents*

Dataset name	Data type	Size	Description	Mandatory
Region	Compound	1	Parameter to describe region of dataset	yes
Projection	Compound	1	Parameter to describe the projection	yes

Table A.2.4 *Region dataset contents*

Dataset name	Data element	Type	Size	Description		Mandatory
Region	Xmin	float	1	"left" margin of region; units [m] of projections coordinate system		yes
				baseline area	–5827500.0	
Region	Xmax	float	1	"right" margin of region; units [m] of projections coordinate system		yes
				baseline area	5827500.0	
Region	Ymin	float	1	"lower" margin of region; units [m] of projections coordinate system		yes
				baseline area	3307500.0	
Region	Ymax	float	1	"upper" margin of region; units [m] of projections coordinate system		yes
				baseline area	+8887500.0	
Region	Dx	float	1	"pixel" increment in x direction in units of projections coordinate system: 15000.0		yes
Region	Dy	float	1	"pixel" increment in y direction in units of projections coordinate system: 15000.0		yes

Table A.2.5 *Projection dataset contents*

Dataset name	**Data element**	**Type**	**Size**	**Description**	**Mandatory**
Projection	Projection name	string	128	“sinusoidal “	yes
Projection	Reference Ellipsoid	string	128	“WGS-84“	yes
Projection	Projection parameter #1	array	depends on projection	X0=0.0, Y0=0.0, Lon0=0.0, Lat0=0.0	yes

A.2.4 Data Group

Table A.2.6 *Data group contents.*

Dataset name	**Data type**	**Size**	**Description**	**Mandatory**
Data1	byte	number of pixels	Product: Fractional cloud cover cloud type cloud top temperature cloud top height cloud top pressure cloud phase cloud optical thickness cloud water path	**YES**
QualityFlag	long	number of pixels	Bit fields	No
Palette	Byte	(256,3)	Predefined colour table	No

Table A.2.7 *Dataset attributes in Data group.*

Dataset name	Attribute name	Type	Size	Description	Mandatory
Data1	Title	string	128	Description of the dataset: According to Table 4-1 e.g. “CFC-DM”	yes
Data1	Unit	string	16	CFC, CTY, CPH: percent CTT: K CTH: meter CTP: hPa COT:- CWP: kg/m^2	yes
Data1	Gain	float	1	CFC, CTY, CTT, CTP, CPH: gain=1 CTH: gain=200 COT: 0.01 CWP: 0.0002	yes
Data1	Offset	float	1	CFC, CTY, CTH, CTP, COT, CPH, CWP: offset=0 CTT: offset=100	yes
Data1	nodata value	Same as the dataset	1	No data values CFC, CTY, CTT, CTH, CTP, CPH: 255 COT: -1.0 CWP: -1.0	yes

A.3 Metadata group for AVHRR baseline products since version 310

A.3.1 Metadata group for AVHRR baseline products

Table A.3.1: *Metadata group contents.*

Attribute name	Type	Size	Description	Mandatory
Title	string	128	As described in Table 3-2	yes
DateAndTime	string	16	Date and time coded as yyyymmdd or yyyymmdd_hhmm For the monthly mean and the monthly mean diurnal cycle, the date of the first day of the month is given	yes
TimeMean	string	32	Time integration „daily mean“, „monthly mean“, „monthly mean diurnal cycle“	yes
Producer	string	32	Processing center “CMSAF_DWD”	yes
Version	string	128	Product version according to configuration management	yes
ProductionMode	string	128	„nominal“, „reprocessed“, „experiment“	yes

A.3.2 Product_Specific_Metadata Group for AVHRR baseline

Table A.3.2: *Product_Specific_Metadata group contents*

Attribute name	Type	Size	Description	Mandatory
Calibration coefficients information	String	128	“pre-launch”, “after-launch”, “Vxx.yy”	no
NWP information applied	String	128	Name and version of NWP model “ECMWF Vxx.yy”, “GME Vxx.yy”	No

A.3.3 Geolocation Group for AVHRR baseline

Table A.3.3 *Geolocation group contents*

Dataset name	**Data type**	**Size**	**Description**	**Mandatory**
Region	Compound	1	Parameter to describe region of dataset	yes
Projection	Compound	1	Parameter to describe the projection	yes

Table A.3.4 *Region dataset contents*

Dataset name	Data element	Type	Size	Description		Mandatory
Region	Xmin	float	1	"left" margin of region; units [m] of projections coordinate system		yes
				baseline area	–5827500.0	
Region	Xmax	float	1	"right" margin of region; units [m] of projections coordinate system		yes
				baseline area	5827500.0	
Region	Ymin	float	1	"lower" margin of region; units [m] of projections coordinate system		yes
				baseline area	3307500.0	
Region	Ymax	float	1	"upper" margin of region; units [m] of projections coordinate system		yes
				baseline area	+8887500.0	
Region	Dx	float	1	"pixel" increment in x direction in units of projections coordinate system: 15000.0		yes
Region	Dy	float	1	"pixel" increment in y direction in units of projections coordinate system: 15000.0		yes

Table A.3.5*: Projection dataset contents for AVHRR baseline product*

Dataset name	Data element	Type	Size	Description	Mandatory
Projection	Projection name	string	128	"sinusoidal "	yes
Projection	Reference Ellipsoid	string	128	"WGS-84"	yes
Projection	Projection parameter #1	array	depends on projection	X0=0.0, Y0=0.0, Lon0=0.0, Lat0=0.0	yes

A.3.4 Data Group for AVHRR baseline

Table A.3.6: *Data group contents.*

Product	Data set name	Data type	size	Description	Mandatory
CFC	CFC_FC_F	byte	777 x 372 pixel	CFC from all polar satellites	yes
CTH	CTH_TH_F			CTH from all polar satellites	
CTP	CTP_TP_F			CTP from all polar satellites	
CTT	CTT_TT_F			CTT from all polar satellites	
COT	COT_OT_F			COT from all polar satellites	
CWP	CWP_AL_F			CWP averaged for cloud & cloud free from all polar satellites	
	CWP_CC_F			CWP averaged only for cloud from all polar satellites	
CTY	CTY_LOW_F			low clouds from all polar satellites	
	CTY_MI_F			middle level clouds from all polar satellites	
	CTY_HO_F			high opaque clouds from all polar satellites	
	CTY_HS_F			high semitransparent clouds from all polar satellites	
	CTY_FR_F			fractional clouds from all polar satellites	
CPH	CPH_WA_F			Cloud phase water from all polar satellites	
	CPH_IC_F			Cloud phase ice from all polar satellites	
	CPH_MX_F			Cloud phase water/ice mixed from all polar satellites	
Quality-Flag	QUAL	long	777 x 372 pixel	Bit fields	no
Palette	PAL	Byte	(256,3)	Predefined colour table	no

Table A.3.7: *Dataset attributes in Data group.*

Dataset name	Attribute name	Type	Size	Description	Mandatory
Acc. to Table A.3.6	Title	string	128	Description of the dataset: According to Table 4-2 e.g. "CFC-DM"	yes
Acc. to Table A.3.6	Unit	string	16	CFC, CTY, CPH: percent CTT: K CTH: meter CTP: hPa COT:- CWP: kg/m^2	yes
Acc. to Table A.3.6	Gain	float	1	CFC, CTY, CTT, CTP, CPH: gain=1 CTH: gain=200 COT: 0.01 CWP: 0.0002	yes
Acc. to Table A.3.6	Intercept	float	1	CTT: intercept=100 all other products: intercept=0	yes
Acc. to Table A.3.6	nodata_value	Same as the dataset	1	No data values. CWP, COT: -1.0 Other products: 255	yes

The following equation transforms the HDF5 data to physical products:

Product_value = (data1 * gain) + intercept

where data1 (e.g. Table A.3.7) are the data from the HDF5 file, product_value the product values in the given unit. Gain and intercept are from Table A.3.7.

Please note that gain and intercept is not applied to the undef_value.

A.4 Metadata group for AVHRR Arctic area

A.4.1 Metadata group for AVHRR Arctic area

Table A.4.1: *Metadata group contents.*

Attribute name	Type	Size	Description	Mandatory
Title	string	128	Description of the dataset: “fractional cloud cover” “cloud type” “cloud top heigth” “cloud top pressure” “cloud top temperature”	yes
DateAndTime	string	16	Date and time coded as yyyymmdd or yyyymmdd_hhmm For the monthly mean and the monthly mean diurnal cycle, the date of the first day of the month is given	yes
TimeMean	string	32	Time integration „daily mean“, „monthly mean“	yes
Producer	string	32	Processing center “CMSAF_DWD”	yes
Version	string	128	Product version according to configuration management	yes
ProductionMode	string	128	„nominal“, „reprocessed“, „experiment“	yes

A.4.2 Product_Specific_Metadata Group AVHRR Arctic area

Table A.4.2: *Product_Specific_Metadata group contents*

Attribute name	Type	Size	Description	Mandatory
Calibration coefficients information	String	128	“pre-launch”, “after-launch”, “Vxx.yy”	no
NWP information applied	String	128	Name and version of NWP model “ECMWF Vxx.yy”, “GME Vxx.yy”	No

A.4.3 Geolocation Group AVHRR Arctic area

Table A.4.3: *Geolocation group contents*

Dataset name	**Data type**	**Size**	**Description**	**Mandatory**
Region	Compound	1	Parameter to describe region of dataset	yes
Projection	Compound	1	Parameter to describe the projection	yes

Table A.4.4: *Region dataset contents*

Dataset name	**Data element**	**Type**	**Size**	**Description**	**Mandatory**
Region	Xmin	float	1	“left” margin of region; units [m] of projections coordinate system Arctic area -2505000.0	yes
Region	Xmax	float	1	“right” margin of region; units [m] of projections coordinate system Arctic area 2505000.0	yes
Region	Ymin	float	1	“lower” margin of region; units [m] of projections coordinate system Arctic area -2505000.0	yes
Region	Ymax	float	1	“upper” margin of region; units [m] of projections coordinate system Arctic area 2505000.0	yes
Region	Dx	float	1	“pixel” increment in x direction in units of projections coordinate system 15000.0	yes
Region	Dy	float	1	“pixel” increment in y direction in units of projections coordinate system 15000.0	yes

Table A.4.5: *Projection dataset contents Arctic product*

Dataset name	Data element	Type	Size	Description	Mandatory
Projection	Projection name	string	128	"Lambert Azimuthal Equal area "	yes
Projection	Reference Ellipsoid	string	128	"sphere with radius r of 6370997.0m"	yes
Projection	Projection parameter	array	depends on projection	X0=0.0, Y0=0.0, Lon0=0.0, Lat0=90.0, r =6370997.0	yes

A.4.4 Data Group AVHRR Arctic area

Table A.4.6: *Data group contents for Arctic area.*

Product	Data set name	Data type	size	Description	Mandatory
CFC	CFC_FC_F CFC_FC_M	byte	334 x 334 pixel	CFC from all polar satellites CFC from METOP	yes
CTH	CTH_TH_F CTH_TH_M			CTH from all polar satellites CTH from METOP	
CTP	CTP_TP_F CTP_TP_M			CTP from all polar satellites CTP from METOP	
CTT	CTT_TT_F CTT_TT_M			CTT from all polar satellites CTT from METOP	
CTY	CTY_LOW_F			low clouds from all polar satellites	
	CTY_MI_F			middle level clouds from all polar satellites	
	CTY_HO_F			high opaque clouds from all polar satellites	
	CTY_HS_F			high semitransparent clouds from all polar satellites	
	CTY_FR_F			fractional clouds from all polar satellites	
	CTY_LOW_M			low clouds from METOP	
	CTY_MI_M			middle level clouds from METOP	
	CTY_HO_M			high opaque clouds from METOP	
	CTY_HS_M			high semitransparent clouds from METOP	
	CTY_FR_M			fractional clouds from METOP	
Quality-Flag	QUAL	long	334 x 334 pixel	Bit fields	no
Palette	PAL	Byte	(256,3)	Predefined colour table	no

Table A.4.7 *Dataset attributes in Data group.*

Dataset name	Attribute name	Type	Size	Description	Mandatory
Acc. to Table A.4.6	Title	string	128	Description of the dataset: According to,.Table 4-3 e.g. "CFC-DM"	yes
Acc. to Table A.4.6	Unit	string	16	CFC, CTY: percent CTT: K CTH: Meter CTP: hPa	yes
Acc. to Table A.4.6	Gain	float	1	CFC, CTY, CTT, CTP: gain=1 CTH: gain=200	yes
Acc. to Table A.4.6	Intercept	float	1	CTT: intercept=100 all other products: intercept=0	yes
Acc. to Table A.4.6	Nodata_value	Same as the dataset	1	No data values. All products: 255	yes

The following equation transforms the HDF5 data to physical products:

Product_value = (data1 * gain) + intercept

where data1 (e.g. Table A.4.7) are the data from the HDF5 file, product_value the product values in the given unit. Gain and intercept are from Table A.4.7.

Please note that gain and intercept is not applied to the undef_value.